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EVALUATION OF MULTIPLE REGRESSION MODELS BASED ON EPIDEMIOLOGICAL FACTORS TO PREDICT LEAF RUST ON WHEAT

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Experimental plots of Lu-26, Pak-81 and Fsd-85 were established during 1995-96 and 1996-97 wheat growifl9 seasons. The crop was artificially inoculated with leaf rust urediniospores and natural inoculum was also relied upon for infection. Stepwise regression was used to develop multiple regression models by employing weekly maximum and minimum air temperatures, rainfali, relative humidity, wind speed and 24 hr wind movement as independent variables while leaf rust severity served as dependent variable. R^2, Mallows C_p and mean square error were used to select the best model. Environmental conditions and leaf rust severity recorded on wheat varieties differed in two seasons. During 1995-96, two multiple regression models containing weekly maximum and minimum temperatures and maximum temperature and relative humidity explained more than 93% of the variability in leaf rust development on Fsd-85 and Pak-81 respectively. During 1996-97, weekly minimum temperature and relative humidity explained more than 90% of the variability in disease development on three varieties. Observed leaf rust severity values and those predicted by these models conformed to each other for most of the varieties.

Key words: epidemiological factors, multiple regression models, leaf rust on wheat

INTRODUCTION

Leaf rust caused by *Puecinia reeondita* Roberge ex Desmaz f. sp. *tritici* is a devastating foliar disease of wheat in Pakistan. Epidemics of this disease have induced significant yield losses in the past and the disease continues to be a major threat to iuture wheat production. In 1972, the epidemic of leaf rust developed 20-30% severity in different areas especially in the foot hills where up to 80% severity was recorded (Hassan, 1973; Bhatti and Ilyas, 1986). In 1973, leaf rust severity ranged from 40-50% with 100% infection on susceptible varieties. However, the crop escaped severe losses due to short duration of the favourable season for the rust epidemic (Hassan, 1973). The epidemics of 1976 and 1978 had 50-80% severity on most of the commercial cultivars and 30% yield losses were recorded in the Punjab (Khan, 1985). Hassan (1979) reported 10% yield losses due to leaf rust in Pakistan.

Leaf rust appears early in the spring on wheat and progresses rapidly depending upon the survival of the pathogen on susceptible germplasm and environmental conditions favourable for disease development. Lack of durable resistance in the available high yielding commercial wheat varieties, presence of diverse virulences of *P. reeondita* f. sp. *tritici* and favourable environmental conditions contribute significantly towards severe outbreak of leaf rust. Wheat varieties resistant to leaf rust races have been developed periodically but most of them have succumbed to virulent races of leaf rust pathogen. Physiological races of leaf rust viz. 12,20, 57, 77, 144, 149, 158 and 184 have been reported from Pakistan (Hassan *et el.,* 1967; Hassan, 1973; Hassan *et al.,* 1974; Hassan *et al.,* 1978). A survey of 11 districts of the province of Punjab during 1981-82 revealed the occurrence of race 117 and 122, former being prevalent in Faisalabad division while the latter was recorded from Faisalabad and Multan divisions (Haq, 1983).

Environmental conditions play a crucial role in driving the pethoqen-host-rust epidemic system. Forecasting of leaf rust epidemics based on conducive environmental conditions may be helpful for economic fungicides application. The objective of these studies was to develop disease predictive models based on environmental conditions and to evaluate their role in forecasting of leaf rust on wheat.

