Temporal Progress of Southern Rust in Maize under Different Environmental Conditions

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ABSTRACT

The progress of the severity of southern rust in maize (*Zea mays*) caused by *Puccinia polysora* was quantified in staggered plantings in different geographical areas in Brazil, from October to May, over two years (1995-1996 and 1996-1997). The logistic model, fitted to the data, better described the disease progress curves than the Gompertz model. Four components of the disease progress curves (maximum disease severity; area under the disease progress curve, AUDPC; area under the disease progress curve around the inflection point, AUDPCi; and epidemic rate) were used to compare the epidemics in different areas and at different times of planting. The AUDPC, AUDPCi, and the epidemic rate were analyzed in relation to the weather (temperature, relative humidity, hours of relative humidity >90%, and rainfall) and recorded during the trials. Disease severity reached levels greater than 30% in Piracicaba and Guaíra in the plantings between December and January. Lower values of AUDPC occurred in later plantings at both locations. The epidemic rate was positively correlated ($P < 0.05$) with the mean daily temperatures and negatively correlated with hours of relative humidity >90%. The AUDPC was not correlated with any weather variable. The AUDPCi was negatively related to both variables connected to humidity, but not to rain. Long periods (mostly >13 h day^{-1}) of relative humidity >90% (that corresponded to leaf wetness) occurred in Castro. Severity of southern rust in maize has always been low in Castro, thus the negative correlations between disease and the two humidity variables.

Additional keywords: temporal analysis of epidemics, staggered plantings, *Puccinia polysora.*

RESUMO

Progresso temporal da ferrugem polisora em milho sob diferentes condições de ambiente

O progresso temporal da severidade da ferrugem polisora causada por *Puccinia polysora* do milho (*Zea mays*) foi quantificado em plantios seqüenciais de outubro a maio em diferentes áreas no Brasil durante dois anos (1995-1996 e 1996-1997). O modelo logístico ajustou-se melhor aos dados que o modelo de Gompertz. Quatro componentes da curva de progresso da doença (severidade máxima da doença; área sob a curva de progresso da doença, AUDPC; área sob a curva de progresso da doença ao redor do ponto de inflexão, AUDPCi; e taxa epidêmica) foram usados para comparar as epidemias nas diferentes áreas e nas diferentes épocas de plantio. A AUDPC, a AUDPCi e a taxa epidêmica foram analisadas em relação a variáveis climáticas (temperatura, umidade relativa, horas de umidade relativa >90% e precipitação) medidas durante os ensaios. A severidade da doença atingiu níveis maiores que 30% em Piracicaba e Guaíra nos plantios de dezembro e janeiro. Valores mais baixos de AUDPC ocorreram nos plantios tardios em ambos os locais. A taxa epidêmica correlacionou-se positivamente ($P < 0,05$) com as temperaturas diárias e negativamente com horas de umidade relativa >90%. A AUDPC não se correlacionou com nenhuma variável climática. A AUDPCi correlacionou-se negativamente com ambas as variáveis ligadas à umidade, mas não se correlacionou com a precipitação. Períodos longos (>13 h por dia) de umidade relativa >90% (que correspondem ao molhamento foliar) ocorreram em Castro. A severidade da doença foi sempre baixa em Castro, o que explica as correlações negativas entre doença e as duas variáveis relacionadas com a umidade.

INTRODUCTION

Maize southern rust, caused by *Puccinia polysora* Underw., has been reported in tropical and subtropical areas to be the most destructive of the rusts that affect maize (*Zea mays* L.) crops (Schall *et al.*, 1983). Crop losses of >50% have been reported in susceptible hybrids (Rezende *et al.*, 1994). In Brazil, this rust is one of the most common diseases of cultivated corn, especially in the mid-west and southwest regions of the country. The importance of southern rust has increased in recent years with the expansion of the crop over periods and into areas not traditionally used for corn. According to Pinto *et al.* (1997) the successive plantings of corn in the same area has resulted in an increase of inoculum of southern rust that made the late plantings of corn more vulnerable to the disease. Late plantings (from January to March) represent 20% of the total area of corn in Brazil. Planting time in Brazil is usually from mid-September to mid-November.

