http://www.pjbs.org

PJBS

ISSN 1028-8880

Pakistan Journal of Biological Sciences

ANSInet
Asian Network for Scientific Information
308 Lasani Town, Sargodha Road, Faisalabad - Pakistan

Pakistan Journal of Biological Sciences, 2 (1): 113-120, 1999 Research Article

Polynomial Regression Models to Characterize Environmental Conditions Conducive for Leaf Rust Development on Winter Wheat in Mississippi

Muhammad Aslam Khan and Larry Eugene Trevathan*
Department of Plant Pathology, University of Agriculture, Faisalabad, Pakistan
*Department of Entomology and Plant Pathology, Mississippi State University, Mississippi State, MS 39762, USA

Abstract
Environmental conditions conducive for leaf rust development were determined at Starkville, MS, during the 1991-92 and 1992-93 wheat growing seasons. Four wheat varieties, grown in a randomized complete block design and infected by natural inoculum, were rated weekly for leaf rust severity. The relationship of weekly maximum, minimum and average air temperatures, dew point, relative humidity, total rainfall, soil temperature, solar radiation and wind movement to leaf rust severity was determined by polynomial regression. Leaf rust severity for each of the varieties was different under differing environmental conditions. In 1992, the relationship between leaf rust severity and weekly air and soil temperatures and solar radiation was linear for most varieties. In 1992, significantly higher solar radiation and soil temperature, lower rainfall and less wind movement contributed to greater leaf rust severity compared to 1993. During two seasons neither quadratic nor qubic regression models fit the data well for most of the environmental parameters. During 1992 leaf rust development on all the four varieties in relation to weekly maximum, minimum and average air temperature and soil temperature was best explained by linear regression models. During 1993, the relationship of environmental condition to leaf rust severity recorded only on Pioneer varieties was best explained by linear regression models. The environmental conditions characterized for maximum leaf rust severity on four varieties included 25-27, 15-20, 21-23°C maxi, min, eve air temperatures and 85-90 percent relative humidity respectively.

Introduction
Leaf rust of wheat, caused by *Puccinia recondita* Roberge ex Desmaz f. sp. *tritici* (Eriks. & E. Henn.) D. M. Henderson, occurs commonly and frequently in the southern United States (Samborski, 1985). Wheat varieties grown in this area lack durable resistance to virulent races of the leaf rust fungus (Leonard *et al*., 1992). Under conducive environmental conditions, severe and widespread outbreaks of this disease can result in significant reductions in wheat yield (Burleigh *et al*., 1969, 1972a, b). Characterization of the environmental conditions conducive for leaf rust development is essential to provide advanced forecasts for chemotherapy.

Attempts to predict leaf and stem rust epidemics, using multiple linear regression, have been reported (Burleigh *et al*., 1969,1972a, b; Eversmeyer and Burleigh, 1970; Eversmeyer *et al*., 1973). Burleigh *et al*. (1969) developed linear equations for predicting wheat leaf rust using measures of disease severity, weekly urediniospore numbers, cumulative urediniospore number, average maximum temperature, hours of free moisture as dew or rain and days of precipitation during the seven days immediately preceding the date of prediction. Percentage disease severity was recorded eight days after the date of prediction. According to these researchers, environmental variables accounted for 70 percent of the variability in wheat leaf rust development. These studies did not include soil temperature, relative humidity, dew point, wind movement or solar radiation.

Efficient and economical control of leaf rust depends upon a complete knowledge of epidemiology. Epidemiological aspects of wheat leaf rust studied in relation to specific climatic conditions have provided an understanding of disease development in certain regions (Fogliani and Caffarri, 1986; Nagarajan and Joshi, 1978; Sahni and Prasada, 1963). Significant progress has been made in understanding leaf rust epidemiology under controlled environmental conditions (Chang *et al*., 1973; Clifford and Harris, 1981; Dirks and Romig, 1970; Eversmeyer *et al*., 1973; Srivastava, *et al*., 1985, 1987; Statler and Nordgaard, 1980; Tomerlin *et al*., 1983; Wiese and Ravenscroft, 1979). For practical disease management, environmental conditions conducive for disease development must be studied in the field. A primary objective of this study was to determine relationship of weekly maximum, minimum and average air temperaures, soil temperature, precipitation, relative humidity, wind movement, solar radiation and dew point with leaf rust development. Results of this study could provide a basis for decisions regarding fungicide application.