MATERIALS AND METHODS

Experimental wheat plots were established in the wheat growing seasons of 1995-96 and 1996-97 at the research area of the Department of Plant Pathology, University of Agriculture, Faisalabad. Three wheat varieties, Lu-26, Fsd-85 and Pak-81 were sown in experimental plots (6 x 1.5 meter) in a randomized complete block design with four replicati<>,ns;These varieties Jrwereselected because t:hev:·l,epr.esenteda range of response to foliar pathog:ens. The crop was>matntalned in good health following conventionalagroOOmicpractices.Leaf rust urediniospore suspension prepare(j frpm r~~;affected leaves -ofr-Pak-B'l collected from Ayub Agricultural Research Institute, Faisalabad was artificially spray inoculated twice a week starting at growth stage 7 (Large, 1954). Artificial inoculation was abondoned when the symptoms of l~af rust appeared on lower leaves:pi$ease,ratings from plots weretsken weekly. Ten plants were selected randomlyandt:'he' flag leaf disease severity was recorded by the rust severity scale described in a manual of assessment keys 'for plant diseases (James, 1971 l. Environm'ental data were taken. from- the Meteorological Department, Univ. of Agrieulture, ·Faisalabad. Spore traps were placed r;8ndemly at.di,ffer,ent places in a radius 0f l-i km. Sever;tyof leaf rust recorded from plots and the weekly environmental data were subjected to step wise regression analysis to determine the significance -of environmental conditions conducive for disease.developmeflt; Multiple regression models were developed employing leaf rust severity for all three varieties for two years as the dependent variable, with environmental.parameters (maximum, minimum air temperature, rain'fall, relative humidity, wind speed, and ,24 hr wind movement) as independent variables. All possible regressions were calculated using SAS with no-intercept model (Anonymous, 1992). Coefficient of determination (R2) (maximum value), mea-nsquare error (MSE) (minimum value) and Mallows Cp (p = number of regressor variables in the model) were used to select the best model to predict leaf, rust severity (Myers, 1990). These data were also graphically plotted and r values were calculated.

RESULTS AND DISCUSSION

During 1996, leaf rust symptoms appeared on lower leaves of Pak-81 during Znd week, and on the flag leaf in the 3rd week of. March. The disease symptoms got intensified in the subsequent three weeks and no symptoms could be recorded during 2nd week of April due to severe necrosis of leaves: Symptoms of leaf rust of low' and mild severity were recorded on Lu-26 and. Fsd-85 respectively. Based on leaf rust' severity scale, Pak~81 was graded susceptible, Lu-26 as moderately susceptible and Fsd-85 as moderately resistant.

During 1997, leaf rust symptoms expression was late. On Pak-81 appearance of rust pustules on flag leaf was evident in the 4th week of March and necrosis of leaves due to disease took place during 2nd week of April. Based on leaf rust severity scale, Pak-81 was graded as moderately Susceptible, Lu-26 rnoderatstv resistant and Fsd-85 as a resistant variety respectively.

Leaf rust severity was significantly higher on Pak-81 compared to Lu-26 and Fsd-85 during both the seasons (Table 1). The disease severity was higher on all varieties du!ing 1996 compared to 1997 but the difference in mean disease severity was not statistically significant. Except weekly minimum temperature and relative humidity, environmental conditions were significantly different during the two seasons CTable 1). Weekly maximum temperature, wind velocity and movement were significantly higher in 1996 compared to 1997. Rainfall in 1997 was significantly heavier than in 1996.

WeeklY,maxiinum air temperature ranged from ~4-30°C durirg disease rating period in 1996. Leaf rust severity on three varieties increased with increase in temperature and the rate of disease development was best explained by linear regression as indicated by higher values (Fig. 1). Except' for high disease severity on Pak-81 at weekly minimum temperature range of 14-1.B-OC; other two varieties had low diseasesev-erity., and the relationship was poorly explained by linear ~egression. During disease rating period of 1997, weekly maximum and minimum temperatures ranged from 22 to 28 and 12 to 180C respectively (Fig. 3). The relationship of these environmental parameters to leaf rust severity was fairly explained by linear regression. However, a perfect linear relationship of leaf rust development was found with increase of minimum temperature from 12 to 18°C and relative humidity from 70 to 85% as indicated by higher values (above 0.90).

Leaf rust development has been reported to be fluctuating with air temperature, initial amount of inoculum anq cultivation of susceptible germplasm (Boelt, 1'986). Leaf rust begins developing on wheat at relatively mild temperature (22-24 QC) and high relative humidity. With rise in temperature and availability of sufficient moisture (3-4 hr of leaf wetness), shorter latent and infectious periods occur on susceptible hosts resulting in rapid fungal sporulation and several successive generations of urediniospore production (Broweder and Eversmeyer, 1987; Suba Rao *et et.,* 1990). During1996, in the 2nd and 3rd week of March, 4 and 18.5 mm total rainfall was recorded, respectively, which may have provided SUfficient moisture for the rapid multiplication of fungus in the subsequent weeks.