The influence of temperature and leaf wetness on the development of maize southern rust has been determined under controlled environments (Melching, 1975; Hollier & King, 1985; Godoy *et al.*, 1999). Infection was favored by temperatures of 23 °C and periods of leaf wetness from 2 to 24 h. Higher temperatures (25 to 27 °C) favored colonization independent of leaf wetness periods (Godoy *et al.*, 1999). Environmental variables have been used as disease predictors in several forecasting systems and simulation models of disease epidemics for different pathosystems (Campbell & Madden, 1990; Bergamin Filho & Amorim, 1995). Temperature and humidity are the environmental variables most used in forecasting for epidemics of foliage diseases. Even if critical, temperature is, in general, less limiting than humidity to the progress of epidemics (Rotem, 1978). When no dry period occurs, disease progress is strictly related to temperature (Bhatti & Kraft, 1992). The information obtained in experiments under controlled environmental conditions can assist simulation and forecasting programs. Nevertheless, since the microclimate provided in environmental chambers differs from that in the field, the results obtained in plant growth chambers need to be verified, or at least supplemented, by field trials (Zadoks, 1978; Rotem, 1988).

The objective of this study was to investigate the influence of climatic variables recorded in meteorological stations in the field on the progress of southern rust in staggered crops of corn in different areas and different periods of time in Brazil.

MATERIAL AND METHODS

Experimental fields

Five experiments were carried out in three different areas of Brazil with distinctly different climatic conditions (the experimental station of Zeneca Co. in Castro, State of Paraná; the experimental station of the University of São Paulo in Piracicaba, State of São Paulo; and the experimental area of the 'Híbridos Especiais Colorado' Company in Guaíra, State of São Paulo). Staggered plantings were used in two seasons for all sites to obtain a broad exposure of the crops to infection by *P. polysora*. In the 1995-1996 growing season, there were five plantings at Piracicaba (November 20 and December 21, 1995, and February 15, March 29, and May 14, 1996) and four plantings at Castro (October 26, November 24, and December 1 and 21, 1995). In the 1996-1997 season, there were four plantings at Piracicaba (October 18, and December 10, 1996, and February 14 and March, 12 1997); three plantings at Castro (30 October, November 28, and December 23, 1996); and five plantings at Guaíra (October 21 and December 14, 1996 and January 15, February 13, and March 15, 1997).

The maize hybrid XL 330, susceptible to *P. polysora*, was planted in experimental plots in ten 10-meter-long rows, 0.80 m apart, with a distance of 0.25 m between plants. Experiments in the plots were conducted according to the conventional practices used in commercial fields, including fertilization with 120 kg of N, 100 kg of P_2O_5, and 100 kg of K_2O per hectare and sprays to control insects when necessary. The experimental plots were placed in areas intensively used for maize cropping. Disease severity was recorded for 51 marked plants selected in the six central rows of the plot. A diagrammatic scale was used to assess the severity of the disease on the seventh leaf (Godoy, 2000). This leaf was usually just below the ear and it remained green for much of the season. Weekly assessments were started when plants showed 12 unfolded leaves and continued until the grains ripened.

Data analysis

Disease progress curves for different periods and areas were plotted over time for the average disease severity of the 51 plants. The logistic model, $Y = B_1 /(1 + B_2 \exp(-B_3 X))$, was used where Y represented disease severity in percentage, B_1 represented the asymptotic stabilization of the curve, B_2 was related to the initial disease, B_3 was the rate of disease progress, and X was days. This model was fitted to the severity values by non-linear regression. Besides the logistic model, the Gompertz model was also fitted to the data. The appropriateness of the models to the data was analyzed by the coefficients of determination (R^2) obtained by non-linear regression between the observed values and time, and by the pattern of the residuals. The logit of disease severity was used to calculate the disease progress rate between two consecutive assessments (Campbell & Madden, 1990).

The AUDPC was estimated by trapezoidal integration (Berger, 1988). The area under the disease progress curve for three consecutive evaluations around the point of the inflection of the curve (AUDPCi) was also calculated by the same method. The inflection point was determined by the mathematical model and it corresponded to the time when Y equalled $B_1/2$, where Y represented the severity and B_1 was the estimated asymptote for the model.

