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Correlation and regression for prediction of wheat leaf rust severity in Bahawalpur and Multan using relevant meteorological data

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Abstract
Various meteorological variables were used as predictors to forecast wheat leaf rust disease severity in Bahawalpur and Faisalabad zones of Southern Punjab. The disease severity data was correlated with various meteorological variables viz., T_{max} (maximum temperature), T_{min} (minimum temperature), T_{ave} (average temperature), T_{prec} (total precipitation), RH_{ave} (average relative humidity), RH_{0300} (relative humidity at 0300 GMT) and relative humidity at 1200 GMT to determine variables yielding highest correlation coefficients, which were included in the regression analysis with terminal disease data. Variables with best coefficient determination (R^2) values were optimized to form model equations – RH_{ave} and T_{prec} were consistently significant with sporadic inclusions of T_{min} and T_{max}. The models, thus obtained were subjected to fitness and significance tests and best-fit models were obtained. RH_{ave} and T_{prec} tunred out to be the most detrimental factors for disease severity in each model. The models were validated by contrasting the predicted disease severity with the actual data, which yielded harmonious results indicating the practicality of the work.

Keywords: Agrometeorology, puccina triticina, regression models, wheat leaf rust.

Introduction

Wheat (*Triticum aestivum* L.) is one of the most economically important and the world's most widely cultivated crop which serves as the staple food for about 40% of the world's population (Anonymous, 2007; Stoskopf, 1985, Wiese, 1987). It is predicted that in order to meet human demand in 2050, crop production must increase annually by 2% on the same area of cultivated land (Van Niekerk, 2001). However, the production is highly constrained by multitude of factors - of which losses to wheat rusts are remarkable (Marasas *et al.*, 2004). Leaf rust caused by *Puccinia triticina* Eriks is a wheat disease of major historical and economic importance worldwide and is the most widespread of three types of rusts causing significant yield losses over large geographical areas (Saari and Prescott, 1985; Samborski, 1985; Roelfs *et al.*, 1992; Marasas *et al.*, 2004; Kolmer, 2005). This disease has appeared in epidemic form several times in Pakistan. During 1978, a national loss of 86 million USD was estimated (Hussain *et al.*, 1980).

Although plant resistance is the main method to avoid epidemics and minimize yield losses, changes in pathogen virulence and the lack of effective durable resistance support the need for forecasting models (Moschini and Pérez, 1999). These models are needed if fungicides are to be effective and economical in reducing crop losses that may be attributed to new races of the pathogen (Eversmayer and Kramer, 1992; Saari and Prescott, 1985).

Crop-weather models for forecasting various parameters of wheat crop have been developed and are being used in various agro-meteorological regimes. More wheat simulation models exist in the world than for any other crop (McMaster, 1993). Wheat rust epidemics have been successfully predicted using mechanistic (Benizri and Projetti, 1992) and empirical approaches (Burleigh *et al.*, 1972; Coakley and Line, 1981; Coakley and Line, 1988; Eversmeyer and Burleigh, 1970). The empirical models were based on either meteorological factors alone (Coakley and Line, 1981; Coakley and Line, 1988; Subba *et al.*, 1990) or both biological and meteorological factors (Burleigh *et al.*, 1972; Eversmeyer and Burleigh, 1970; Eversmeyer and Kramer, 1992). While most previous studies analyzed a few selected cultivars, a leaf rust-prediction models were developed in Europe and Argentina that considered mean disease severities observed on several cultivars (Daamen *et al.*, 1992; Moschini and Pérez, 1999). The objective of this study was to find an appropriate relationship between disease severity and meteorological data through correlation and to formulate an appropriate equation for a forecast model.

Materials and Methods

Collection of Data

Disease Database

Leaf rust severity data was obtained for 19 commercial cultivars of wheat (Fig. 1) from Crop Disease Research Institute, National Agriculture Research Council. Disease data was available for seasons spanning 2002-2007 for geographically distinct areas of Southern Punjab viz., Bahawalpur and Faisalabad.

