Predictive Model for "Mal de Rio Cuarto" Disease Intensity

G. J. March, Instituto de Fitopatología y Fisiología Vegetal, Cno. 60 Cuadras km 51/2 Cnel. Olmedo, 5119 Córdoba, Argentina; **M. Balzarini,** Facultad de Ciencias Agropecuarias, Universidad Nacional de Córdoba; C.C. 509, Córdoba, Argentina; and **J. A. Ornaghi, J. E. Beviacqua,** and **A. Marinelli,** Facultad de Agronomía y Veterinaria, Universidad Nacional de Río Cuarto, Estafeta Postal 9, Río Cuarto 5800, Argentina

ABSTRACT

March, G. J., Balzarini, M., Ornaghi, J. A., Beviacqua, J. E., and Marinelli, A. 1995. Predictive model for "Mal de Rio Cuarto" disease intensity. Plant Dis. 79:1051-1053.

"Mal de Rio Cuarto" (MRC) virus disease is the most important virus disease of maize (*Zea mays* L.) in Argentina with the rural areas near Chaján, Sampacho, and Suco (in Rio Cuarto, province of Córdoba) being the most affected. A predictive model for MRC before planting a crop was developed based on the disease intensity over nine agricultural years (1981–82 to 1989–90) and a series of weather variables for that period (such as minimum, mean, and maximum temperatures, number of frosts, and amount of rainfall). To build the model, agricultural years were divided into two groups according to the percentage of severely affected plants (intensity). A year was considered "mild" if the percentage of severely affected plants was less than 20% and "severe" if the percentage was higher. A discriminant stepwise procedure was used to analyze data. The average maximum temperatures in June, July, and August, the average maximum temperatures in July and August, and the total rainfall in June, July, and August were found to be significant forecasters of disease intensity. The model was validated in the agricultural years of 1990–91, 1991–92, 1992–93, and 1993–94. The relative intensity of the disease was adequately forecasted and confirmed for those years. Results support the feasibility of forecasting MRC intensity prior to planting maize in the area under study.

Additional keyword: epidemiology

"Mal de Río Cuarto" (MRC) virus disease is the most important virus disease of maize (*Zea mays* L.) in Argentina. Approximately 350,000 ha of maize are planted in the Rio Cuarto area (province of Córdoba) each year, and MRC has caused losses of 5 to 60% in this area in the previous decade (14). "Mal de Rio Cuarto" virus (MRCV), maize rough dwarf virus (MRDV), and rice black streaked dwarf virus (RBSDV) isolated in China (RBSDV-C) and Japan (RBSDV-J), can all be considered strains of the same virus (16).

MRC is a monocyclic disease. The initial inoculum source is vector insects *Delphacodes kuscheli* Fennah (15,19) that mainly develop on oat (*Avena sativa* L.) and wheat (*Triticum aestivum* L.), where they acquire the virus, and then migrate to maize (18,19). The greatest losses occur when infection takes place during the early stages of crop development (20).

Disease forecasting systems that can predict an outbreak or increase in disease intensity based on weather, host, or pathogen conditions (12) are important in disease management (1,5,6,9,24). Some models have been developed that predict incidence of disease before planting. This is particularly important when disease intensity is significantly determined by the initial inoculum (1,5,6).

A model intended to forecast the relative intensity of MRC prior to planting maize was developed on the basis of disease intensity over nine agricultural years (1981–82 to 1989–90) and various climatic variables recorded during the winter season.

MATERIALS AND METHODS

Field data. MRC intensity, percentage of plants severely affected, was evaluated during nine agricultural years (1981–82 to 1989–90) in maize fields in Chaján, Sampacho, and Suco (in Rio Cuarto, province of Córdoba). Fifty commercial crops planted between the third week in October and the first week in December (when most maize fields are planted) were evaluated each year. The three or four cultivars monitored each year represented 80% of all commercial cultivars planted in the study area.

One hundred samples along an X-shaped path through each field were taken, with 50 samples taken along each of the two arms of the X. Sampling sites were spaced 30 rows, with 0.70 m between the rows, and each sample consisted of 25 consecutive plants in the same row. The X-shaped path was traveled in such a way that an area of about 10 ha was traversed in each field.