Temperature in °C (T), % relative humidity (RH), and rainfall in mm (R) were recorded during the seasons by meteorological stations located near the experimental fields. The number of hours with relative humidity greater than 90% (RH >90%) was used as an estimate of leaf wetness, since dew is usually formed on the leaves when the relative humidity exceeds 90% (Sutton *et al.*, 1984; Friesland & Schrödter, 1988).

The daily mean values for the four climatic variables (T, RH, hr of RH >90%, and rainfall) were related to three variables of the epidemics (epidemic rate, AUDPC, and AUDPCi) by Pearson's correlation coefficient. The epidemic rates calculated between two consecutive assessments were related with environmental variables recorded a week before, since the incubation period for this disease ranges from seven to 12 days under the average temperature conditions where the studies took place (Godoy *et al.*, 1999). The AUDPC was related to the average weather variables recorded during the period of the progress of the epidemic. The software PlotIT (Scientific Programming Enterprises, Haslett, MI, USA) and Statistica (StatSoft, Tulsa, OK, USA) were used in the analyses.

RESULTS AND DISCUSSION

The maximum severity of maize southern rust ranged from 0 to 54% in the 1995-1996 season (Figure 1) and from 0 to 66% in the 1996-1997 season (Figure 2) in the different locations. The logistic model fit the disease severities better than the Gompertz model (data not presented) and thus the logistic model was used for the analysis of the temporal progress of the epidemics. Coefficients of determination (R^2) of the nonlinear regression analysis were between 0.78 and 0.99 (Table 1). It was not possible to fit the model to curves with less than three positive data points (second and third plantings in Castro and fourth planting in Piracicaba, in 1995-1996) or when there was no disease (fourth planting in Castro and the fourth and fifth plantings in Piracicaba in the 1995-1996 season; and the first planting in Castro in 1996-1997).

The asymptotes (parameter B_1 of the logistic model) were always quite low (<1%) in all plantings in Castro and in the late plantings in Piracicaba and Guaíra. Explosive epidemics, with asymptotes greater than 30%, occurred only in Piracicaba and Guaíra in the plantings between December and February (Table 1 and Figures 1 and 2). During the two-year period, the plantings in Castro did not go beyond December due to unfavorably cool temperatures for the crop. The average temperature for the whole period in Castro was lower than in Piracicaba and Guaíra, always below 22 ºC (Table 2, and Figs. 1 and 2).

Southern rust of maize has been described in the literature as a disease of hot climates, favored by temperatures around 25 ºC (Melching, 1975; Hollier & King, 1985; Raid *et al.*, 1988; Godoy *et al.*, 1999). The differences in the progress of the disease, observed in the different experiments and times of planting, seemed to have a more direct relationship with temperature than with humidity. In Piracicaba, Guaíra, and Castro, the severity of rust was quite low in the late plantings, although the frequency of leaf wetness periods (RH >90%) was the same as those in the early plantings (Table 2, Figures 1 and 2). The average temperature in late plantings was close to 20 ºC (Table 2). Raid *et al*. (1988) in studies of epidemics of *P. polysora* in Pennsylvania and Maryland suggested that temperature was the most limiting factor for the occurrence of epidemics in the northern United States.

The rate of disease progress was significantly correlated ($P < 0.05$) with the variables temperature (T) and length of periods of leaf wetness (hours with RH >90%) (Table 3). The fastest epidemic rates were observed during higher average temperatures and shorter leaf wetness periods. The minimum leaf wetness period for *P. polysora* to begin an infection is 2 h and the infection efficiency increases with the lengthening of the leaf wetness period (Melching, 1975; Hollier & King, 1985; Godoy *et al.*, 1999). The variables AUDPCi ($P = 0.018$) and epidemic rate ($P = 0.035$) were negatively correlated with hours when RH >90% (Table 3). This relationship seems to lack any biological meaning. The statistical dependency between these variables does not necessarily provide evidence of a causal relationship between them (Butt & Royle, 1990).

