Tropical Plant Pathology, vol. 36, 3, 160-168 (2011)

www.sbfito.com.br

RESEARCH ARTICLE / *ARTIGO*

Predicting population level of *Delphacodes kuscheli*, vector of *Mal de Río Cuarto virus*, and climate risk in the Argentine Pampas using meteorological models

José A. Ornaghi[1], Guillermo J. March[2], Ricardo C. Moschini[3], Malvina I. Martínez[3] & Graciela T. Boito[1]

[1]Facultad de Agronomía y Veterinaria, Universidad Nacional de Río Cuarto, 5800 Río Cuarto, Córdoba, Argentina; [2] Instituto Nacional de Tecnología Agropecuaria - INTA, Instituto de Fitopatología y Fisiología Vegetal, X5020ICA Córdoba, Argentina; [3] Instituto Nacional de Tecnología Agropecuaria - INTA, Instituto de Clima y Agua, Pdo. de Hurlingham, Buenos Aires, Argentina

Author for correspondence: Ricardo C. Moschini, e-mail: rmoschini@cnia.inta.gov.ar

ABSTRACT

The planthopper *Delphacodes kuscheli* Fennah (Hemiptera: Delphacidae), principal insect vector of *Mal de Río Cuarto virus* on corn in Argentina, produces severe disease outbreaks when migration of large macropterous populations coincides with early corn growth stages. Linear models based on winter environmental variables were developed to explain variation of macropterous populations accumulated on oat until November 30 (1993-2001) in La Aguada (department of Río Cuarto, Córdoba, Argentina). Using daily records of maximum and minimum temperatures and precipitation, variables were generated and processed in different periods from June 1 to September 20. The best bivariate model (R^2=0.97) had the lowest mean square error, was selected by Stepwise procedure, and its validation was highly satisfactory. It included the variable DDTxn, which accumulates mean temperature values exceeding 10°C on days with maximum and minimum temperature >24.5°C and 11°C, respectively, and DPr, which counts days with precipitation (>0mm). These variables were processed from July 1 to September 19. Using this model (correctly validated against independent observations in Chaján, Sol de Mayo and Espinillo -department of Río Cuarto- for 2, 3 and 7 years, respectively), climate risk in the Pampas region was evaluated relative to insect population levels in the endemic area.

Key words: *Mal de Río Cuarto virus*, corn disease, management strategies, predictive models, vector population dynamics.

INTRODUCTION

The *Mal de Río Cuarto virus*-MRCV (genus *Fijivirus*, family *Reoviridae*) causes the most important viral disease on corn (*Zea mays* L.) in Argentina (Lenardon et al., 1998; March et al., 1995). Corn crops in the department of Río Cuarto (province of Córdoba) and neighboring growing areas in San Luis, La Pampa and Buenos Aires provinces - usually identified as the Mal de Río Cuarto (MRC) endemic area - are affected with different intensity every year. The first outbreak occurred in the 1981/82 growing season, affecting corn crops in the endemic area and producing losses of about 40 million US dollars (March et al., 1997); 15 years later, in the 1996/97 growing season, an outbreak spread outside the endemic area for the first time, affecting crops in the most important growing areas of Argentina: in the Pampas region to the east of Córdoba, and Santa Fe and Buenos Aires provinces, with losses estimated at about 120 million US dollars (Lenardon et al., 1998). Recently, in the 2006/07 growing season, another epidemic occurred that spread to different agricultural areas of these provinces, with losses estimated at about 70 million US dollars by the Secretaría de Agricultura y Alimentación of the province of Córdoba (Lenardon et al., 2007).

Population dynamics of insect vectors and their role as epidemic agents are important components of epidemic structures of viral diseases (Ferris & Berger 1993; Jeger et al., 2004; Madden et al., 1990, 2000; Raccah & Irwin, 1988). Different studies have associated insect vector populations with climatic variables and some predictive models of disease intensity have been developed (Heathcote, 1986; Madden et al., 1983; Mora-Aguilera et al., 1993; Ochoa-Martinez et al., 1999; Plumb et al., 1986).