The assessment was carried out when maize grains were in the dough stage (approximately 90 days after planting) and only took into account severely affected plants. Plants sampled were characterized by shortened internodes, thickened and flattened stalks, degenerated leaves or leaves reduced to sheaths, malformed cobs, and proliferating grainless ears. Moreover, there were enations protruding from the veins in the back of the leaves. Average MRC intensity was evaluated for each agricultural year in the area under study. These data made up the dependent series. Each year was then classified as "mild" or "severe" according to whether intensity was under or over 20%, respectively.

Independent series were made by using minimum, average, and maximum air temperature values, number of frosts, and amount of rainfall recorded during the months (May through September) previous to the sowing period mentioned above. These data were obtained from the Agrometeorological Section of the Universidad Nacional de Río Cuarto. The daily values of these variables were averaged or added according to the various periods (Table 1).

Discriminant analysis. Discriminant analysis is a statistical technique that allows individuals or objects (e.g., years) to be classified into exclusive and exhaustive groups, on the basis of a set of independent variables with a low error rate (4). It was used in this context to discriminate agricultural years against MRC intensity on the basis of environmental variables prevailing at the time of preplanting.

A discriminant stepwise selection was conducted to determine which variables were to be included in the model because of the number of available forecaster variables (4); R^2 was used as the selection criterion while the statistical F was taken at $\alpha = 0.15$.

Variables selected by means of the discriminant stepwise procedure (22) are not necessarily those that will allow the best possible model to be developed. Nevertheless, careful use of the stepwise selection combined with the biological knowledge of data makes the procedure a valuable tool to build a discriminant model. Then, the subset of selected variables by means of the discriminant stepwise procedure was used together with other variables with a view to choosing the most suitable predictive model.

Corresponding author: G. J. March
E-mail: ifitovir!march@intact.edu.ar

Accepted for publication 6 July 1995.

The inequality of the dispersion structures (i.e., variance and covariance) of both groups ("mild" and "severe") was evaluated prior to obtaining the discriminant function (17). Discriminant functions were evaluated with two methods to calculate error rates: (i) re-substitution, and (ii) cross-validation (4,10,23).

The discriminant model for predicting MRC intensity before planting of maize was also validated in the field in the ensuing four agricultural years (1990–91, 1991–92, 1992–93, and 1993–94). Each climatic variable was substituted in the model by those corresponding to the new cycle, which was then classified according to the result obtained. Then, disease intensity was evaluated through the method depicted before.

Table 1. Description of environmental variables used in the discriminant analysis

Variable	Variable descriptions
V_1	Average mean temperatures in June, July, August, and September.
V_2	Average mean temperatures in June, July, and August.
V_3	Average mean temperatures in August and September.
V_4	Average mean temperatures in July and August.
V_5	Average mean temperatures in July, August, and September
V_6	Average minimum temperatures in June, July, August, and September.
V_7	Average minimum temperatures in June, July, and August.
V_8	Average minimum temperatures in August and September.
V_9	Average minimum temperatures in July and August.
V_{10}	Average minimum temperatures in July, August, and September.
V_{11}	Average maximum temperatures in June, July, August, and September.
V_{12}	Average maximum temperatures in June, July, and August.
V_{13}	Average maximum temperatures in August and September.
V_{14}	Average maximum temperatures in July and August.
V_{15}	Average maximum temperatures in July, August, and September.
V_{16}	Number of frost days in June, July, August, and September.
V_{17}	Number of frost days in June, July, and August.
V_{18}	Number of frost days in August and September.
V_{19}	Number of frost days in July and August.
V_{20}	Number of frost days in July, August, and September
V_{21}	Total rain in June, July, August, and September.
V_{22}	Total rain in June, July, and August.
V_{23}	Total rain in August and September.
V_{24}	Total rain in July and August.
V_{25}	Total rain in July, August, and September.

[a] Environmental data supplied by Agrometeorology Section of the University of Río Cuarto. Temperature recorded in C° and rain in mm.