Materials and Methods
Experimental plots were established using a Randomized Complete Block Design with four replications at the Mississippi Agricultural and Forestry Experiment Station, Plant Science Research Center, Mississippi State University, Starkville. Coker 9323 and 9733 and Pioneer 2548 and 2555 were sown on 29 October 1991. In 1992, Pioneer

2548 and 2555 were sown on 9 November. The Coker lines were not included in 1992.

Plots were limed and fertilized based on soil analysis according to recommendations of the Mississippi Cooperative Extension Service. Nitrogen was applied to plots at the rate of 100 kg/ha in a single spring application. Diclofop-methyl (1.10 kg ai/ha) and thiameturon (0.02 kg ai/ha) were applied at the 3- to 4-leaf stage, respectively, for the control of wild garlic (*Allium vineale* L.) and winter annuals.

Natural inoculum was relied upon as the source of infection in both seasons. Disease observations were made weekly in both seasons beginning when flag leaves exhibited rust pustules until the leaves became necrotic. The flag leaf of each of 10 plants, chosen at random from each plot, was rated for rust severity by comparing the percentage leaf area covered by rust pustules with the leaf rust severity scale developed by James (1971).

Data on weekly maximum, minimum and average air temperatures (°C), soil temperature (°C), relative humidity (%), precipitation (cm), total wind movement (km/hr for 24 hr), solar radiation (mj/m^2) and dew point (°C) were recorded with sensors attached to a battery-operated EasyLogger-900 Field Unit (Omnidata International Inc., Logan, Utah, 84321) containing internal random access memory (RAM) configurations with storage of 25,000 data points. Data retrieved from electronic storage packs via a Polycorder-600 Series (Omnidata International Inc., Logan, Utah, 84321) were downloaded to a 486 Computer (Micro-professionals, Lansing, IL 60473). The field unit and the desktop computer were compatible through "EasyTool" and "EasyTerm" software supplied by Omnidata International Inc. In order to determine the relationship between environmental conditions and leaf rust development, weekly environmental data (consisting of nine environmental variables) were subjected to linear and quadratic regression using Statistical Analysis System (SAS) software (Myers, 1990; Neter *et al.*, 1990; SAS, 1992).

Results

Leaf rust severity differed significantly among varieties in 1992, but not in 1993 (Table 1). In 1992, leaf rust severity on Coker 9733 was significantly higher compared to other varieties (Table 2). In 1993, the two Pioneer varieties had similar leaf rust severity ratings.

In 1992, wheat varieties responded differently to environmental conditions recorded after disease initiation (Fig. 1-3). Disease development on Coker 9323, Pioneer 2548 and Pioneer 2555 was low to moderate. The relationship between leaf rust development on these three varieties and weekly air temperature (max/min/ave) and soil temperature was explained by the linear model: $Y = b_0 + b_1X_1 + e$, where Y = percent of flag leaf area

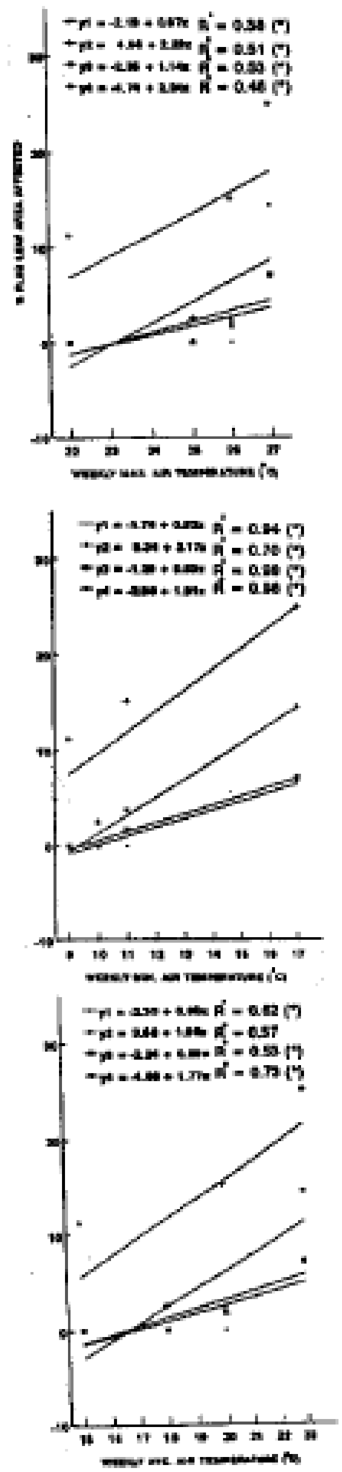

Fig. 1: Relationship of weekly air temperatures to me leaf rust severity on Coker 9323 (Y1), Coker 973 (y2), Pioneer 2548 (y3) and Pioneer (2555 (y4) Starkville, Mississippi, 1992.
*Indicates significant regression at $p < 0.05$