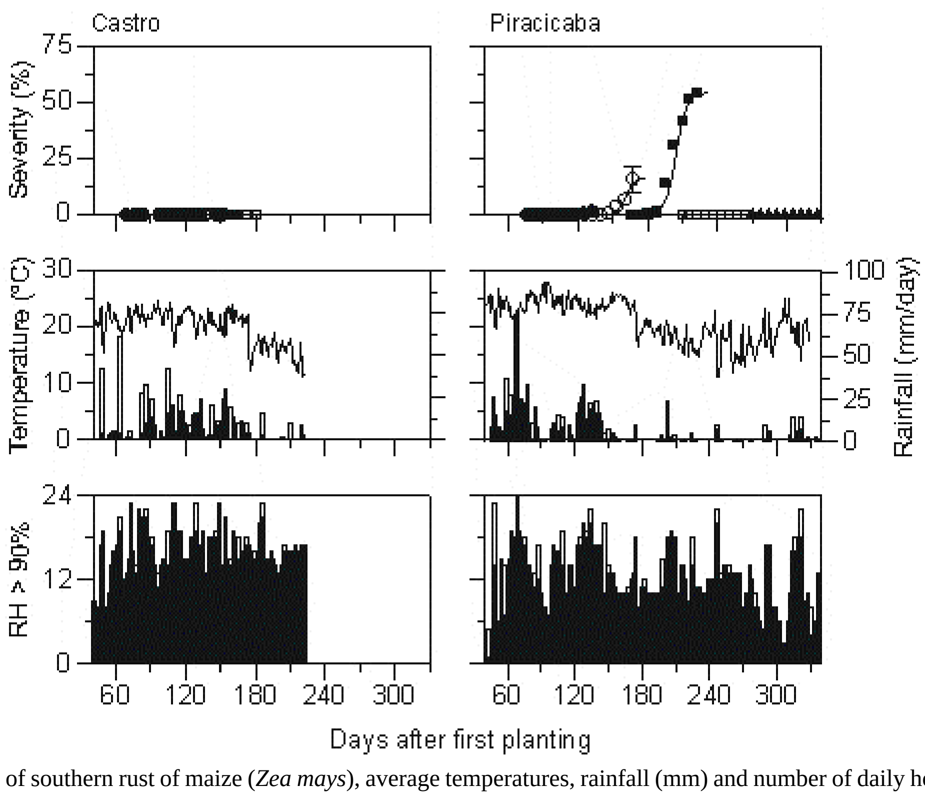

FIG. 1 - Progress curves of southern rust of maize (*Zea mays*), average temperatures, rainfall (mm) and number of daily hours of leaf wetness (RH>90%) in Castro and Piracicaba, in different planting times in 1995-1996. (closed circles represent first planting date, opened circles, the second, closed squares, the third, opened squares, the fourth, and triangles, the fifth).

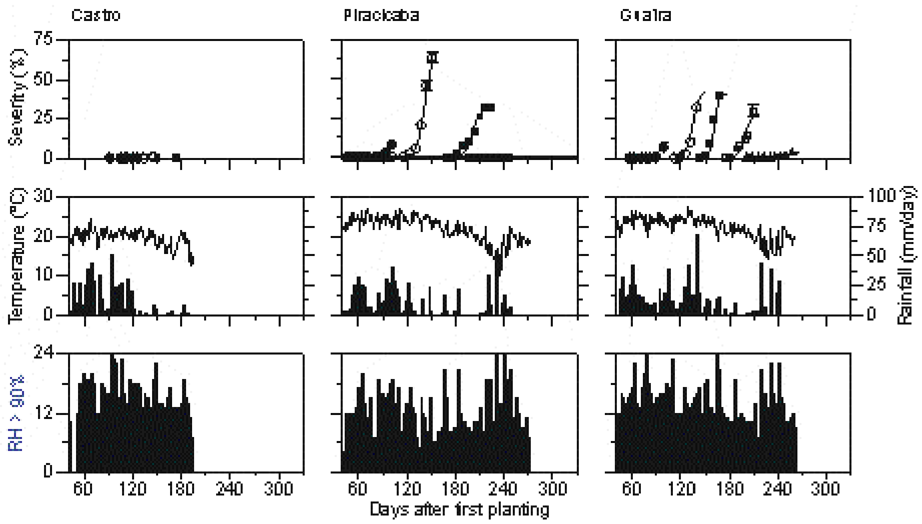

FIG. 2 - Progress curves of southern rust of maize (*Zea mays*), average temperatures, rainfall (mm) and number of daily hours of leaf wetness (RH>90%) in Castro, Piracicaba and Guaíra, in different planting times in 96/97. (closed circles represent first planting date, opened circles, the second, closed squares, the third, opened squares, the fourth, and triangles, the fifth).