RESULTS

The discriminant stepwise analysis enabled the selection of three environmental variables: average maximum temperatures in June, July, and August (V_{12}); average maximum temperatures in July and, August (V_{14}); and amount of rain in July, August, and September (V_{25}) (Table 2), on the basis of data corresponding to the 1981 to 1989 period. However, the variables from which the best predictive model was obtained were V_{12}, V_{14}, and amount of rain in June, July, and August (V_{22}). The possibility of error classification with this model is the lowest that can be obtained for a linear combination of forecasters. "Severe" years were characterized by average maximum temperatures and rainfall recordings that were higher than those corresponding to "mild" years (Table 3). The multivariate test for the no-effect assumption among groups indicated significant statistical differences between "mild" and "severe" years (Wilk's lambda, $P = 0.001$) (5).

A weighted covariance matrix was used because variance homogeneity was not rejected ($\alpha = 0.1$). A linear discriminant function was obtained, thus model (*D*) was: $D = -242.82 + 36.35\ V_{12} - 19.87\ V_{14} - 0.48\ V_{22}$.

The mean discriminant value for "mild" years was $D_M = -28.52$ with a standard deviation $S_M = 7.80$. The corresponding values for "severe" years were $D_S = 28.52$ and $S_S = 7.36$, respectively.

The function for a new agricultural year (D_N) whose MRC intensity is unknown can be obtained by substituting V_{12}, V_{14}, and V_{22} in the discriminant function with the corresponding values for that year.

The rule to determine which of the two groups D_N belongs to is: If $|D_N - D_M| < |D_N - D_S|$, then, the agricultural year under consideration shall be termed "mild" concerning the relative intensity of the disease; otherwise, it shall be considered "severe." If both modules are equal the assignment to the groups will be randomized.

The discriminant value (*D*) was obtained for each cycle included in the development of the model (1981–82 to 1989–90) and it was then assigned to the corresponding group. All years were classified accordingly (Table 4); the same result as that yielded by the cross-validation process was obtained ("apparent" and "leave-one-out" error rates were zero).

The values recorded for environmental variables of the 1990–91, 1991–92, 1992–93, and 1993–94 agricultural years were the following: V_{12} = 17.6, 15.3, 16.1, and 16.6; V_{14} = 17.95, 15.3, 15.9, and 17.0; and V_{22} = 24.5, 75.3, 22.5, and 15.8 respectively. Consequently, the agricultural years of 1990–91, 1991–92, 1992–93, and 1993–94 were classified as "severe," "mild," "severe," and "severe," respectively (Table 4). These predictions were validated in each year via the corresponding assessment of MRC intensity in the field. In 1990–91, 1991–92, 1992–93, and 1993–94, average disease intensity for 50 maize crops planted in the area under study between the third week in October and the first week in December was 44, 5, 30, and 35%, respectively.

Table 2. Average values for descriptors of variables

Variables[a]	"Mild" years	"Severe" years
V_{12}	15.60	17.10
V_{14}	16.12	17.18
V_{22}	18.32	67.55

[a] See Table 1 for descriptions of variables.

Table 3. Significant variables from stepwise discriminant analysis

Variables[a]	R^2	*F*	Prob. > *F*
V_{12}	0.8768	35.57	0.0019
V_{14}	0.5969	7.40	0.0417
V_{25}	0.8682	32.94	0.0022

[a] See Table 1 for descriptions of variables.

Table 4. Predictive and actual classification of years for the relative intensity of "Mal de Río Cuarto" disease with the disciminant functions (*D*)

Year	*D*[a]	Predicted[b]	Actual[c]
1981–82	23.13	Severe	Severe
1982–83	–18.27	Mild	Mild
1983–84	37.26	Mild	Mild
1984–85	–28.92	Mild	Mild
1985–86	–29.65	Mild	Mild
1986–87	22.81	Severe	Severe
1987–88	40.34	Severe	Severe
1988–89	23.43	Severe	Severe
1989–90	30.91	Severe	Severe
1990–91	28.44	Severe	Severe
1991–92	–26.80	Mild	Mild
1992–93	15.70	Severe	Severe
1993–94	15.20	Severe	Severe

[a] Values obtained by means of the discriminant function.