The planthopper *Delphacodes kuscheli* Fennah (Hemiptera: Delphacidae) is the main insect vector of MRCV in the endemic area. While this planthopper has been recorded in different growing areas (Remes Lenicov & Virla 1999), its population dynamics has been studied in the department of Río Cuarto (Boito, 2005; Ornaghi et al., 1993; Remes Lenicov et al., 1991; Tesón et al., 1986). Also, studies of the influence of agroecosystem on abundance and spatial distribution of *D. kuscheli* have demonstrated that the insect population present in the endemic area strongly decreases towards non-endemic regions (Grilli & Gorla, 2002).

In the department of Río Cuarto, *D. kuscheli* populations develop in the winter season, mainly on oat (*Avena sativa* L.) and wheat (*Triticum aestivum* L.) crops subjected to grazing production practices. The insect acquires the MRCV in these crops; then the macropterous forms migrate to corn from September-October to December (Boito, 2005; March et al., 1997; Ornaghi et al., 1993; Remes Lenicov et al., 1991; Tesón et al., 1986). Given that corn is not a host colonized by *D. kuscheli* and infectivity of field populations is relatively low, one of the main causes of outbreaks is the migration of *D. kuscheli* macropterous forms in high population densities coinciding with the early stages of corn growth (March et al., 2002; Ornaghi et al., 1993, 1999).

Based on historical data of MRC intensity (1981-1993) and on winter meteorological variables, a predictive model of disease intensity was developed (March et al., 1995). This pre-seeding forecasting system (September 1) and monitoring of *D. kuscheli* populations from August to December are the basis for outlining disease management strategies (Lenardon et al., 2004). No published studies (Lenardon and March, pers. com.) showed a significant (p=0.021-0.0008) and strong (R2=0.60-0.92) correlation between macropter population density (monitored in direct grazing oat commercial fields) and MRC incidence, evaluated in corn experimental plots (weekly sowing dates) for 10 years. Given the importance of *D. kuscheli* in the spread of MRCV, the objectives of this study were to develop and to validate winter meteorological-based models for predicting population density of macropterous vector in the endemic area, and to estimate the associated climate risk in the principal corn growing areas of Argentina.

MATERIALS AND METHODS

Development of predictive models

D. kuscheli macropters were counted at approximately 7-day intervals on an oat field located in La Aguada (32º58'S, 64º47'W), department of Río Cuarto, from August to December of the 1993-2001 growing seasons (N=9 years), following the method developed by Ornaghi et al. (1993). On each sampling date four samples were taken using a 38cm diameter sweep net. Each sample unit consisted of the material collected in 25 consecutive insect net sweeps. Specimens in the samples were frozen with carbon dioxide in the field, and taken to the laboratory for sorting and identification. Delphacids were identified (99% of *D. kuscheli*) and categorized as nymphs and adults, and these were classified as brachypters, macropters, females and males. All the sampling points were commercial oat fields managed under direct grazing by cattle throughout the winter-spring period and without the use of insecticides.

D. kuscheli macropter weekly values were gradually accumulated every year from August to December (different end sampling dates). The dependent variable was the total annual macropters accumulated from August until November 30 (fixed end sampling date). The number of macropters collected until November 30 was annually calculated by linear interpolation of the values accumulated until the immediately previous and following sampling dates (Table 1).

