PREDICTION OF DIEBACK DISEASE OF *DALBERGIA SISSOO* (SHISHAM) BASED UPON ENVIRONMENTAL FACTORS AND TREE AGE

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Abstract. Dieback of forest trees is considered as serious problem in most parts of the world. Shisham an important multipurpose tree of the Indian subcontinent is suffering from dieback. Changing climate in most parts of the world is considered an important factor of ecosystem disturbance. Impact of environmental variables, tree age and water table on the dieback of shisham was examined in different regions of Punjab, Pakistan. Significant correlation was observed between environmental variables and dieback in minimum, moderate and maximum infected trees among three age classes. Water table and rainfall expressed non- significant correlation. A multiple regression model was developed to determine the relationship between environmental variables and dieback. Coefficient of determination value ($R^2 = 0.89$) depicts that model is statistically good. Model indicated that most of the predictor variables has minor role in disease development except age and time span. With one unit increase in age and time span disease will increase 4.15 and 5.25 units respectively. Values of partial R-square indicated that age class (0.5253), time span (0.2943) and relative humidity (0.0552) are major contributors in disease development. It was concluded form the study that age and time span are significant predictor of dieback.
Keywords: *characterization, disease incidence, correlation, climatic factors, predictive model*

Introduction

Dieback of forest trees is a periodic event caused by premature loss of tree health and forest stand vitality (Clatterbuck, 2006). Forest decline and dieback have been reported from different forest ecosystems and climatic zones of the world (Lowman, 1991; Jump et al., 2006) and in the recent past mortality rate has increased in many forest ecotypes of the world (Hosking, 1989; Jursik, 2004). Natural disturbances, including biotic and abiotic stresses are inherent components of forest ecosystems affecting their functioning and biodiversity (Boydet et al., 2013; Thom and Seidl, 2016). About two to three

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decades ago dieback of *Dalbergia sissoo* was reported in different regions of Pakistan (Ciesla, 1994). *D. sissoo* being a nitrogen fixing tree and multiple uses is an important tree of social forestry with good economic returns (Lal and Singh, 2012; Ahmad et al., 2013; Farooq et al., 2018; Rashid et al., 2019). Dieback is a major threat to this multipurpose tree (Ahmad et al., 2016, 2017) and has affected millions of trees in Southern Asia (Vogel et al., 2011). Symptoms of shisham dieback are approximately similar to dieback of mango in southern Punjab of Pakistan (Khan et al., 2014) Climate change, fungal pathogens and nutrient deficiencies have been considered as the major causes of tree decline and dieback (Simpson, 1993; Rajput et al., 2008). In different regions of the world fungal pathogens have been recognized as the responsible causal organisms of tree decline and climate change has also been find associated with forest dieback (Ahmad et al., 2016). Environmental stresses contribute to tree mortality and occurrence of forest diseases due to different pathogens will probably become more common and severe in the near future, as different biotic and abiotic factors are strongly influenced by climatic change (Sturrock et al., 2011; Raza et al., 2015). Dieback in northern hardwood forests was strongly linked with the global climatic change; the coefficient of determination value (R2 = 0.49) in the regression analysis showed that climatic changes were responsible for 49% of the dieback occurring in northern hardwood forests (Auclair et al., 2005). An increasing trend in the forest mortality and dieback due to drought was observed. the linear regression model suggested a very strong association between tree mortality and drought conditions due to low rainfall and high temperature (Phillips et al., 2009; Allen et al., 2010). The extent of forest dieback linked with global climate change would be greater than that observed in the past (National Research Council, 2001). High rate of shisham mortality in India was linked with changing climatic conditions, such as increased drought, extremes of winter and summer, with severe foggy conditions which adversely affected the photosynthesis and other physiological processes of the trees (Singh, 1980; Kaushal et al., 2002).

Age is also considered an important factor in development of forest dieback. Nepstad et al. (2008) reported that as trees are perennial woody plants which grow slowly but the mortality rate of trees was very much higher, even within a period of few months as compare to its growth rate which is very interesting. Older trees were more susceptible to dieback compared with younger trees (Auclair et al., 2010). Little scientific information is known about the spread and development of the disease in individual forest trees in different age groups (Timmermann et al., 2017). Sperry et al., 1991 suggested that in older trees, the membranes associated with vessels and tracheids rupture easily under ecological stresses. Acharya and Subedi (2000) recorded mortality of over-mature dieback-affected *D. sissoo* trees in a short period of even few weeks. Along with tree age, certain species of fungi, such as *F. solani* and *G. lucidum*, killed over 20% of older trees of *D. sissoo* under abiotic stresses in Bihar (Chaturvedi et al., 2002).