Meteorological Database

Meteorological data of Bahawalpur and Faisalabad was obtained from the Pakistan Meteorological Department's Data Repository maintained at Islamabad and Lahore stations. The database had following environmental variables which were utilized in predicting leaf rust severity: (i) Total monthly accumulated precipitation in millimeters; (ii) Average relative humidity (RH) as calculated from the 0300 GMT and 1200 GMT observations as well as mean 0300 GMT and 1200 GMT RH observations. (iv) mean minimum temperature; (v) mean maximum temperature; (vi) Average monthly temperature as reckoned from mean minimum and maximum temperature.

Estimating correlation

The disease severity data for each season was correlated with weather variables to establish a relationship, if any, using SPSS (Table. 1). The variables which produced high positive correlation coefficients were observed. Since, the disease severity data for the 19 cultivars under study exhibited a similar pattern of prevalence in the five-year period, therefore mean of the disease severity of all the varieties was reckoned for each year. The mean of the annual disease severity of all the varieties was correlated with weather variables which gave more or less the same correlation coefficients as were observed with individual disease severities (Fig. 2). Wherefore, the mean was used for further analysis as to reckon a generalized equation for all the varieties in a locality.

Regression analysis

The meteorological variables of months of March and April which correlated positively or in a linear manner with the mean disease severity was selected for regression analysis with the mean disease severity using SPSS Regression Modeling as well as with Microsoft Excel Data Analysis tool.

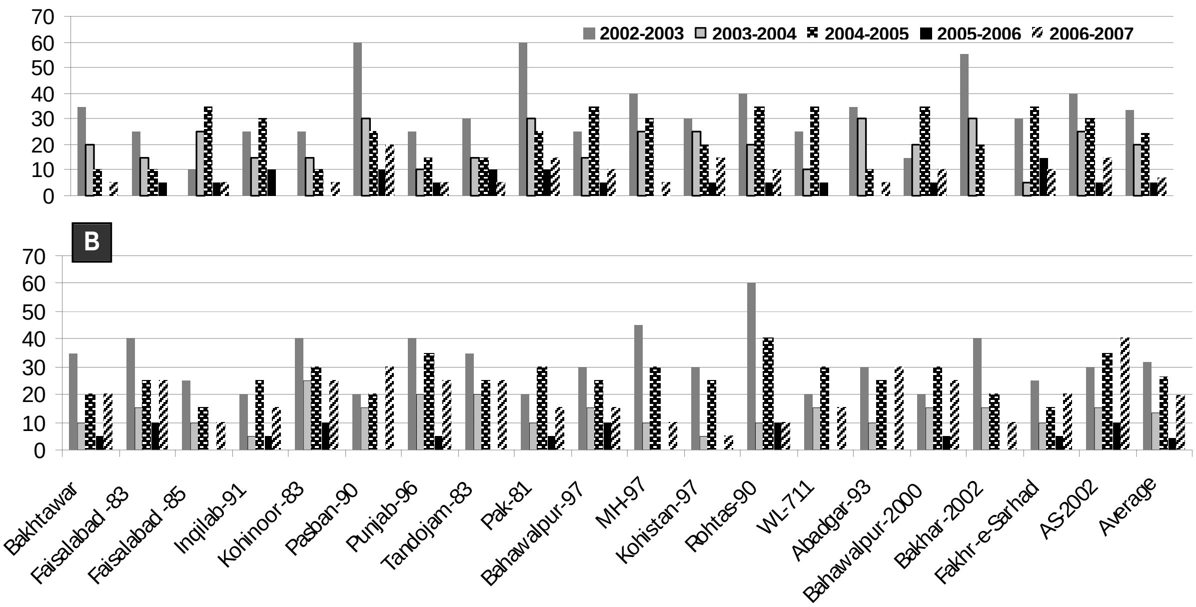

Fig. 1: Wheat leaf rust severity as exhibited by 19 commercial varieties over 5 seasons spanning 2002 to 2007 in (A) Bahawalpur, (B) Faisalabad.

Model development and fitness tests

Regression analysis of meteorological variables and mean disease severity resulted in development of numerous two- and three-variable equations. Determination co-efficient (R^2) value for each equation was observed and only those equations were selected which were found to be most appropriate as suggested by R^2 value. The models were evaluated for minimization of standard errors of the predictions, stability of the regression coefficient signs, plotting of standard residuals against predictions and time, variance inflation factors (VIFs) of the coefficients, Durbin-Watson statistics, F-Test and the accuracy of the predictions that were made for the years included in development of the model.