Table 1. Comparison of weekly environmental conditions and leaf rust severity recorded on wheat varieties during 1995-97

Environmental parameters	1995-96	1996-97	LSD
Maximum air temperature (QC)	28.75 a*	25.50 b	1.32
Minimum air temperature (QC)	15.61 a	15.50 a	1.06
Relative humidity (%)	73.00 b	77.00 b	2.67
Rainfall (mm)	00.89 b	2.57 a	1.02
Wind velocity (km/hr)	4.89 a	3.99 b	0.33
Wind movement (km/24hr)	7297.00 a	4630.00 b	396.66
	Leaf rust severity		
Wheat varieties			
Lu-26	1.04 aB	1.39 aB	1.32
Fsd-85	1.08 aB	0.51 aB	1.29
Pak-81	6.52 aA	3.78 aA	4.22
LSD	3.24	1.77	

*Mean values within rows not sharing a small letter and within columns not sharing a capital letter differ significantly as determined by the LSD test (P = 0.05).

Table 2. Multiple regression equations (y1 = Lu-26, y2 = Fsd-85, y3 = Pak-81) based on weekly environmental conditions and predicted leaf rust severity during 1995-97

Regression equations (1995-96) ($y = b_0 + b_1x + b_2x$ ...)	Leaf rust severity: Observed	Predicted	R^2
y1 = -26.39 + 0.23x_1 * - 2.01 x_2 * + 0.002x_3 *	1.00	0.99	0.94
(where x_1 indicates relative humidity, x_2 wind speed and	3.50	3.15	
x_3 wind movement respectively)	2.33	3.17	
	3.66	3.17	
y2 = 0.46 + 0.40x_1 * - 0.70x_2 *	0.00	0.07	0.99
(where x_1 indicates maximum temperature	0.00	0.11	
and x_2 minimum temperature respectively)	2.88	2.82	
	1.44	1.52	
y3 = -24.84 + 1.47x_1* - 0.15x_2*	0.00	0.05	0.99
(where x_1 indicates maximum temperature	4.99	5.11	
and x_2 relative humidity respectively).	8.10	8.05	
	12.98	12.95	
Regression equations (1996-97)			
y1 = -8.70 + 0.45x_1 * + 0.03x_2	0.00	0.20	0.98
(where x_1 indicates minimum temperature	0.33	0.54	
and x_2 relative humidity respectively)	1.81	1.89	
	3.42	3.32	
y2 = -2.23 + 0.17x_1 * + 0.0005x_2	0.00	0.10	0.97
(where x_1 indicates minimum temperature	0.14	0.24	
and x_2 relative humidity respectively)	0.56	0.60	
	1.34	1.29	
y3 = 0.02 + 0.78x_1 - 0.11x_2	2.05	1.02	0.91
(where x_1 indicates minimum temperature	1.95	3.03	
and x_2 relative humidity respectively)	2.99	3.40	
	8.13	7.65	

*Indicates significant regression.