Fig. 2:

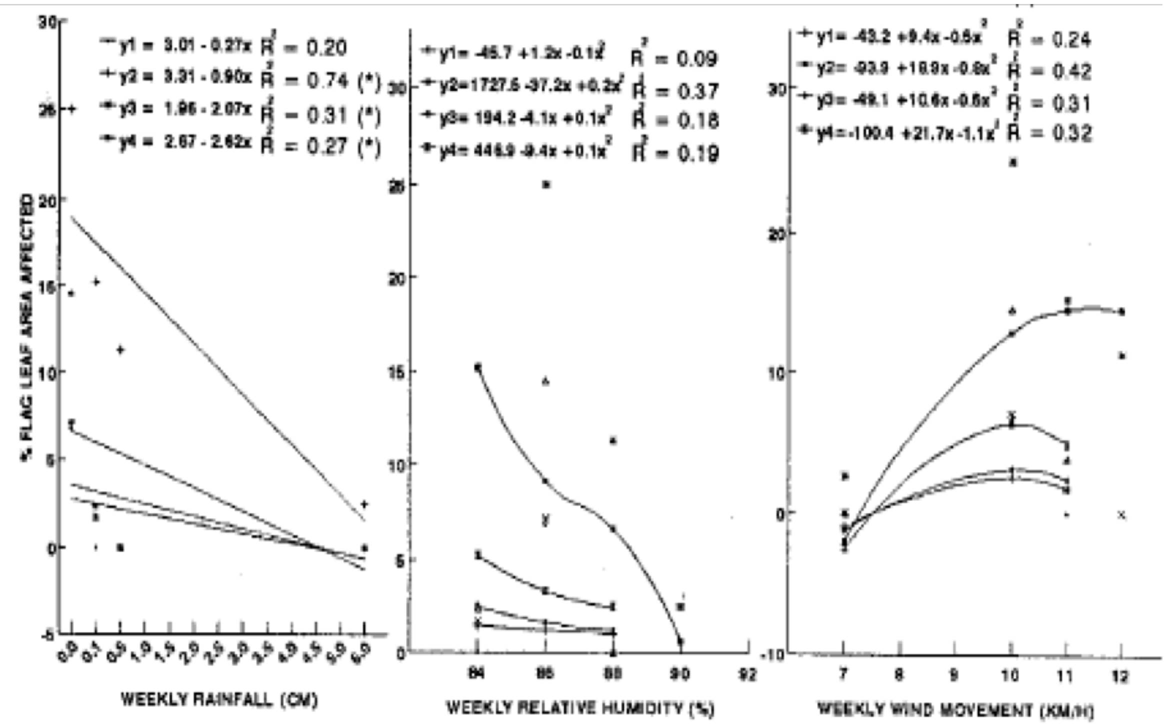

FIG. 3

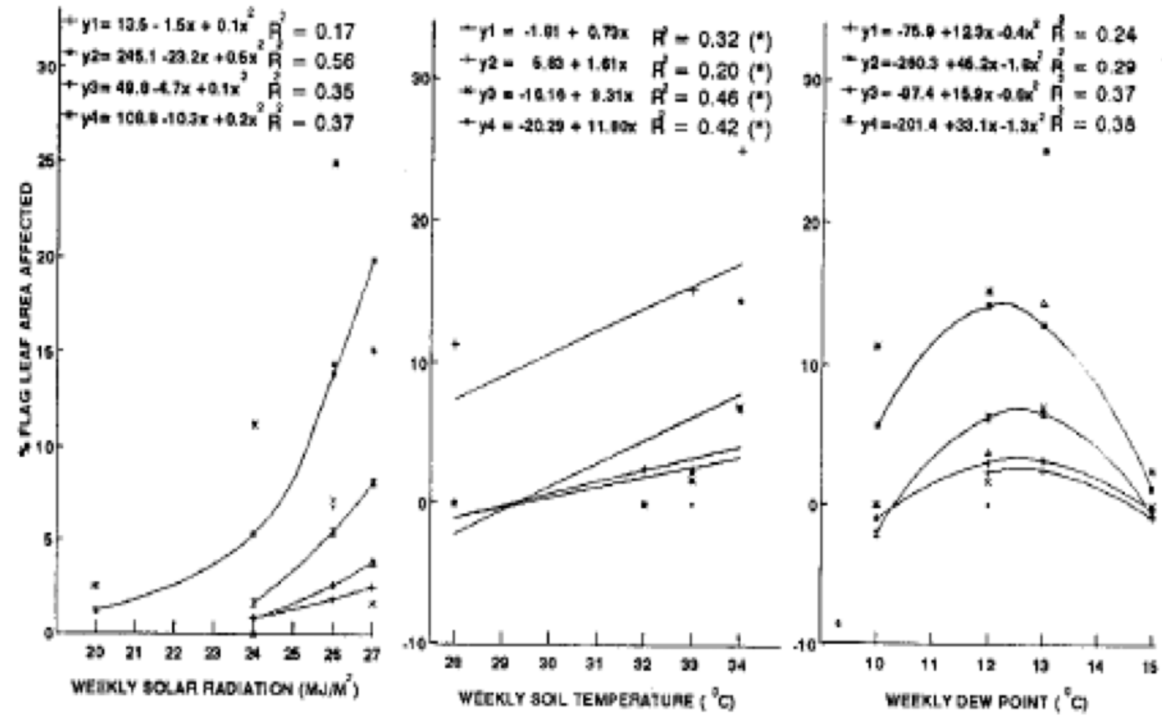

Fig. 2: Relationship of weekly rainfall, relative humidity and wind movement to mean leaf rust severity on Coker 9323 (y1), Coker 9733 (y2), Pioneer 2548 (y3) and Pioneer 2555 (y4) at Starkville, Mississippi, 1992).
*Indicates significant regression at $p < 0.05$

Fig. 3: Relationship of weekly solar radiation, soil temperature and dew point to mean leaf rust severity on Coker 9323 (Y1), Coker 9733 (y2), Pioneer 2548 (y3) and Pioneer (2555 (y4) at Starkville, Mississippi, 1992.
*Indicates significant regression at $p < 0.05$