The minimum wetness period determined in controlled conditions (Godoy *et al.*, 1999) was established during one cycle of the disease where the other environmental variables were kept constant. Even though long periods of leaf wetness may be favorable for infection, the same condition may inhibit other phases of the disease cycle, e.g., dissemination (Rotem *et al.*, 1973; Amorim *et al.*, 1995).

Prolonged periods of leaf wetness in Castro, where the severity of the disease has always been quite low (Figures 1 and 2), were probably the cause of the negative correlation for both AUDPCi and epidemic rate versus hours with RH >90%. The cause for low severity of the disease in Castro may be attributed to the low temperatures, the negative influence of high humidity in the dispersion of the pathogen, or to a combination of both factors. Experiments designed to evaluate the effects of long periods of leaf wetness and its interaction with temperature in the dispersion of uredospores should be conducted to test these hypotheses. Similar situations have already been reported in other pathosystems (Butt & Royle, 1990; Amorim *et al.*, 1995). Predictive equations of rust in wheat (*Triticum aestivum* L.) leaves with unrealistic relationships between weather variables and disease progress have not been validated in field trials because they were not biologically significant (Moschini & Pérez, 1999).

TABLE 1 - Parameters (B_1, B_2, and B_3)[z] and coefficients of determination (R^2) for the logistic model [$Y = B_1 /(1 + B_2 \exp(-B_3 X))$] fitted to progress curves of southern rust of maize (*Zea mays*) at three sites in two seasons

Season	Site	Planting date	Model parameters B_1	B_2	B_3	R^2
1995-1996	Piracicaba	20 Nov 95	2.3	6.1×10^{7}	0.14	0.97
		21 Dec 95	16.4	7.6×10^{9}	0.23	0.97
		15 Feb 96	54.2	3.5×10^{7}	0.18	0.99
	Castro	26 Oct 95	0.6	1.9×10^{5}	0.13	0.96
		24 Nov 95	0.4	4.2×10^{4}	0.14	0.98
		7 Dec 95	0.1	5.1×10^{9}	0.32	0.78
1996-1997	Piracicaba	18 Oct 96	7.7	6.7×10^{17}	0.43	0.99
		10 Dec 96	66.3	9.2×10^{9}	0.24	0.99
		14 Feb 97	30.8	3.8×10^{5}	0.16	0.98
	Guaíra	21 Oct 96	12.5	6.6×10^{8}	0.21	0.98
		14 Dec 96	43.2	9.2×10^{9}	0.31	0.99
		15 Jan 97	40.5	2.8×10^{9}	0.33	0.99
		13 Feb 97	28.4	1.2×10^{6}	0.19	0.95
		15 Mar 97	4.3	3.4×10^{8}	0.19	0.99

[z] B_1 is maximum asymptotic severity (%), B_2 is related to initial disease, and B_3 is the epidemic rate in logits day^{-1}.

Integral variables, like AUDPC, are calculated over a long period of time and do not allow the analysis of temporary environmental variations that usually occur during the progress of an epidemic. Thus, AUDPC and AUDPCi, the latter representing the area under the disease progress curve of approximately a 15-day period, were not influenced by average temperatures. The individual epidemic rates, which took into account the increment of disease severity in short periods of time during the epidemic, was more associated with climatic variables in the correlation analysis (Table 3).