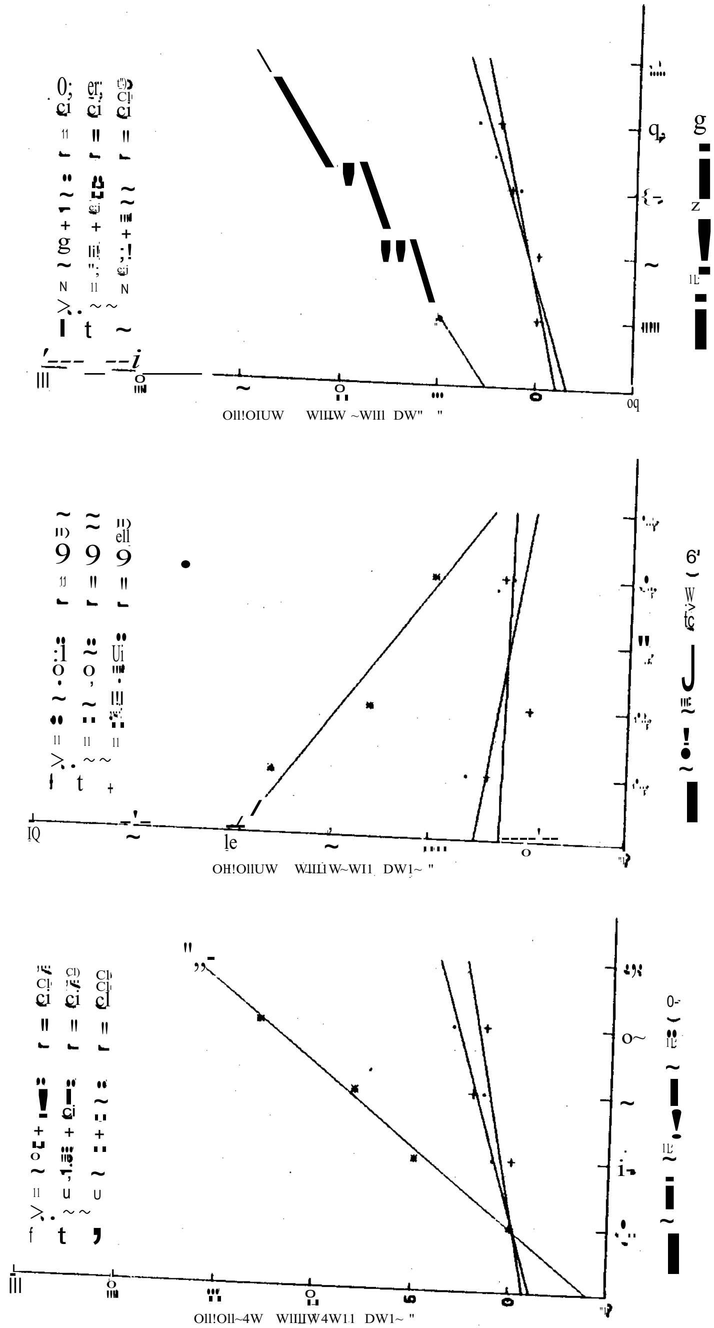

Fig. 1. Relatipnship of weekly air temperature (rnax, & min.) and relative humidity to leaf rust development of Lu-26 (y1), Fsd-85 (y2) and Pak-81 (y3) during 1996.