Daily records of maximum (Tx) and minimum (Tn) temperatures and precipitation (Pr) were provided by the meteorological station of the Facultad de Agronomía y Veterinaria, Universidad Nacional de Río Cuarto, located in La Aguada. Daily mean temperature (Td) was calculated as half the sum of the daily minimum and maximum temperatures. From these daily weather records, the following predictive meteorological variables were

TABLE 1 - Total annual *Delphacodes kuscheli* macropters collected on oat (*Avena sativa*) in La Aguada (Río Cuarto department, Córdoba, Argentina) from August to December (different end sampling dates) and from August until November 30 (fixed end sampling date)

Year	Total macropters (accumulated from August to December)	Total macropters [1] (accumulated from August until November 30)
1993	938	859
1994	1189	957
1995	1326	1047
1996	2203	2149
1997	2203	1924
1998	653	270
1999	1605	468
2000	451	190
2001	706	577

[1] Total macropters accumulated until November 30 were annually calculated by linear interpolation of the values accumulated until the immediately previous and following sampling dates.

calculated: DDTxn: total accumulation of degree-days (°C day) above different base Td that ranged from 10 to 14°C, when Tx and Tn are greater than threshold values (range: Tx: 22-25°C; Tn: 10-14°C); DDTd: total accumulation of degree-days (°C day) above different base Td (range analyzed: 10-14°C), if daily precipitation (Pr)=0 mm; DTn: total days with Tn lower than thresholds that ranged from 10 to 13°C; MTn: mean of daily Tn (ºC); MTx: mean of daily Tx (ºC); DPr: number of days with Pr greater than different thresholds (range: 0-5 mm); TPr: cumulative daily Pr (mm) greater than different thresholds (range: 0-5 mm).

From June 1 to September 20, several time subperiods were analyzed and predictive variables were processed. The Rsquare routine from SAS was selected to identify the periods with the strongest associations between annual total number of macropters collected until November 30 and winter meteorological variables, by analyzing the coefficients of determination (R^2). A final selection of predictive models was based on the following criteria: R^2 values, mean square error (MSE), Stepwise procedure (significance level for entry into the model: 0.05), and validation behaviour using independent data of *D. kuscheli* macropterous populations collected during 2, 3 and 7 years in Chaján (33º33'S, 65º01'W), Sol de Mayo (33º07´S, 64º09´W) and Espinillo (33º01'S, 64º21'W), respectively, and meteorological data from Chaján and Servicio Meteorológico Nacional (SMN) station in Río Cuarto for Sol de Mayo and Espinillo. The three sites are located in the department of Río Cuarto.

Climate risk in the Pampas region relative to population level of *Delphacodes kuscheli*

Daily meteorological records of Tx, Tn and Pr for the 1971-2006 series were available from 37 meteorological stations (SMN-INTA: Instituto Nacional de Tecnología Agropecuaria) in the Argentine Pampas region. The macropter population level accumulated until November 30 was estimated for each meteorological station and for each one of the 36 years of the series, using the selected and validated predictive model. Then the percentage of years with the population level of collected macropters predicted as "High" (H: >818), "Intermediate" (I: <=818 and >493) and "Low-Nil" (L:<=493 macropters) was calculated (threshold values corresponded to the 60 % and 40 % percentiles, respectively, and were obtained from the series of 36 annual values predicted by the selected model in Río Cuarto). The "Very high" (VH) population level was consistent with values higher than 80% (1204 wing forms). Percent values of years with "High" and "Intermediate" macropter population levels were spatially displayed (map) by means of a grid with linear variogram (Kriging procedure) of the entire Pampas region.

Precipitation

To analyze the possible influence of precipitation on oat and wheat crop growth, on which *D. kuscheli* populations developed, and on corn planting date in the three growing seasons when the most important outbreaks occurred, rainfall data from June to November were considered in Río Cuarto (1981, 2006) and La Aguada (1996), as well as rainfalls occurring in the closest years (1982, 1997, 2004) with similar *D. kuscheli* population characteristics and when no outbreaks occurred.

RESULTS

The strongest associations between winter meteorological variables and the total number of macropters collected until November 30 were found between July 1 and September 19 (81 days). The best fitted models (simple and bivariate ones) were the following:

Dkma = 322.7+17.15 DDTxn (R^2=0.94; MSE=158.5) Model A

Dkma = 528.2+16.98 DDTxn-34.49 DPr (R^2=0.97; MSE=0108.4) Model B

where Dkma: number of Delphacodes kuscheli macropters accumulated until November 30; DDTxn: total accumulation of degree-days above 10°C (base daily mean temperature), when daily Tx (maximum temperature) and Tn (minimum temperature) are greater than 24.5°C and 11°C, respectively; DPr: number of days with precipitation (Pr>0mm).