The effective use of chemical agents against plant diseases requires knowledge of the epidemiology of disease. Understanding disease dynamics, including the pathogen life cycle, provides the basis for forecasting disease outbreaks. Because shisham decline massively reduces both the economic gains and the social uses of this tree, the aim of integrated disease management must be to reduce these losses. Approaches are required which aim to avoid frequent recurrence of shisham decline epidemics. Much research, therefore, remains to be done. Disease severity in relation to different age classes of shisham has not been assessed, and no correlation has been determined between disease

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occurrence and the water table. The impact of varying environmental conditions in relation to spread of disease has not been studied quantitatively. Therefore the objective of study was to assess the relationship between shisham dieback, environmental variables and tree age.

Materials and methods

D. sissoo dieback disease data collection

A comprehensive survey of different *D. sissoo* (shisham) growing regions of Punjab province of Pakistan was carried out to collect the data regarding incidence of dieback disease (*Fig. 1*). Data were collected for the three consecutive years. Furthermore on the basis of disease severity we categorized the trees into three categories i.e. minimum infected, moderately infected and dead or fully affected trees.

Characterization of environmental factors conducive for shisham dieback in field conditions

Data collected for the incidence of shisham dieback from the different ecological zones of Punjab were subjected to correlation analysis with different climatic variables. The influence of each environmental variable (maximum and minimum air temperature, rainfall, relative humidity wind velocity, age and water table) on the severity of shisham dieback occurrence was determined by correlation.

Regression analysis

Regression analysis was used to determine any link between environmental/climatic factors and disease incidence/development (Chatterjee and Hadi, 2006). There are two types of models i.e. simple and multiple regression models (*Eqs. 1* and *2*). For developing simple linear regression models, the response variable (Y), in this case disease, was a function of the single predictor or explanatory variable (X), here an environmental/climatic variable. The equation for simple linear regression is:

$$Y = \beta 0 + \beta 1X \quad \text{(Eq.1)}$$

where β0 is the intercept and β1 is the slope. In multiple linear regression, however, there are more explanatory or predictor variables when compared with simple linear regression. The relationship is described by:

$$Y = \beta 0 + \beta 1x1 + \beta 2x2 + \cdots + \beta i\ xi + \epsilon \quad \text{(Eq.2)}$$

where x represents the collection of i predictors x1, x2,...xi in the model, and β1, β2,...βi are the corresponding regression coefficients and ∈ is the random error or disturbance.

Development of disease predictive model for the field study

A predictive model for the field data on disease incidence and severity was also developed. Weekly environmental data comprising of maximum and minimum air

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temperatures, relative humidity, average rainfall and wind speed were collected from the Regional Meteorological Station, Lahore. All the collected environmental data, tree age, underground water table data and dieback disease incidence data in the different districts of Punjab (Faisalabad, Lahore, Sargodha, Sahiwal, Okara, Rawalpindi, Multan, Bahawalpur, Rahim yar khan and Dera Ghazi Khan) from November 2009 to April 2010 and the same months during 2010-11, were subjected to analysis of variance to evaluate the effect of abiotic factors on disease incidence by using the Least Significant Difference Test (LSD at $P < 0.05$).

The influence of these environmental conditions on disease severity was determined by correlation analyses (Steel et al., 1997). R^2, Mallows Cp and mean square error (MSE) were the criteria used to select the best models (Khan and Illayas, 1999).