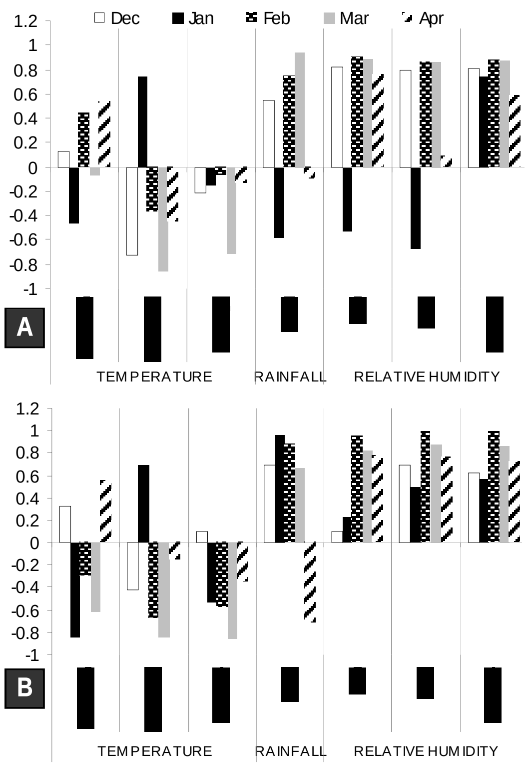

Fig. 2: Correlation of mean disease severity with different meteorological variables for (A) Bahawalpur, (B) Faisalabad.

Results and Discussion

Correlation

Disease severity almost always produced high correlation coefficients with monthly RH_{ave} and T_{prec}, both of which dictate leaf wetness duration. The results for correlation are detailed in Fig 2.

Regression analysis

Regression analysis of the meteorological factors and the disease severity for each cultivar resulted in development of numerous bivariate and trivariate equations with adjusted R^2 greater than 0.75. The best simple and multiple equations for predicting mean maximum leaf rust severity, including meteorological factors as linear independent components, are presented in Table 2.

Goodness of fit and tests of significance

Various goodness of fit and significance tests were applied to check the practicality of models in making correct forecasts. (Table 2). Determination coefficient (R^2) values for each model were reckoned and no value below 0.90 was observed which is a good indicator for forecast models.

Adjusted R^2 values were used to compare models. Bivariate models with RH_{ave} and T_{prec} as predictors exhibited high adjusted R^2 values. To evaluate the significance of difference between adjusted R^2 values of models, predicted DS was plotted against actual DS (Fig. 4, 5). Trivariate models were only slightly close to the slope of the trendline than their comparable bivariate models.

Durbin-Watson statistics for all the models always lied between 1.6-2.3 with values frequenting around 2.0. The Variace Inflation Factor (VIF) for all the model coefficients were found to be significant. The highest VIF was observed to be at 2.93, however, most values were found to be close to 1. Results of F-statistic are summarized in Table 1.

Model validation

After reckoning the statistical fitness of the models, the models were also validated by contrasting predicted leaf rust severity levels using the equated model with those actually observed in seasons spanning 2002 to 2007 at the respective stations (Bahawalpur and Faisalabad) (Fig 3). Model equations for Bahawalpur stably forecasted disease severity for all the seasons. Slightly under- and over-predictions were observed which were adjusted by applying standard error taking the actual disease severity as reference. Both the predicted and adjusted made dependable predictions, except in February, 2005-2006, which might be taken as statistic anomaly considering the fact that the equations constantly predicted disease severity close to the actual in all other seasons. For Faisalabad, March and April equations produced wayward predictions frequently, particularly in the seasons 2004-2005 and 2005-2006. All other equations were considerably accurate in forecasting disease severity. Under- and over-predictions were adjusted by applying standard error using actual disease severity as reference.

The meteorological factors that affect disease development were identified and included in regression analysis, resulted in equations for each month of a wheat growing season. The predictive models developed here are empirical and based on the analysis of historical series of disease severity and meteorological data. Similar approaches with modifications were carried out by Coakley *et al.* (1981, 1988), Daamen *et al.* (1992) and Moschini and Fortugno (1996).