FIG. 4

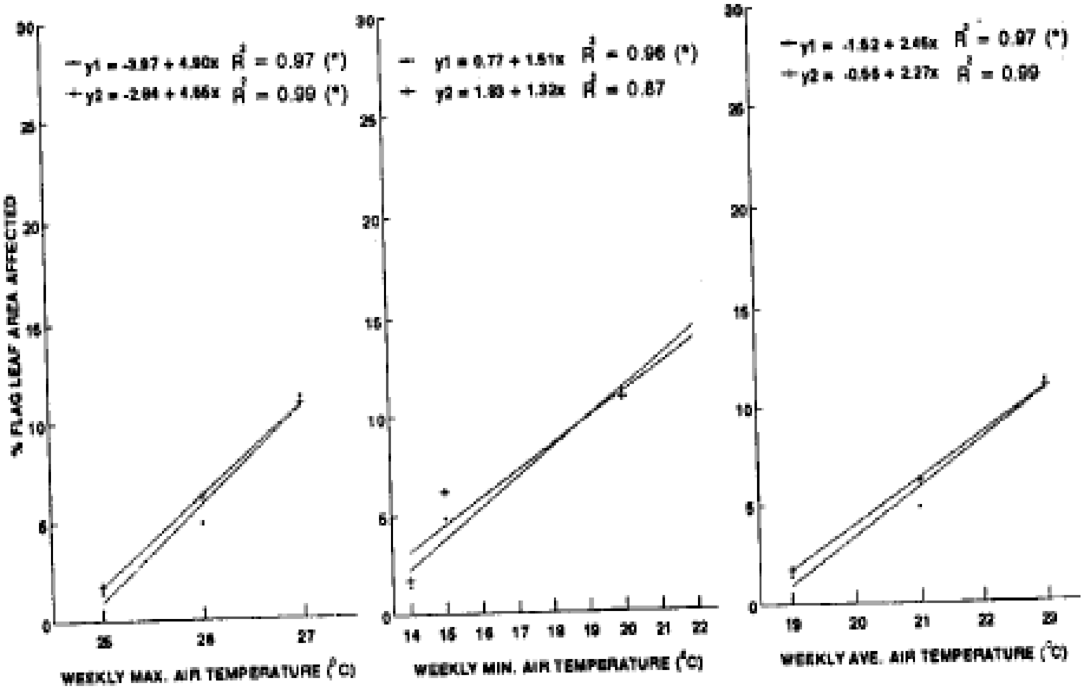

Fig. 5

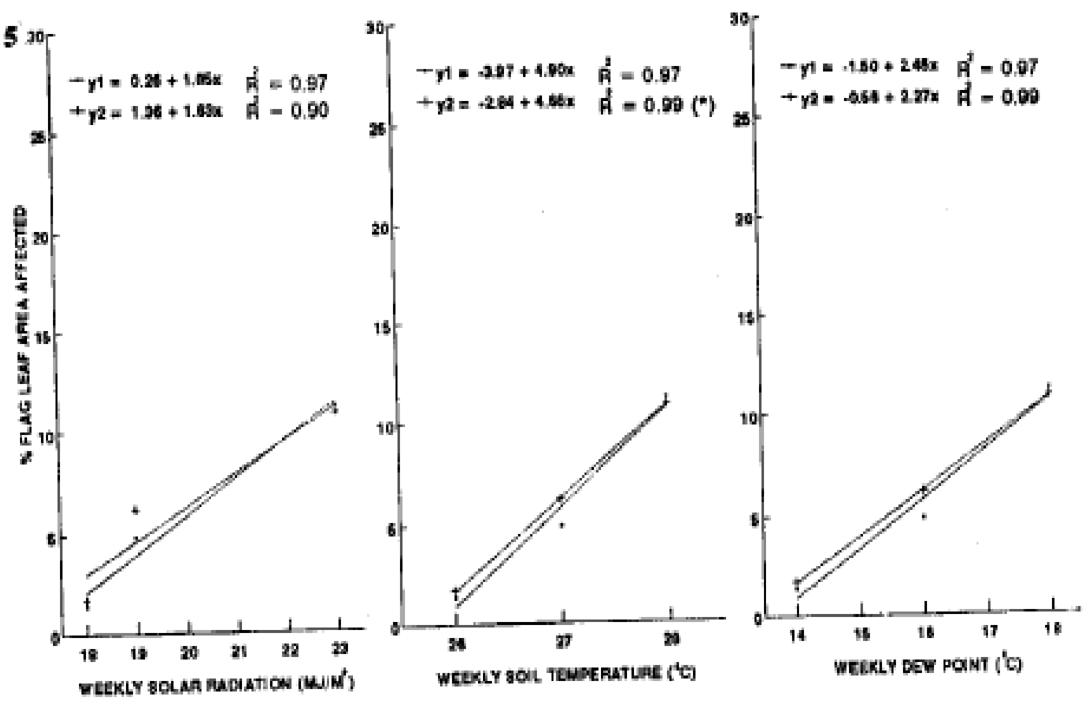

Fig. 4: Relationship of weekly air temperature to mean leaf rust severity on Pioneer 2548 (y1) and Pioneer 2555 (y2) at Starkville, Mississippi, 1993. *Indicicates significant regression at $p<0.05$

Fig. 5: Relationship of weekly solar radiation, temperature and dew point to mean leaf r severity on Pioneer 2548 (y1) and Pioneer 25 (y2) at Starkville, Mississippi, 1993.
*Indicates significant regression at $p<0.05$

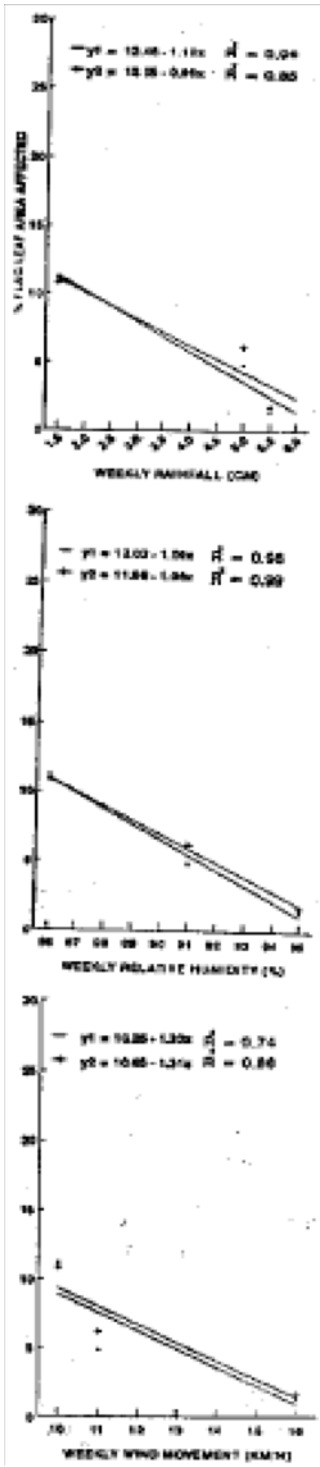

Fig. 6: Relationship of weekly rainfall, relative humidity and wind movement to mean leaf rust severity on Pioneer 2548 (y1) and Pioneer (2555 (y2) at Starkville, Mississippi, 1993.
*Indicates a significant regression at $p<0.05$

covered by rust pustules; b_o and b_1 are parameter estimates of intercept and slope, respectively; X = temperature. (maximum, minimum or average) and e = random error. The relationship of weekly maximum, minimum air temperature and soil temperature to leaf rust development on Coker 9733. was also explained by linear model (Fig. 1, 3).