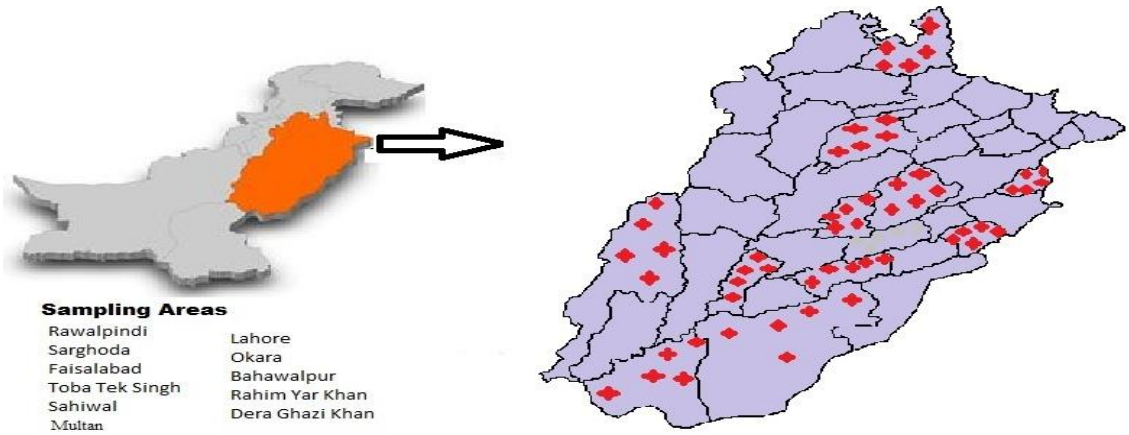

Figure 1. *Study area map showing eleven districts of Punjab province*

Results

Correlation between environmental variables and host (minimum, moderate and maximum infected trees of shisham) in different ecological zones of Punjab

There was a significant correlation between environmental variables (rainfall, relative humidity, minimum temperature, maximum temperature, wind velocity and water table) and host (minimum, moderate and maximum infected with dieback disease) of three age classes in different areas of Punjab ($P < 0.05$). Water table and rainfall expressed non-significant correlation with dieback disease in all categories of host (minimum, moderate and maximum infected with dieback). A weak and negative association was found between maximum temperature and minimum infected (r = -0.190), positive in moderately infected (r = 0.176) and fully infected trees (r = 0.175) followed by wind velocity in minimum infected (r = -0.166), moderately affected (r = 0.184) and fully infected trees (0.129). Similar results were expressed by maximum temperature (minimum infected, r = -0.105; moderately infected, r = 0.150; maximum infected, r = 0.138) and relative humidity in minimum infected (r = 0.106), moderately infected (r = -0.125) and maximum infected (r = -0.076) trees (*Figs. 2, 3* and *4*).

Regression analyses of environmental variables against dieback disease were carried out independently to observe the effects of each environmental variable separately on the disease development in the major shisham grown areas of the Punjab province. *Table 1* showed the regression equations and R^2 of the correlations of environmental

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variables with the minimum trees. R^2 value shows that 39.2% of variation in dieback disease was explained by the host categories', followed by time span (20.5%), maximum temperature (3.6%), wind speed (2.7%), minimum temperature (2.4%), relative humidity (1.1%), rainfall (0.3%) and water table (0.2%). For minimum infected trees, category of host was responsible for 29.1% of variation, followed by time (15.7%), wind speed (3.4%), maximum temperature (3.0%), minimum temperature (2.2%), relative humidity (1.5%), water table (0.2%); rainfall did not explain any variation. Similar trend was detected in maximum infected trees, where as 37.6% variation was explained by age class, followed by time span (18.6%), maximum temperature (3.1%), minimum temperature (1.9%), wind speed (1.7%), relative humidity (0.6%), rainfall (0.5%) and 0.2% by water table.

Table 1. *Regression equations of minimum, moderate and maximum infected trees with different variables*

Categories of host								
Trees with minimum infection			**Moderately affected trees**			**Trees with maximum infection**		
Regression equation	**R^2**	**S.E**	**Regression equation**	**R^2**	**S.E**	**Regression equation**	**R^2**	**S.E**
Min.I= 86.6 - 8.47	39.2	8.61	Mod.I=6.59 + 3.50	29.1	4.46	Max.I = 6.80+4.95	37.6	5.21
Time = 84.7 - 10.0	20.5	9.85	Time = 7.30 +4.20	15.7	4.87	Time = 8.15 + 5.70	18.6	5.94
W T= 68.7+0.0416	0.2	11.03	W T =14.1-0.0221	0.2	5.29	W T = 17.2-0.022	0.2	6.59
RF= 69.5+0.491	0.3	11.03	RF=13.6-0.086	0.0	5.30	RF = 16.9-0.410	0.5	6.58
R.H = 63.7+0.078	1.1	10.98	RH=16.9-0.0432	1.5	5.26	RH= 19.3 - 0.0331	0.6	6.57
Min.T = 72.8-0262	2.4	10.91	Mini.T=12.2+0.120	2.2	5.24	Mini.T = 15.1+0.139	1.9	6.53
Max.T = 77.1+0.273	3.6	10.84	Max.T=10.4+0.120	3.0	5.23	Max.T = 12.6+0.150	3.1	6.49
WS= 71.1-1.50	2.7	10.89	WS=12.9+0.797	3.4	5.21	WS = 16.0+0706	1.7	6.53