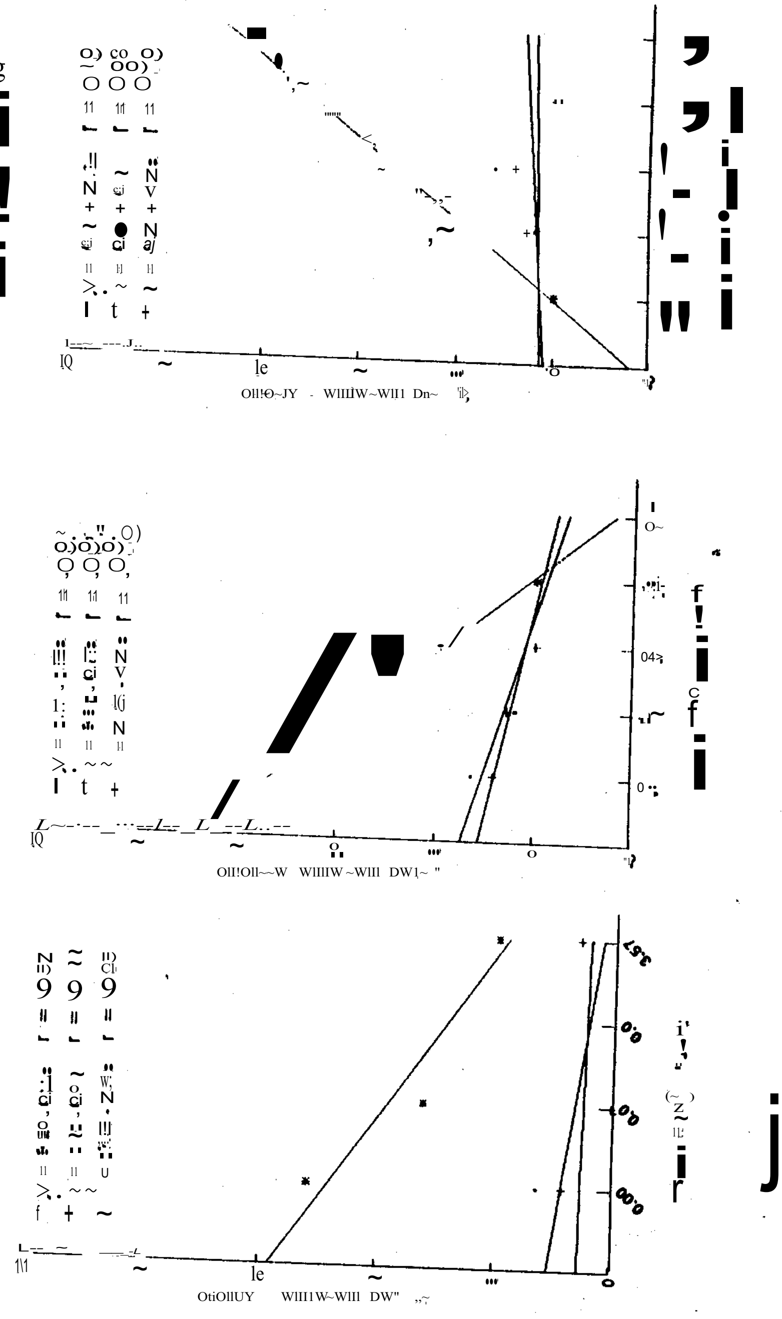

Fig. 2. Relationship of weekly rainfall, wind speed and movement to the development of leaf rust on Lu-26 (y1), Fsd-85 (y2) and Pak-81 (y3) during 1996.