The relationship between weekly total rainfall and leaf rust severity on all four varieties was negative (Fig. 2). Linear models resulted in significant fit to weekly rainfall and disease severity data for Coker 9733 and Pioneer varieties. Maximum leaf rust severity was observed on all varieties when rainfall was below 1 cm (Fig. 2). At 6 cm weekly total rainfall, leaf rust was minimum on Coker 9733 and no disease occurred on the other varieties. Leaf rust on Pioneer 2548 and 2555, initiated when no rainfall was recorded and decreased as rainfall increased. There was no relationship between weekly relative humidity, wind movement, solar radiation and dew point to leaf rust severity on all four varieties (Fig. 2, 3).

In 1993, a linear regression model explained the relationship between weekly air temperatures (max/min/ave) and leaf rust development on Pioneer 2548 (Fig. 4). Weekly maximum air temperature and soil, temperature were the only environmental parameters that resulted in significant fit to the leaf rust severity data for Pioneer 2555 (Fig. 4, 5). In spite of the high R^2 values for weekly rainfall, relative humidity, solar radiation, wind movement and dew point, linear regression was not significant (Fig. 5, 6).

In 199.3, leaf rust severity progressed in a linear fashion on Pioneer 2548 at maximum air temperatures of 25-27°C, minimum air temperatures of 14-20°C, average air temperatures of 19-23°C, soil temperatures of 26-28°C, solar radiation of 18-23 mj/m^2 and dew points between 14-18°C (Fig. 4, 5). Leaf rust severity was maximum on Pioneer 2548 and 2555 at total weekly rainfall of 1.5 cm, relative humidity of 86% and wind movement at 10 km/h. Leaf rust severity decreased when rainfall, wind movement and relative humidity increased (Fig. 6).

Discussion

During 1992, ˉleaf rust was initiated earlier than in 1993. The relationship of weekly air and soil temperatures, solar radiation and dew point with disease severity was linear in most varieties. Higher weeklyirainfall and wind movement resulted in lower leaf rust severity. Weekly solar radiation had a significant influence on disease development during both seasons. During 1992, solar radiation was greater throughout the season, which may have been conducive to inoculum survival compared to 1993 when solar radiation was lower. According to Eversmeyer and Kramer (1994), significantly more inoculum survived exposure to high temperature and solar radiation occurring during the summer and fall than survived the, lower temperature and

Table 1: Analysis of variance of leaf rust severity, on wheat varieties during two seasons (1991-92, 1992-93) at Starkville, Missisippi

Leaf rust severity	1991-92			1992-93		
Source of variation	df	F Value	Pr > F	df	F Value	Pr > F
Replications (Blocks)	3	1.41	0.3042	3	0.69	0.6181
Varieties	3	19.06	0.0001*	1	19.06	0.8791
Error	9			3		
Total	15			7		

*Significant ($p<0.05$)

Table 2: Mean leaf rust severity (% flag leaf area covered by rust pustules), yield (kg/ha) and 1,000-kernel weight (g) during two seasons (1991-92 and 1992-93) at Starkville, Mississippi

Varieties	1991-92 Leaf rust severity	1992-93 Leaf rust severity
Coker 9323	6.82c[x]	-
Coker 9733	24.87a	-
Pioneer 2548	7.12c	11.22a
Pioneer 2555	14.49b	10.86a
LSD	6.51	6.48

[x]Means within columns not sharing a letter differ significantly at the 5% level of probablity as determined by the LSD test

solar radiation during winter.

Air temperatures conducive for leaf rust development during 1992 were similar to those reported by several authors (Fogliani and Caffarri, 1986; Nagarajan and Joshi, 1978). Air temperature not only affects survival, latent period, growth, infectious period and sporulation of the leaf rust fungus, but also the age and relative susceptibility of the host (Clifford and Harris, 1981; Eversmeyer *et al.*, 1973; Hyde, 1982; Subba Rao *et al.*, 1989; Tomerlin *et al.*, 1983; Wiese and Ravenscroft, 1979). The early appearance of rust on Coker 9733 may have resulted from the presence of sufficient amounts of initial inoculum and conducive temperatures for fungal growth. The delayed appearance of leaf rust on Coker 9323, Pioneer 2548 and 2555 may be due to temperature sensitive, adult plant resistance to infection by *Puccinia recondita* f. sp. *tritici* as reported in other wheat varieties (Hyde, 1982; Pretorius *et al.*, 1988).