Several environmental variables may affect the production, dispersal, and survival of urediniospores (Eversmeyer, 1995). Temperature, humidity, and light may have pronounced effects on spore longevity. Winter temperatures and precipitation incremented the urediniospore amount while lower relationship occurred when spring weather was considered. (Chester, 1943, 1946, 1950). A strong association between severity and hydric variables such as precipitation and relative humidity was observed as previously recorded by Daamen *et al.*, (1992).

For December, the hydric variables (Table 1, equation 1) described the maximum leaf rust severity expected ($R^2 = 0.9128$). Disease severity especially increased with increasing maximum temperature range of 15 to 22 °C when the RH_{ave} is greater than 60%, coinciding with the end of December. Due to the lack of dew data, days without precipitation and RH over 70% marginally explained the severity variation. The identified meteorological variables were consistent with controlled environment findings that indicated that the minimal continuous dew period necessary for infection increased from 4 to 6 h at optimal temperature (15 °C for *P. triticina)* to at least 16 h at suboptimal temperature (Pope *et al.*, 1995).

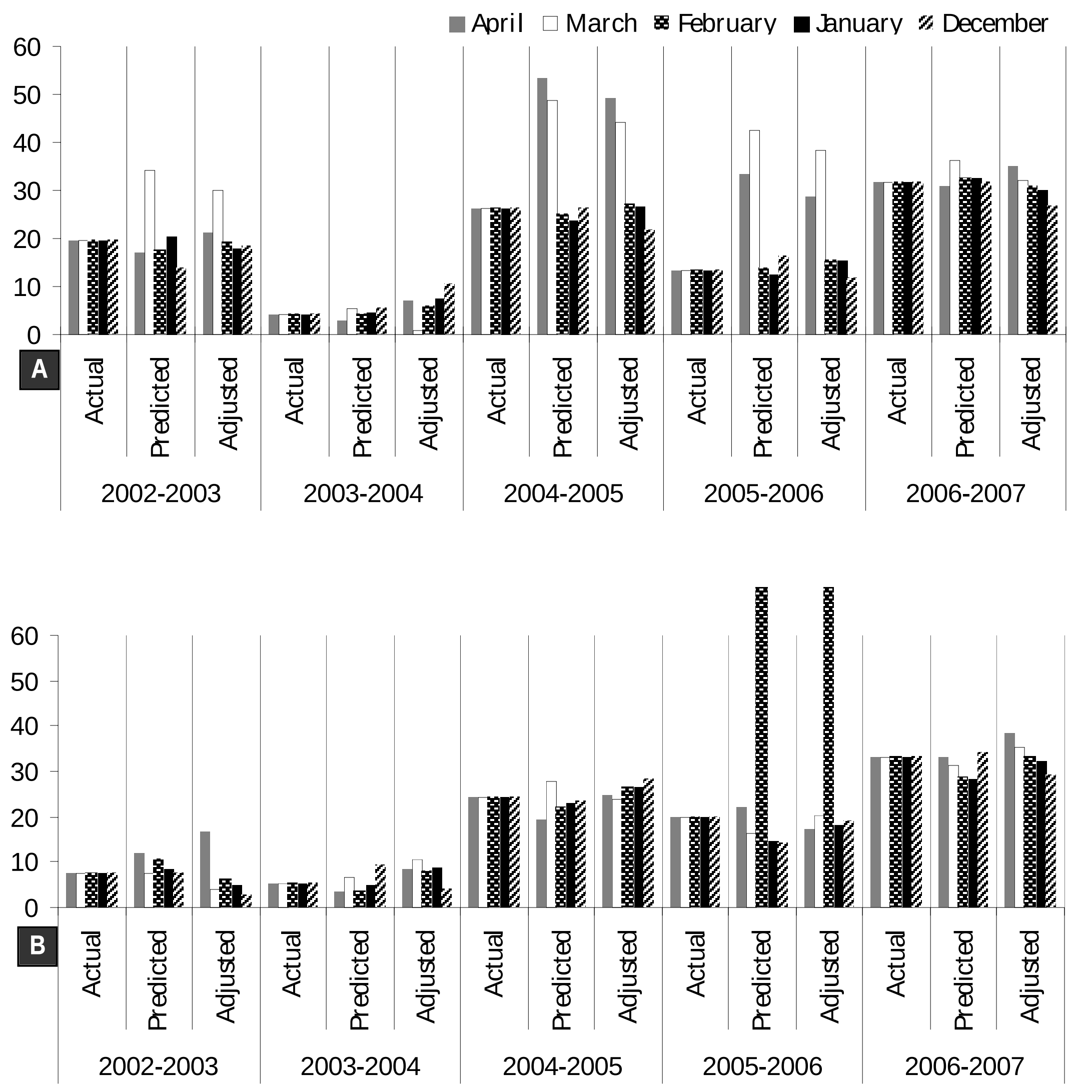

Fig. 3 – Relationship between the actual disease severity, predicted disease severity and standard error adjusted predicted severity for season spanning 2002-2007 in (A) Bahawalpur, (B) Faisalabad.

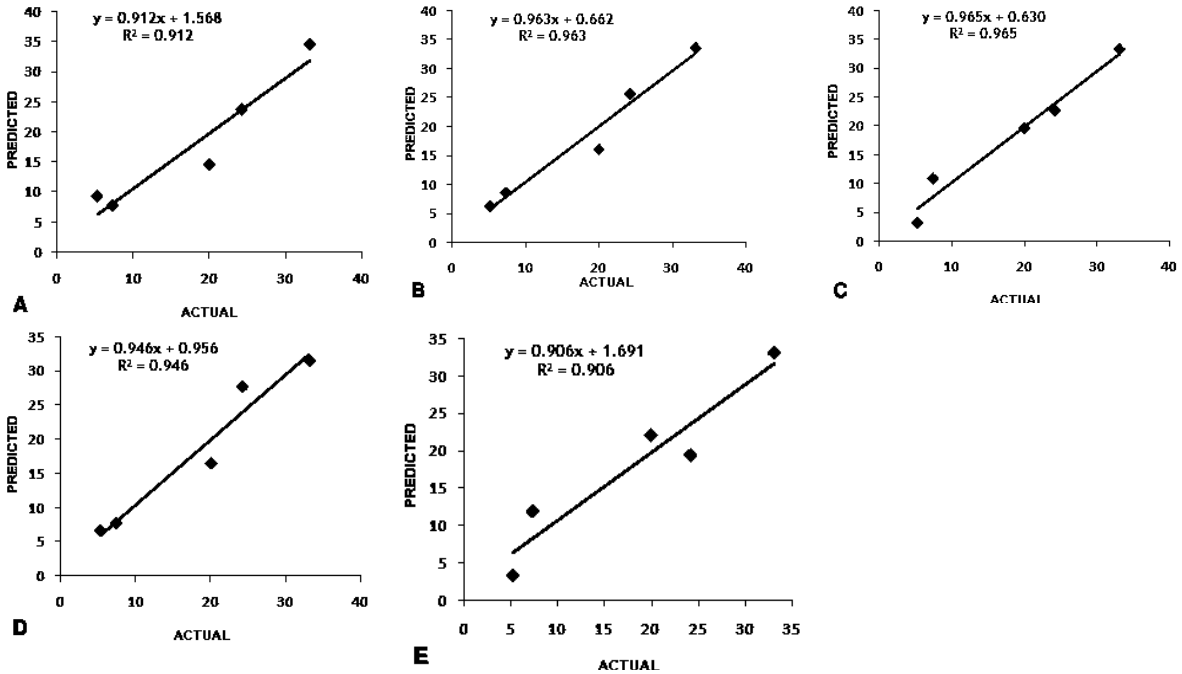

Fig. 4: Actual disease severity vs. predicted disease severity (shown as dots) as forecasted by equated models for Bahawalpur. A= December, B= January, C= February, D= March, E= April.