The use in this study of a susceptible hybrid planted in intensively cultivated areas of maize provided two of the needed elements for the development of the rust (susceptible host and presence of inoculum). Nevertheless, there were no epidemics in all three planted areas in certain periods due to limitations imposed by weather conditions. Rust pathogens reproduce profusely, infect, and disperse very quickly under favorable conditions, even with a minimum amount of inoculum, to cause devastating epidemics (Rotem, 1978). The opposite is also true, as shown in this study and in the study of viruses of rice (*Oryza sativa* L.) in Africa (Heinrichs *et al.*, 1997). When environmental conditions are not favorable, the presence of inoculum, even in high quantities, would not be enough to cause a destructive epidemic. The severity of rust, reported in late plantings in commercial areas (Pinto *et al.*, 1997) was not

TABLE 2 - Mean daily temperature (T), mean daily relative humidity (% RH), and number of hours with relative humidity higher than 90% for different sites and epochs during epidemics of southern rust of maize (*Zea mays*) in Brazil

Site	Planting date	Weather variables		
		T (°C)	% RH	Hr RH 90%
Piracicaba	20 Nov 95	24.7	83.1	11.3
	21 Dec 95	24.2	85.4	12.2
	15 Feb 96	20.5	80.9	10.2
	29 Mar 96	17.7	81.4	11.3
	14 May 96	18.3	70.6	6.7
Castro	26 Oct 95	21.7	88.4	14.7
	24 Nov 95	21.5	89.1	15.1
	7 Dec 95	21.2	89.4	15.5
	21 Dec 95	21.2	88.7	15.3
Piracicaba	18 Oct 96	24.2	80.8	9.3
	10 Dec 96	24.4	79.2	9.4
	14 Feb 97	20.3	75.2	8.5
	12 Mar 97	18.9	79.3	9.5
Castro	30 Oct 96	20.5	90.1	15.5
	28 Nov 96	20.4	87.1	13.6
	23 Dec 96	17.4	81.1	12.6
Guaíra	21 Oct 96	24.2	86.2	13.6
	14 Dec 96	24.6	80.3	11.4
	15 Jan 97	23.3	81.8	12.3
	13 Feb 97	21.3	75.9	9.1
	15 Mar 97	18.9	79.7	10.1

TABLE 3 - Pearson's coefficients (*r*) and levels of significance (*P*) for the relationship between the area under the progress curve for southern rust of maize (AUDPC), the area under disease progress curves for three assessments around the inflection point (AUDPCi), and the disease progress rate between two consecutive assessments versus average weather variables [temperature (T), relative humidity (% RH), number of hours with relative humidity higher the 90% (RH >90), and rainfall]. Analysis was with the combined data sets of the seasons of 1995-1996 (Piracicaba and Castro) and 1996-1997 (Piracicaba and Guaíra)

Weather variable	AUDPC		AUDPCi		Disease progress rate	
	r	*P*	*r*	*P*	*r*	*P*
T (ºC)	0.22	0.339	0.31	0.308	0.24	0.005
% RH	-0.38	0.083	-0.64	0.019	-0.13	0.116
RH >90%	-0.37	0.093	-0.64	0.018	-0.18	0.035
Rain (mm)	-0.36	0.108	-0.49	0.088	-0.08	0.323

the only consequence of the accumulation of inoculum. The explosive epidemics observed in the second, third, and fourth plantings in Piracicaba and Guaíra were evidence that both inoculum and favorable weather were necessary for the development of the disease. With the early planting dates, the inoculum was probably quite low; in the late planting dates, ample inoculum was available but weather was not favorable.

LITERATURE CITED

AMORIM, L., BERGER, R.D., BERGAMIN FILHO, A., HAU, B., WEBER, G.E., BACCHI, L.M.A., VALE, F.X.R. & SILVA, M.B. A simulation model to describe epidemics of rust of Phaseolus beans II. Validation. Phytopathology 85:722-727. 1995.

BHATTI, M.A. & KRAFT, J.M. Effects of inoculum density and temperature on root rot and wilt of chickpea. Plant Disease 76:50-54. 1992.

BERGAMIN FILHO, A. & AMORIM, L. Sistemas de previsão e avisos. In: Bergamin Filho, A., Amorim, L. & Kimati, H. (Eds.) Manual de Fitopatologia - Princípios e Conceitos. São Paulo. Ceres. 1995. pp.627-646.

BERGER, R.D. The analysis of effects of control measures on the development of epidemics. In: Kranz, J. & Rotem, J. (Eds.) Experimental Techniques in Plant Disease Epidemiology. Berlin. Springer. 1988. pp.137-151.