In spite of greater rust development when weekly rainfall was low, the generalization of a perfect, inverse relationship with disease severity may not be accurate. The frequency of rain showers and hours of free moisture on wheat leaves are critical for leaf rust development. According to Eversmeyer and Burleigh (1970), hours of free moisture proved to be the most accurate measure of moisture available for leaf rust development rather than days of precipitation. In their studies, the inclusion of a precipitation variable increased the accuracy of prediction over that with no moisture available. In the current studies, leaf wetness was recorded by a sensor attached to a wheat flag leaf. The data recorded was not considered as reliable as measurements of the changes in leaf wetness conditions occurring at more than one level in the crop canopy. During 1992, higher leaf rust severity may have been due to conducive relative humidities and low wind movement. Maximum disease severity was recorded at 84-86 percent relative humidity and 10 km/h total wind movement. During 1993, low disease severity was recorded in the first two weeks of May due to high relative humidity. Disease severity was greatly reduced at relative humidities above 90-95 percent. A critical relative humidity of 85 percent may be the threshhold between higher and lower rust severities.

During two seasons, neither linear, nor quadratic regression models significantly fit the data for relative humidity, wind movement or dewpoint. One explanation for this was greater variation in disease severity data. Regression of daily environmental variables against leaf rust severity in both seasons did not result in significant fit to the data and most parameter estimates were not significant. Increased disease observations and accurate measurement with computer image analysis could increase the preciseness of these data and their usefulness for disease prediction. Under field conditions the complexity of environmental conditions and the high degree of multicolinearity among environmental variables, makes precise disease prediction difficult. Additionally, environmental variables used in multiple or non-linear regression models are sensitive to the order of entry. Environmental variables in this study were entered based on the evaluators assessment of th biological significance of each variable to disease development. However, under field conditions the role and significance of each environmental variable may vary depending upon the pattern of climate and topography. Leaf rust development is a function of temperature fluctuation, hourly leaf wetness, relative humidity and wind movement when sufficient amount of virulent, initial inoculum are deposited on a susceptible wheat variety. Disease forecasts utilizing environmental conditions and indirect assessment if initial inoculum have been reported (Billing, 1974, 1980; Castor *et al*., 1975; Stevens, 1934; Thomson *et al*., 1982). Urediniospore inoculum effects on leaf rust development have been described in quantitative terms (Burleigh *et al*., 1969; Dirks and Romig, 1970; Subba Rao *et al*., 1990). When actual spore numbers were used to predict disease severities, R^2 values were low (Burleigh *et al*., 1969). Data regarding urediniospore virulence frequency, virulence association and distribution of *Puccinia recondita* f. sp. *tritici*, in the southeastern United State could provide information on patterns of leaf rust epidemics and their prediction. During 1993, higher rainfall and wind movement may have resulted in the washing of inoculum from leaf surfaces. Results of these studies indicate that environmental conditions conductive for disease development if recorded on weekly basis fit linear regression models. Data recorded on hourly basis especially minimum temperature, relative humidity and leaf wettnes may be more fruitful for accurate leaf rust forecasting. Advance warning forecasts regarding expected disease pressure could suggest prophylactic measures for economic leaf rust management by protecting wheat with expected high yields under such environments.

References

Billing, E., 1974. The effect of temperature on the growth of the fireblight pathogen, *Erwinia amylovora*. J. Applied Microbiol., 37: 643-648.

Billing, E., 1980. Fireblight *Erwinia amylovora* and weather: A comparison of warning systems. Ann. Applied Biol., 95: 365-377.

Burleigh, J.R., A.P. Roelfs and M.G. Eversmeyer, 1972a. Estimating damage to wheat caused by *Puccinia recondita tritici*. Phytopathology, 62: 944-946.

Burleigh, J.R., M.G. Eversmeyer and A.P. Roelfs, 1972b. Development of linear equations for predicting wheat leaf rust. Phytopatholoy, 62: 947-953.

Burleigh, J.R., R.W. Roming and A.P. Roelfs, 1969. Characterization of wheat rust epidemics by numbers of uredia and number of urediospores. Phytopathology, 59: 1229-1237.

Castor, L.L., J.E. Ayers, A.A. MacNab and R.A. Krause, 1975. Computerized forecasting system for Stewart's bacterial disease on corn. Plant Dis. Rep., 59: 533-536.

Chang, H.S., L. Calpouzos and R.D. Wilcoxson, 1973. Germination of hydrated uredospores of *Puccinia recondita* inhibited by light. Can. J. Bot., 51: 2459-2462.