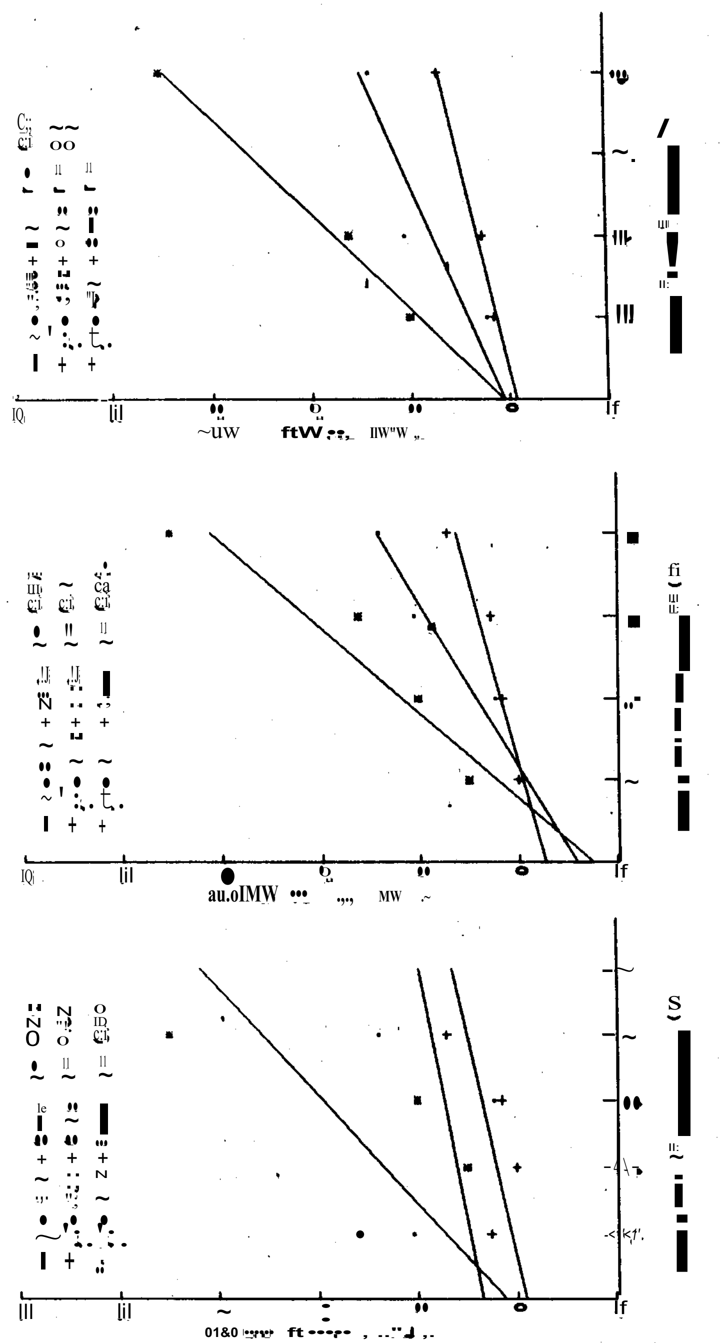

Fig. 3, Relationship of weekly air temperature (max. & min.) and relative humidity to leaf rust development on Lu-26 (y1), Fsd-85 (y2) and Pak-81 (y3) during 1997.