BUTT, D.J. & ROYLE, D.J. Multiple regression analysis in the epidemiology of plant diseases. In: Kranz, J. (Ed.) Epidemics of Plant Diseases. Berlin. Springer. 1990. pp.143-180.

CAMPBELL, C.L. & MADDEN, L.V. Introduction to Plant Disease Epidemiology. New York. John Wiley & Sons. 1990.

FRIESLAND, H. & SCHRÖDTER, H. The analysis of weather factors in epidemiology. In: Kranz, J. & Rotem, J. (Eds.) Experimental Techniques in Plant Disease Epidemiology. Berlin. Springer. 1988. pp.115-134.

GODOY, C.V. Influência de variáveis climáticas no desenvolvimento da ferrugem polysora na cultura do milho. (Tese de Doutorado). Piracicaba. E.S.A. Luiz de Queiroz, Universidade de São Paulo. 2000.

GODOY, C.V., AMORIM, L. & BERGAMIN FILHO, A. Influência da duração do molhamento foliar e da temperatura no desenvolvimento da ferrugem do milho causada por *Puccinia polysora*. Fitopatologia Brasileira 24:160-165. 1999.

HEINRICHS, E.A., SY, A.A., AKATOR, S.K. & OYEDIRAN, I. Seasonal occurrence of rice yellow mottle virus in lowland rice in Cote d' Ivoire. International Journal of Pest Management 43:291-297. 1997.

HOLLIER, C.A. & KING, S.B. Effect of dew period and temperature on infection of seedling maize plants by *Puccinia polysora*. Plant Disease. 69:219-220. 1985.

MELCHING, J.S. Corn rusts: types, races and destructive potential. Proceedings of the 30th Annual Corn and Sorghum Research Conference. Chicago. 1975. pp.90-115.

MOSCHINI, R.C. & PÉREZ, B.A. Predicting wheat leaf rust severity using planting date, genetic resistance, and weather variables. Plant Disease 83:381-384. 1999.

PINTO, N.F.J.A, FERNANDES, F.T. & OLIVEIRA, E. Milho. In: Vale, F.X.R. & Zambolim, L. (Eds.) Controle de Doenças de Plantas. Viçosa. UFV-MEC. 1997. pp.821-864.

RAID, R.N., Pennypacker, S. P. & Stevenson, R. E. Characterization of *Puccinia polysora* epidemics in Pennsylvania and Maryland. Phytopathology 78:579-585. 1988.

REZENDE, I.C., SILVA, H.P. & PEREIRA, O.A.P. Perda da produção de milho causada por *Puccinia polysora* Underw. Anais do XX Congresso Nacional de Milho e Sorgo, Goiânia. 1994. p.174.

ROTEM, J. Climatic and weather influences on epidemics. In: Horsfall, J.G. & Cowling, E.B. (Eds.) Plant Disease: an Advanced Treatise. Vol. 2. How Disease Develops in Populations. New York. Academic Press. 1978. pp.317-337.

ROTEM, J. Techniques of controlled-condition experiments. In: Kranz, J. & Rotem, J. (Eds.) Experimental Techniques in Plant Disease Epidemiology. Berlin. Springer. 1988. pp.19-31.

ROTEM, J., BEN-JOSEPH, Y. & REUVENI, R. Design and use of an automatic humidity chamber in phytopathological research. Phytoparasitica 1:39-45. 1973.

SCHALL, R.A., MCCAIN, J.W. & HENNEN, J.F. Distribution of *Puccinia polysora* in Indiana and absence of a cool weather form as determined by comparison with *P. sorghi*. Plant Disease 67:767-770. 1983.

SUTTON, J.C., GILLESPIE, T.J. & HILDEBRAND, P.D. Monitoring weather factors in relation to plant disease. Plant Disease 68:78-84. 1984.

ZADOKS, J.C. Methodology of Epidemiological Research. In: Horsfall, J.G. & Cowling, E.B. (Eds.) Plant Disease: an Advanced Treatise. Vol. 2. How Disease Develops in Populations. New York. Academic Press. 1978. pp.63-96.

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