Clifford, B.C. and R.G. Harris, 1981. Controlled environment studies of the epidemic potential of *Puccinia recondita* f. sp. *tritici* on wheat in Britain. Trans. Br. Mycol. Soc., 77: 351-358.

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

Eversmeyer, M.G. and C.L. Kramer, 1994. Survival of *Puccinia recondita* and *P. graminis* urediniospores as affected by exposure to weather conditions at one meter. Phytopathology, 84: 332-334.

Eversmeyer, M.G. and J.R. Burleigh, 1970. A method of predicting epidemic development of wheat leaf rust. Phytopathology, 60: 805-811.

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

Fogliani, G. and E. Caffarri, 1986. [Experimental researches in Oltrepo Pavese (*Padana Valley*), on wheat rust epidemiological aspects related to the climatic conditions]. J. Phytopathol., 115: 2-20, (In Italian).

Hyde, P.M., 1982. Temperature-sensitive resistance of the wheat cultivar Maris Fundin to *Puccinia recondite*. Plant Pathol., 31: 25-30.

James, W.C., 1971. A Manual of Assessment Keys for Plant Diseases. APS Press, USA., ISBN: 978-0-89054-081-7, Pages: 90.

Leonard, K.J., A.P. Roelfs and D.L. Long, 1992. Diversity of virulence within and among populations of *Puccinia recondite* f. sp. *tritici* in different areas of the United States. Plant Dis., 76: 500-504.

Myers, R.H., 1990. Classical and Modern Regression with Applications. 2nd Edn., Duxbury/Thompson Learning, Boston, USA., ISBN-13: 9780534380168, Pages: 488.

Nagarajan, S. and L.M. Joshi, 1978. Epidemiology of brown and yellow rusts of wheat over North India. II. Associated meteorological conditions. Plant Dis. Rep., 62: 186-188.

Neter, J., W. Wasserman and M.H. Kutner, 1990. Applied Linear Statistical Models: Regression, Analysis of Variance and Experimental Designs. 3rd Edn., IRWIN, Boston, USA., ISBN-13: 9780256083385, Pages: 1181.

Pretorius, Z.A., F.H.J. Rijkenberg and R.D. Wilcoxson, 1988. Effects of growth stage, leaf position and temperature on adult-plant resistance of wheat infected by *Puccinia recondita* f. sp. *tritici*. Plant Pathol., 37: 36-44.

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

Sahni, M.L. and R. Prasada, 1963. A study on the environmental conditions influencing the development of the three rusts of wheat in the neighbourhood of Delhi: Incidence of wheat rusts in relation to initial spore showers and weather condition. Indian Phytopathol., 16: 285-294.

Samborski, D.J., 1985. Wheat Leaf Rust. In: The Cereal Rusts, Volume 2: Diseases, Distribution, Epidemiology and Control, Roelfs, A.P. and W.R. Bushnell (Eds.). Chapter 2, Academic Press, Orlando, FL., USA., ISBN-13: 9780121484026, pp: 39-59.

Srivastava, K.D., L.M. Joshi and S. Nagarajan, 1985. A linear equation for predicting severity of leaf rust of wheat. Indian Phytopathol., 36: 116-120.

Srivastava, K.D., L.M. Joshi and S. Nagarajan, 1987. Liberation of uredospores of *Puccinia recondita* f. sp. *tritici* under varying wind speeds. Indian Phytopathol., 40: 474-477.

Statler, G.D. and J.T. Nordgaard, 1980. Leaf wettability of wheat in relation to infection by *Puccinia recondita* f. sp. *tritici*. Phytopathology, 70: 641-643.

Stevens, N.E., 1934. Stewart's disease in relation to winter temperatures. Plant Dis. Rep., 18: 141-149.

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

Subba Rao, K.V., J.P. Snow and G.T. Berggren, 1989. Effect of growth stage and initial inoculum level on leaf rust development and yield loss caused by *Puccinia recondita* f. sp. *tritici*. J. Phytopathol., 127: 200-210.

Thomson, S.V., M.N. Schroth, W.J. Moller and W.O. Reil, 1982. A forecasting model for fire blight of pear. Plant Dis., 66: 576-579.

Tomerlin, J.R., M.G. Eversmeyer, L.E. Browder and C.L. Kramer, 1983. Temperature and host effects on latent and infectious periods and on urediniospore production of *Puccinia recondita* f. sp. *tritici*. Phytopathology, 73: 414-419.

Wiese, M.V. and A.V. Ravenscroft, 1979. Environmental effects on inoculum quality of dormant rust uredospores. Phytopathology, 69: 1106-1108.