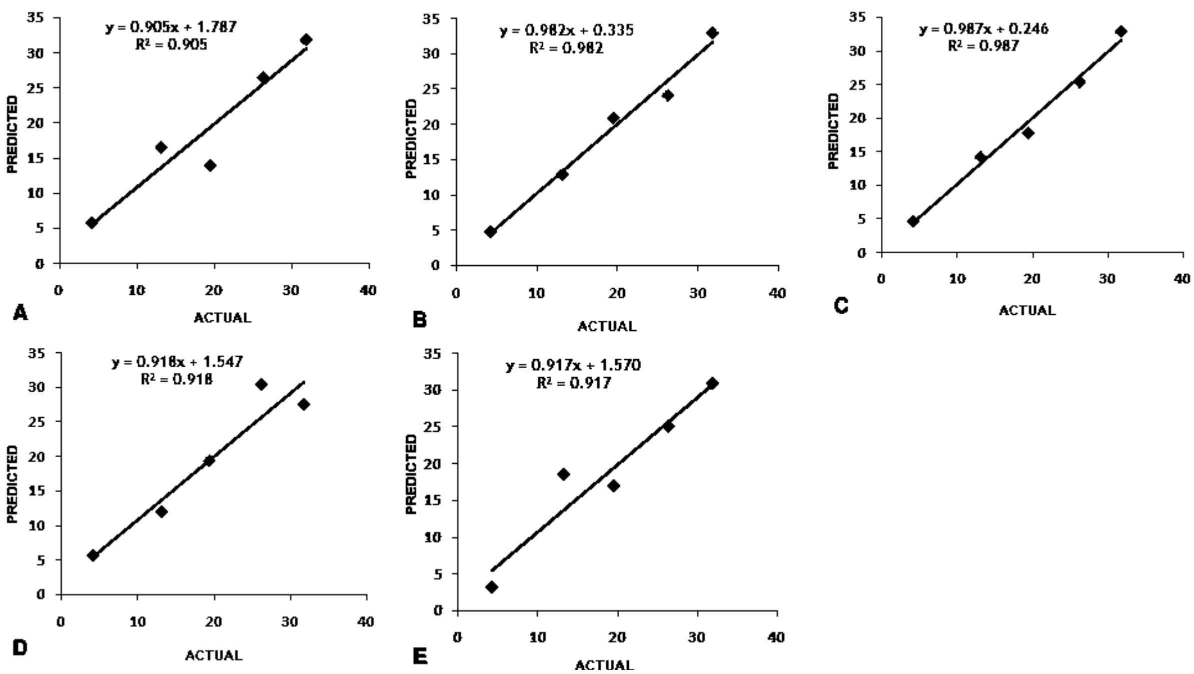

Fig. 5: Actual disease severity vs. predicted disease severity (shown as dots) as forecasted by equated models for Faisalabad. A = December, B = January, C = February, D = March, E = April.

In January, T_{max} was highly implicated in disease development along with RH_{ave} (Fig. 2). This was perhaps because the average daily maximum temperature in January ranged from 20-25 ^{o}C which optimizes the infection potential of the *P. triticina* as observed by Chester (1946). There was optimal hydric variables prevalence in February. RH_{ave} and T_{prec} were the most influential factors for disease development in February. (R^2 = 0.9650).

A low correlation between thermic variables particularly daily average maximum temperature in March and April and observed terminal disease data was found, suggesting that thermal variables alone may be of little predictive value as far as early summer days are concerned. This might be due to high daily maximum temperatures which are characteristic of South Asian countries including Pakistan. However, RH still dictated the disease severity in both the months, while total precipitation in April showed a negative trend for disease severity. This observation might be explained by assuming that the disease has already established itself during the succeeding terminal winter months and fungus is undergoing colonization which doesn't specifically require as much moisture as for the precipitation to fulfill it.

Shaner and Powelson (1971) reported that constant or mean temperatures above 22 to 25 ºC inhibited the rust fungus. It is thought that the higher temperatures from early to late March directly limited the fungus and thereby were unfavorable to infection.

The validation of the prediction models for using disease severity data of 2002-2007 indicated high agreement between observed and model-predicted severity levels. In some cases, the results were under-predicted or over-predicted, however, the standard error adjusted results showed good promise.

The models developed were based on 5 years of data, however, it was sufficient to indicate the appropriate meteorological factors which highly implicate in disease development. RH and Precipitation almost always produced high correlation coefficients with disease severity data which indicates the importance of presence of free moisture on leaf surface for infection development. Since, there was insufficient data for leaf wetness or dew point temperature, RH and total precipitation proved to be good determinants of leaf wetness, taking leaf wetness as a function of RH and rainfall.

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