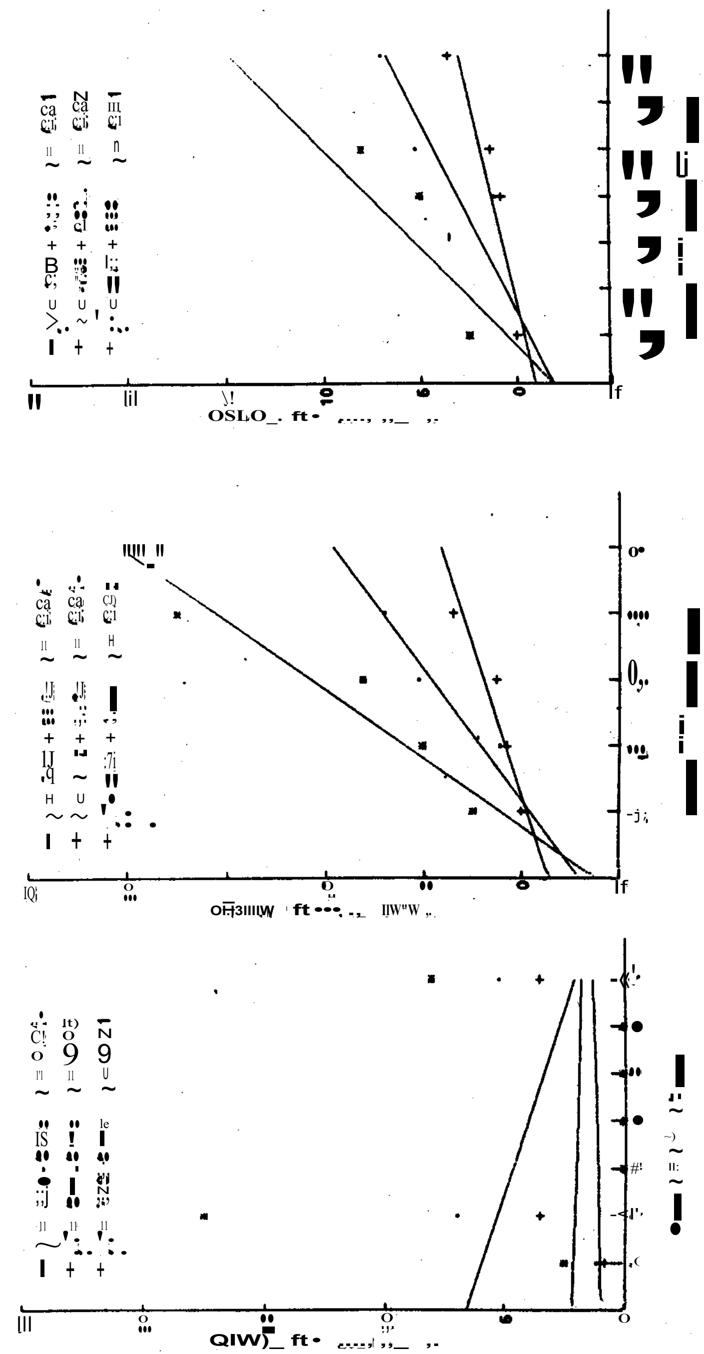

Fig. 4. Relationship of weekly rainfall, wind speed and movement to the development of leaf rust on Lu-26' (y1), Fsd-85 (y2) and Pak-81 (y3) during 1997.

Rise in temperature with sufficient moisture creates humid conditions and at weekly relative humidity range of 70-80%, leaf rust increased on the three wheat varieties (Fig. 1). During 1997, 3.16, 6.63 and 49.35 mm rainfall occurred in the 3rd and 4th week of March and 1st week of April respectively. Thus total amount of rainfall during 1997 although significantly intensive than in 1996 was late when wheat crop was already at physical maturity (Feeke's growth stage 10.1),, having very small amount of green tissue left. The. relationship of weekly rainfall and wind speed with leaf rust development was negative. However, a perfect linear relationship was not found. in case of rainfall with disease development. This may be due to the frequency of rain showers and hours of free moisture on wheat leaves which might be critical for leaf rust development. A linear decrease in rate of leaf rust development on wheat varieties with relation to increase in weekly wind speed from 14-17 kmlhr was recorded (Fig. 2). However, except for Pak-81 , there was no relationship of weekly wind movement to the development of leaf rust on Lu-26 and Fsd-85. During 1997, the rate of leaf rust development in relation to weekly wind speed of 4-5 kmlhr and wind movement of 4000-6000 km/24hr was best explained by linear regression as indicated by high r values (Fig. 4). Actually the wind direction rather than the wind speed or 24 hr movement may play a significant role in disease development.. Thus wind velocity recorded on hourly basis would be more useful for accurate disease prediction. According to Hassan (1964),, considering the wind direction, the urediniospores first move from north to south and establish infection on wheat first in the southern areas where crop is sown earlier than the northern parts of the country. Moreover, the temperature during December and Januarv is more favourable for rust fungus infection. As the temperature in the central plains becomes suitable for infection, the disease appears in this region due to the introduction of primary inoculum from southern area to northern plains.

In the current studies, the crop was artificially inoculated and the natural inoculum was also relied upon for infection. But the amount of inoculum assessed in terms of number of urediniospores recorded by spore traps installed in the vicinity was scarce, which may indicate the disease development from locally surviving inoculum. However, the possibility of inoculum landing from high altitudes cannot be excluded. The urediniospore number was not included to determine the relationship with disease development, because effects on leaf rust development by uredi.niospore number described in quantitative terms have been reported (Dirks and Romig, 1970; Eversmeyer *et al.,* 1973). When actual spore numbers were used to determine. the relationship with disease severity, R^2 values were low (Eversmeyer *et al.,* 1973). Thus the data recorded just on spore number carries little value unless the urediniospore virulence frequency, virulence association and distribution of *Puccinia recondita* f. sp. *tritici* are determined in a certain region (Khan and Ilyas, 1997).

Since environmental conditions were different during the two seasons, therefore data could not be lumped for prediction of leaf rust to avoid interactive effects. Multiple regression models consisting of maximum + minimum temperature, relative humidity + wind speed + wind movement during 1996 and minimum temperature + relative humidity during 1997 explained 90% of the variability in leaf rust development on three wheat varieties(Table 2). Leaf rust severity values recorded on wheat varieties and predicted by different models were in agreement in respect of most of the varieties during the two seasons (Table 2). The independent variables are sensitive to the order of their entry into a model and more than one variable in one model may have rnulticelinearltv, with other variables (Myers, 1990). Besides, weekly rainfall and wind speed data may not be accurate for leaf rust prediction, because frequency and amount of rain showers and wind velocity greatly influence spore landing, dispersal and distribution. Similarly, relative humidity may also differ at different heights in a crop canopy at different time intervals.