[b] Relative intensity assigned through the predictive model: "mild" (<20% of severely affected plants) or "severe" (>20% of severely affected plants).

[c] Relative intensity assessed in the field.

DISCUSSION

Most studies of how climate affects plant disease have been concerned with day-to-day weather conditions rather than with year-to-year climatic variability (2). A minimum of 8 years of disease data from one location is needed for correlation and regression analysis; and 10 or more years provides the best chance for success (3).

This work has been based upon that carried out by Madden et al. (13), who developed a predictive system for the relative intensity of the maize dwarf mosaic virus (MDMV) in preplanting. In such a pathosystem, johnsongrass (*Sorghum halepense* (L.) Pers.) is the overwintering host of most MDMV strains that are transmitted to maize in a nonpersistent manner by a number of aphid species (8).

Regarding the MRC pathosystem, there is the possibility that winter climatic conditions have a direct influence on the development of *D. kuscheli* populations and an indirect influence on them by affecting the growth of oat and wheat crops. Mild winters would favor the expansion of *D. kuscheli* populations and therefore the incidence of the disease on maize fields planted in the period under study. March et al. (15) have recently noted that during the planting period in 1990 and 1992 ("severe" years) higher populations of vector insects occurred than in 1992 ("mild" year). On the other hand, winter rainfall would favorably influence the growth of both oat and wheat and thus indirectly affect delphacid populations in a favorable manner (18).

The influence of temperature in MRDV epidemiology has been pointed out in many countries of the Mediterranean region (7) and in Argentina (11,21). However, these reports only considered prevailing temperatures during the period of maize planting.

The model presented here allowed all agricultural years under study to be classified correctly with a zero error rate, which indicates its reliability. Moreover, the model was validated in the following four agricultural years that were characterized by different values of relative disease intensity.

The predictive model developed here is empirical since it is based on the analysis of historical series of disease intensity data and series of weather variables (9,12). Although many would feel that fundamental forecasting systems are preferable to empirical ones because of their explanatory capability, many useful and functional forecasting systems are empirical (12).

Forecasting systems provide guides for disease management (5). If a severe MRC year is forecasted, the producer will be able to choose the most suitable technology available, to reduce disease intensity and thus diminish or avoid unwanted losses.

ACKNOWLEDGMENTS

We are deeply indebted to Laura Giorda for her support, assistance, and willingness to help at all times. Financial support was partially provided by grants from CREA Chaján-Sampacho and PROMARC (Proyecto Mal de Río Cuarto-INTA).