WT: Water table; Mini. T: Minimum temperature (°C); Max. T: Maximum temperature (°C); WS: Wind speed (Km/h); RF: Rainfall (mm); Min.I: Trees with minimum infection; Max. I: Maximum infected trees; Mod.I: Moderately infected trees

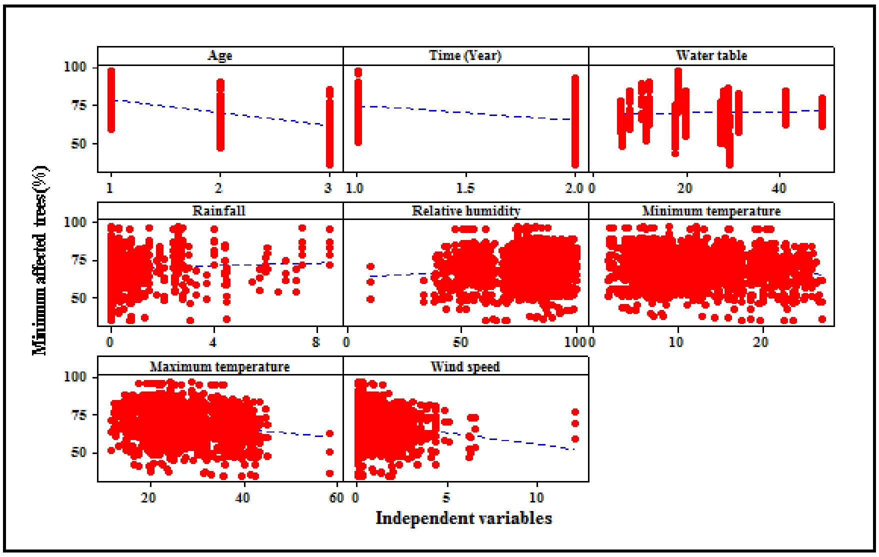

Figure 2. *Effect of different environmental variables on proportions of minimum affected D. sissoo trees in Punjab*

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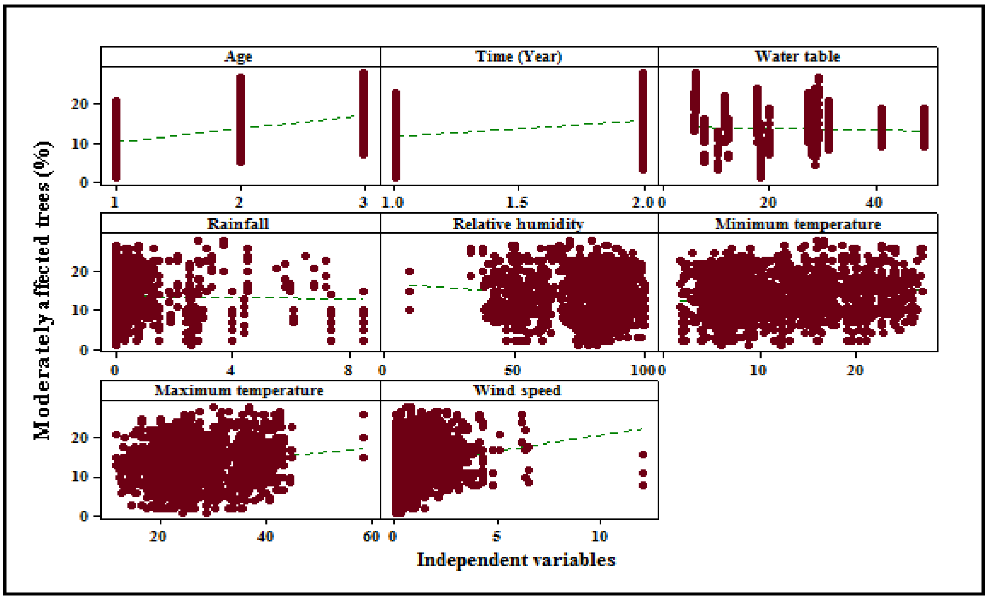