It is difficult to propose one model for leaf rust prediction because different models give different predictions under varying environmental conditions. Several years environmental and disease severity data along with urediniospore virulence qualitative data may be useful in accurate disease prediction. Based on two seasons environmental data, higher leaf rust severity during 1996 may be due to sufficient amount of inoculum with early rainfall, average temperature of 22-26°C and relative humidity above 85%.

REFERENCES

Anonymous. 1992. SAS User's Guide:Statistics. Version. 6.03. SAS Institute, Cary, NC, USA.

Bhatti, M. A. R. and M. B. Ilyas. 1986. Wheat Diseases in Pakistan. In Problems and Progress of Wheat Pathology in South Asia (Ed. L.M. Joshi, D.V. Singh & K.V. Srivastava),, pp. 401. Malhotra Pub. House, New Delhi.

Broweder, L. E. and M. G. Eversmeyer. 1987. Influence of temperature on development of *Puccinia recondita* on *Triticum aestivum* 'Suwon' 85. Phytopath. 77:423-425.

Dirks, V. A. and R. W. Romig. 1970. Linear models applied to variation in numbers of cereal rust uredospores. Phytopath. 60:246-251.

Eversmeyer, M. G., J. R. Burleigh and A. P. Roelfs. 1973. Equations for predicting wheat stem rust development. Phytopath. 63:348-351.

Haq, E.1983. Prevalance of leaf rust races of wheat in Punjab. M.Sc. Thesis, Univ. Agri., Faisalabad.

Hassan, S. F. 1964. Epidemiology of wheat rusts in Pakistan. Proc. Nat. Sem. on Breeding Wheat Rust for Resistance in Pakistan, pp. 46-47.

Hassan, S. F., M. A. S. Kirmani and M. Hussain, 1967. Some new records of physiological races of *Puccinia recondita* Rob. ex. Desm. sp. *tritici* in Pakistan. W. Pak. J. Agri. Res. 5:179-183.

Hassan, S. F. 1973. Wheat diseases and their relevance to improvement in Pakistan. Proc. 4th FAO/Rockfeller Foundation Wheat Seminar, pp. 84-85.

Hassan, S. F., M. A. S. Kirmani and S. A. Rizvi. 1974. Wheat disease situation in Pakistan during the crop year 1972-73. Pak. J. Bot. 6:89-91.

Hassan, S. F., M. A. S. Kirmani and M. Hussain. 1978. Prevalence of leaf rust races of wheat. Annual Rep., CDRI, Islamabad.

Hassan, S~ F. 1979. Wheat diseases situation in Pakistan. Paper presented at Nat. Sem. on Wheat Res. and Prod.,Islamabad.

Jarnes, C. 1971. A Manual of Assessment Keys for Plant Diseases. Canada Dept. of Agri. Publ. No. 1458.

Khan, M. A. 1985. Wheat breeding and rust epidemiology in Pakistan. Proc. Nat. Sem. on Epidemiology and Forecasting of Plant Diseases; Univ. Agri., Faisalabad.

Khan, M. A. and M. B. Ilyas. 1997. Characterization of environmental conditions conducive for leaf rust development on wheat. Sci. Int. (Lahore),9(21:163-165.

Large, E. C. 1954. Growth stages in cereals. Illustration of the Feekes scale. Plant Pathol. 3: 128-129.

Myers, R. H. 1990. Classical and Modern Regression with Application. 2nd ed. PWS-KENT Puhl. Co., Boston, USA.

Roelfs, A. P. 1986. Development and impact of regional cereal rust epidemics. In Plant ~isease Epidemiology, Vol. 1, Population Dynamics and Management (Ed. K.J. Leonard & W.E. Fry), pp. 129-150. Macmillan Pub. Co., New York.

Suba Rao, K. V., G. T. Berggren and J. P. Snow. 1990. Characterization of wheat leaf rust epidemics in Louisiana. Phytopath. 80:402-410.