LITERATURE CITED

1. Campbell, C. L., and Madden, L. V. 1990. Introduction to Plant Disease Epidemiology. John Wiley & Sons, New York.
2. Coakley, S. M. 1988. Variation in climate and prediction of disease in plants. Ann. Rev. Phytopathol. 26:163-181.
3. Coakley, S. M. 1989. Historical weather data: its use in epidemiology. Pages 54-83 in: Plant Disease Epidemiology. Vol. 2, Genetics, Resistance, and Management. K. J. Leonard and W. E. Fry, eds. McGraw-Hill, New York.
4. Dillon, W. R., and Goldstein, M. 1984. Discriminant analysis: The two group problem. Pages 360-392 in: Multivariate Analysis, Methods and Applications. W. R. Dillon and M. Goldstein, eds. John Wiley & Sons, New York.
5. Fry, W. E. 1982. Principles of Plant Disease Management. Academic Press, New York.
6. Fry, W. E., and Fohner, G. R. 1985. Construction of predictive models: I. Forecasting disease development. Pages 161-178 in Advances in Plant Pathology, Vol. 3. C. A. Gilligan, ed. Academic Press, London.
7. Harpaz, I. 1972. Maize Rough Dwarf. Israel Universities Press, Jerusalem.
8. Knoke, J. K., and Louie, R. 1981. Epiphytiology of maize virus diseases. Pages 92-102 in: Virus and Viruslike Diseases of Maize in the United States. D. T. Gordon, J. K. Knoke and G. E. Scott, eds. South Cooperative Service Bulletin 247. Ohio Agric. Res. Dev. Center, Wooster.
9. Krause, R. A., and Massie, L. V. 1975. Predictive systems modern approaches to disease control. Ann. Rev. Phytopathol. 13:31-47.
10. Lachenbrusch, P. A., and Mickey, M. A. 1968. Estimation of error rates in discriminant analysis. Technometrics 10:1-10.
11. Lenardón, S. L., March, G. J., Beviacqua, J. E., Marinelli, A., Ornaghi, J. A., and Astorga, E. M. 1985. Diferentes épocas de siembra del maíz como alternativa para disminuir la incidencia del maize rough dwarf virus. IDIA 441-444:42-45.
12. Madden, L. V., and Ellis, M. A. 1988. How to develop plant disease forecasters. Pages 191-208 in: Experimental Techniques in Plant Disease Epidemiology. J. Kranz and J. Rotem, eds. Springer-Verlag, Berlín.
13. Madden, L. V., Knoke, J. K., and Louie, R. 1983. Classification and prediction of maize dwarf mosaic intensity. Pages 238-242 in: Proceedings International Maize Disease Colloquium and Workshop. D. T. Gordon, J. K. Knoke, L. R. Nault, and R. M. Ritter, eds. Ohio Agric. Dev. Center, Wooster.
14. March, G. J., Ornaghi, J. A., Beviacqua, J. E. and Marinelli, A. 1993. Intensidad del Mal de Río Cuarto y pérdidas causadas a la producción de maíz en las campañas agrícolas 1981/82 a 1991/92. Gac. Agron. 76:384-388.
15. March, G. J., Ornaghi, J. A., Beviacqua, J. E., Sánchez, G., and Giuggia, J. 1993. Aportes para el desarrollo de una estrategia de manejo del Mal de Río Cuarto. Pages 47-48 in: Resúmenes Workshop "Mal de Río Cuarto del Maíz." Córdoba, Argentina.
16. Milne, R. G. 1993. Methods for reovirus strain characterization. Pages 9-12 in Resúmenes Workshop "Mal de Río Cuarto del Maíz." Córdoba, Argentina.
17. Morrison, D. F. 1976. Multivariate Statistical Methods. McGraw-Hill, New York.
18. Ornaghi, J. A., Boito, G. T., Sánchez, G., and March, G. J. 1993. Estudios de las poblaciones de *Delphacodes kuscheli* Fennah en avena, trigo y centeno. Pages 39-40 in: Resúmenes Workshop "Mal de Río Cuarto del Maíz." Córdoba, Argentina.
19. Ornaghi, J. A., Boito, G. T., Sánchez, G., March, G. J., and Beviacqua, J. E. 1993. Studies on the population of *Delphacodes kuscheli* Fennah in different years and agricultural areas. J. Genet. Breed. 47:277-282.
20. Ornaghi, J. A., Boito, G. T., Sánchez, G., and Marinelli, A. 1991. Incidencia del maize rough dwarf virus-Río Cuarto según su transmisión en diferentes estados fenológicos del maíz y tiempos de inoculación. Pages 45-46 in: Taller de Actualización sobre Mal de Río Cuarto. Pergamino, Argentina.
21. Rodríguez Pardina, P. E., Balzarini, M., and Laguna, I. G. 1993. Influencia de distintas variables climáticas en los niveles de infección del virus causal del "Mal de Río Cuarto" en maíz en el área de Manfredi. Pages 57-58 in: Resúmenes Workshop "Mal de Río Cuarto del maíz." Córdoba, Argentina.
22. SAS Institute, Inc. 1988. The stepdisc procedure. Pages 910-922 in: SAS/STAT User's Guide, release 6.03 ed. Cary, N.C.
23. SAS Institute, Inc. 1988. The discrim procedure. Pages 459-477 in: SAS/STAT User's Guide, release 6.03 ed. Cary, N.C.
24. Thresh, J. M. 1986. Plant virus disease forecasting. Pages 359-386 in: Plant Virus Epidemiology: Monitoring, Modelling and Predicting Outbreaks. G. D. McLean, R. G. Garret, and N. G. Ruesink, eds. Academic Press, London.