Figure 3. *Effect of different environmental variables on proportions of moderately affected D. sissoo trees in Punjab*

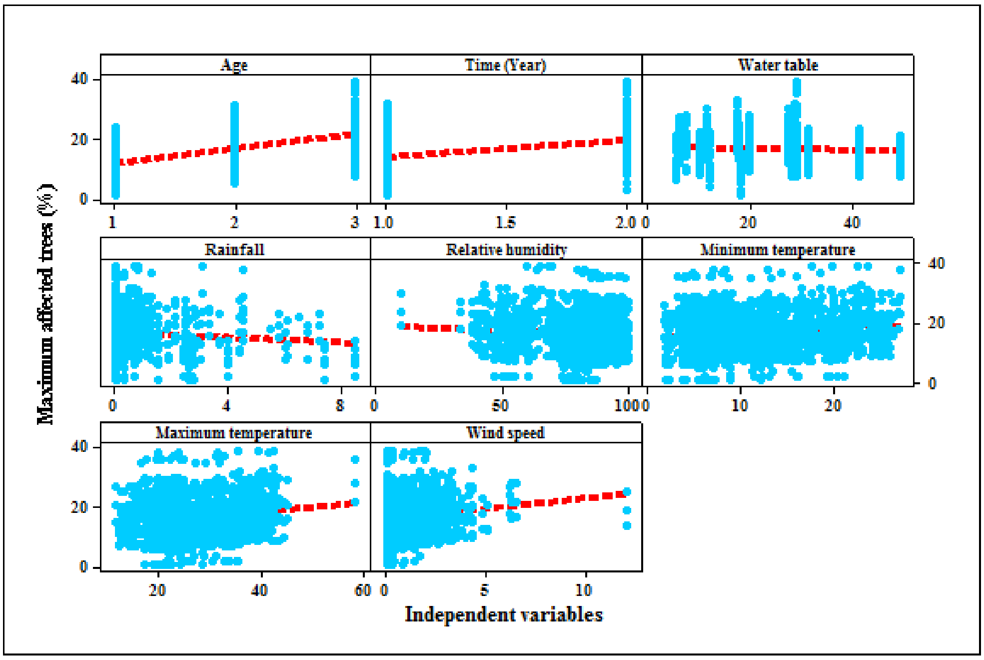

Figure 4. *Effect of different environmental variables on proportions of maximum affected D. sissoo trees in Punjab*

Dalbergia sissoo dieback disease predictive model based on field survey data

Data of dead shisham trees due to dieback disease about different categories of host were collected from different shisham grown areas of Punjab (Pakistan) through a comprehensive survey. The effect of host category, environmental variables (Minimum and maximum temperature, rainfall, relative humidity, wind velocity and water table)

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and years (time) on dieback disease development was determined by correlation and regression analysis. A multiple regression model was developed to determine the inter-relationships between environmental and the development of dieback disease (*Eq. 3*). With R^2 value of 0.89, the model was statistically justified at $P < 0.05$ and, therefore, can be used to predict the likelihood of dieback occurring under a given set of environmental and other variables.

$$Y = 2.51 + 4.15\,x_1 + 5.25\,x_2 + 0.00866\,x_3 - 0.113\,x_4 - 0.0611\,x_5 - 0.0115\,x_6 - 0.0092\,x_7 + .0.514\,x_8 \quad \text{(Eq.3)}$$

$R^2 = 0.89$, x_1 = host category, x_2 = year (time), x_3 = water table, x_4 = rainfall, x_5 = relative humidity, x_6 = minimum temperature, x_7 = maximum temperature, x_8 = wind velocity.

The model indicated that most predictor variables had a small role in disease development. Age class and time span, however, had an important role. The model equation suggests that with one unit increase in age, dieback incidence will increase by 4.15 units in shisham plantations; with a single unit increase in time span (years), the change in dieback would be 5.25. For rainfall, relative humidity, minimum and maximum temperature, the negative values indicate that an increase in these variables will reduce disease incidence. In the principle component analysis, using the forward selection method, an optimum model was developed. The summary of the forward selection process (*Table 2*) shows that the partial R^2 value after entering the age variable was 0.5253 and for year, relative humidity and wind velocity it was 0.2943, 0.0552 and 0.0154, respectively. Beyond these variables, there was negligible increase in the R^2 value. The R^2 value for both the full model and optimum models was the same (0.89).

Then model was evaluated according to the procedures described by the Chaterjee and Hadi (2006) by a) through comparison of the dependent variable (Dieback disease) and regression coefficients with physical theory b) comparison of observed and predicted data.

Table 2. *Summary of forward selection*

Sr#	Variable entered	Partial R-square	Model R-square	Pr > F
1	Host category (minimum, moderate and maximum infected)	0.5253	0.5253	<0.000
2	Time (year)	0.2943	0.8196	<0.000
3	Relative humidity (%)	0.0552	0.8748	<0.000
4	Wind speed (Km/h)	0.0154	0.8902	<0.000
5	Rainfall (mm)	0.0009	0.8911	<0.000
6	Water table	0.0004	0.8915	<0.023
7	Min Temperature (ºC)	0.0003	0.8919	<0.040

Comparison of the dependent variable (dieback disease) and regression coefficients with physical theory

Coefficient of determination (R^2) was an important parameter derived from the present work. Standard error was good with 1.5532 value (*Table 3*) The regression model was significant at $P < 0.05$ (*Tables 4* and *5*). Minimum and maximum

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temperatures were non- significant in the full predictive model. Role of water table and rainfall were also not much significant and summary of forward selection represents the same (*Table 2*) while all other parameters were significant. In the optimum model age, year, relative humidity and wind velocity were the major contributors in the disease development (*Eq. 4*). The coefficients, standard error, t stat and P values of full and optimum models are given in *Tables 3, 4* and *5*, respectively. It has been concluded from the above results that the model is very good for prediction.

Optimum predictive model for field data:

$$Y = 1.65 + 4.15\ \text{Age} + 5.20\ \text{Year} - 0.0523\ \text{RH} + 0.544\ \text{WS} \qquad \text{(Eq.4)}$$

$R^2 = 0.89$.

The model was also assessed by comparing the observed and predicted data. *Figure 5* shows that majority of the predictions fell between the 95% confidence intervals and 95% predictive intervals, demonstrating a very good relationship between predicted and observed data. Based on the R^2 (89%), the CI and PI model can be used for forecasting the dieback disease of shisham in various climatic conditions in the future.

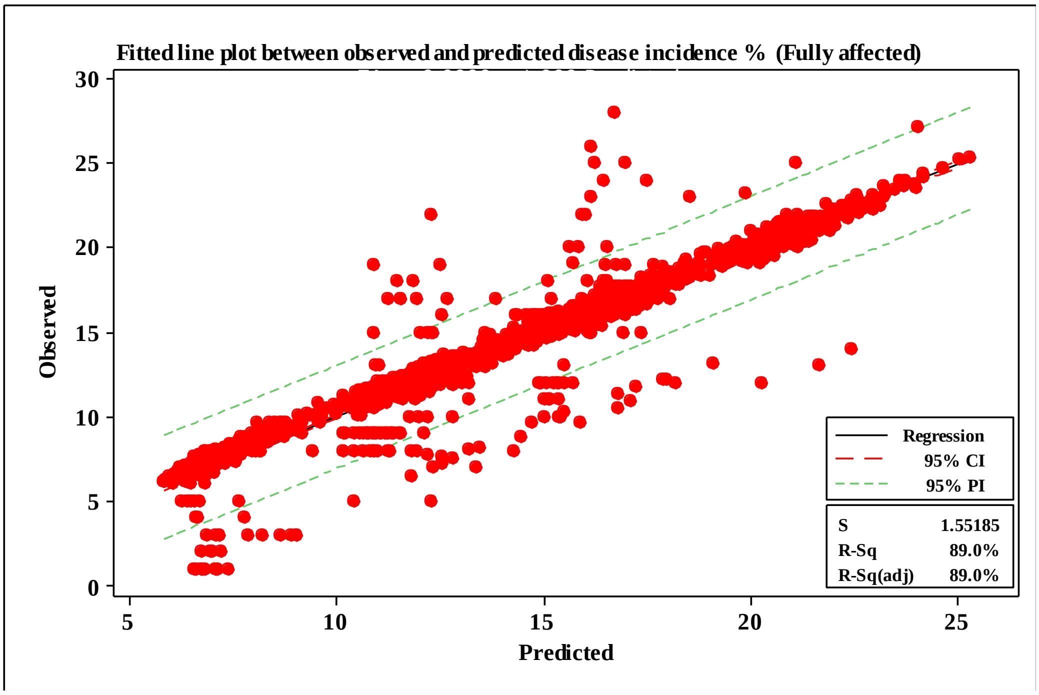

Figure 5. *Fitted line plot for dieback disease in maximum affected trees of Shisham with predicted and observed data points at 95% confidence and predictive interval*

Table 3. *Regression statistics of optimum predictive model for the maximum infected trees*

Regression statistics	
R-square	0.89
Adjusted R-square	0.89
Standard error	1.5532
Observations	1583

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Table 4. *ANOVA for optimum predictive model of maximum infected trees*

SOV	Df	SS	MS	F	P value
Regression	4	30889.5	7722.4	3200.57	<0.000
Error	1579	3809.8	2.4		
Total	1583	34699.3			

Table 5. *Coefficient of variables, standard error, t stat and P-value*

Predictors	Coefficients	Standard error	T stat	P-value
Constant	1.65	0.29	5.57	0.000
Age	4.15	0.047	86.91	0.000
Year	5.20	0.078	66.44	0.000
Relative humidity	-0.052	0.0029	-17.62	0.000
Wind velocity	0.54	0.036	14.87	0.000

Discussion

Dieback is a major threat to *D. sissoo* and has caused huge damage in all areas where this tree is cultivated. In Pakistan dieback of shisham has been recorded in different regions but severity differs with region (Gill and Aziz, 2004; Ahmad et al., 2016). In present study, a detailed survey of *D. sissoo* in four different agro-ecological zones of Punjab, Pakistan was conducted and considerable variation was observed in the incidence of dieback disease in the different zones of Punjab. Similar results were reported by Bajwa et al. (2003) from shisham plantations in all regions of Punjab. In present study incidence of disease was observed in different age classes of host (minimum, moderately and maximum infected trees).

The current work showed that tree age, and climatic factors including relative humidity, minimum and maximum temperature and wind velocity, were significantly correlated ($P < 0.05$) with incidence of dieback disease in the different agro-ecological zones. Tree age showed a prominent and strong association with dieback disease in all the examined districts and zones. Amongst the climatic factors, maximum temperature and wind velocity were more important compared to other variables. Baksha and Basak (2000) and Sharma et al. (2000) correlated mortality of *D. sissoo* with different ages of trees, and found low disease incidence in the early stages of growth, but greater susceptibility in older and larger trees leading to a high mortality rate compared to young plants. These results also support the conclusions of Boland et al. (2004) and Sturrock (2007), Dukes et al. (2009), Tubby and Webber (2010), Timmermann et al. (2017). The disease predictive model developed through regression analysis of the field survey data in this work utilized age class, environmental variables (minimum and maximum temperature, rainfall, relative humidity and wind velocity), time span (years) and underground water table to generate the model. Age class and time span played very important roles in the development of dieback under the field conditions. Hosking and Hutcheson (1992) showed that dieback of *Cordyline australis* was associated with old trees and attack of pathogens. Acharya and Subedi (2000) reported mortality of over mature dieback affected *D. sissoo* trees in a short period of even few weeks. Phillips et al. (2009) and Allen et al. (2010) observed an increasing trend in forest dieback and mortality due to drought on the basis of literature available from 1984 to 2010. In 1984,

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only 1% tree mortality was linked with drought, whereas in 2010 the figure was 4%; the value of $R^2 = 0.61$ in the linear regression model showed a very strong association between tree mortality and drought conditions due to low rainfall and high temperature. These results support the findings reported here, that with the passage of time environmental stresses increased forest mortality. Different researchers (Negi, 2002; Sidhu et al., 2002; Chaudhry, 2006; Thom and Seidl, 2016) observed that the reoccurrence of climatic changes in *D. sissoo* plantations for more than two years may seriously disturb plant growth and reduce resistance of plants to different pathogens which ultimately causes the death of the trees. These findings are confirmed in this present study.

Conclusions

Mortality of *Dalbergia sissoo* due to dieback disease is linked with tree age as disease incidence in different age classes were observed and correlated with various environmental factors. Association was observed between disease and different climatic factors. Varying level of water table in different agro ecological zones of Punjab Province of Pakistan was not considered as a major threat to shisham dieback. Time span in regression equations indicates that with the passage of time disease severity will increase. Farmers and foresters should be careful about the symptoms of disease and harvesting will be a better option for the most affected trees. In future changing climatic conditions of Pakistan can spread disease to least affected areas.

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