Validation of models

Total numbers of macropters recorded in 2, 3 and 7 growing seasons in Chaján, Sol de Mayo and Espinillo, respectively, were used to validate models A and B (Table 2). The simple model including the variable DDTxn had the highest R^2 value (0.94); however, it exhibits a trend towards overestimation, thus failing to predict the low population levels observed in 1988 and 1991 in Espinillo. The variable DDTd (R^2 =0.63) only works with threshold values of daily mean temperature (base Td) and fails to express insect dependence on days with wide range of temperatures, but with high daily minimum and maximum values. These conditions were observed in 1996, when MRCV caused the most widespread epidemic. The variable DDTxn explains this situation correctly.

The simple model including DPr (negative slope) only accounts for 5% of variation in the vector population level until November 30, but the variable makes a significant contribution when included in a bivariate model along with DDTxn. The resulting model B was selected as the most appropriate by Stepwise procedure. It also exhibited the highest coefficient of determination, lowest estimation error and optimal performance when it was validated against independent data. Hence, it was selected for application in the subsequent analyses.

TABLE 2 - Population levels of *Delphacodes kuscheli* macropters collected until November 30 versus levels predicted by simple linear A. and bivariate B. models in Chaján, Sol de Mayo and Espinillo (Río Cuarto, Córdoba, Argentina)

Site	Year	Number of macropters collected until November 30[1]	Model A[2]	Model B[2]
Chaján	1996	2570 (H)	Yes[3]	Yes
	1997	940 (H)	Yes	Yes
Sol de Mayo	1998	464 (L)	Yes	Yes
	1999	1394 (H)	Yes	Yes
	2000	109 (L)	Yes	Yes
Espinillo	1988	207 (L)	No	Yes
	1989	1639 (H)	Yes	Yes
	1990	9489 (H)	Yes	Yes
	1991	154 (L)	No	Yes
	1993	1798 (H)	Yes	Yes
	1994	1010 (H)	Yes	Yes
	1995	1195 (H)	Yes	Yes

[1] Population level categorized as High (H):>818 macropters; Intermediate (I): between <=818 and >493; and Low-Nil (L) (<=493).

[2] Model A: Dkma=322.7+17.15 DDTxn, with Dkma being the number of Delphacodes kuscheli macropters accumulated until November 30 and DDTxn: total accumulation of degree-days above 10 °C (base daily mean temperature), when Tx (maximum temperature) and Tn (minimum temperature) are greater than 24.5°C and 11°C, respectively. Model B: Dkma=528.2+16.98 DDTxn-34.49 DPr, being DPr: number of days with precipitation (Pr>0 mm). Variables are processed from July 1 to September 19.

[3] Yes: agrees**;** No: does not agree**.**

Climate risk in the Pampas region relative to *Delphacodes kuscheli* population level

Figure 1 illustrates the spatial distribution of climate risk level (% of years) with "High" (a) and "Intermediate" (b) population level of *D. kuscheli* macropters accumulated until November 30, predicted by bivariate model B. Annual population values predicted were categorized as "High" (more than 818 macropters) and "Intermediate" (between <=818 and >493). For the disease endemic area, a "High" vector population level is estimated in 2-3 years out of 10, climate risk increasing towards the NE of this core area. The greatest frequency of intermediate vector levels is concentrated in the Central-Eastern portion of Córdoba. Both maps show the very low climate risk in Central-Southern Buenos Aires with respect to the possible detection of high population levels.

Figure 2 shows population levels of *D. kuscheli* macropters accumulated until November 15, until November 30 and until December 30, and values of the variable DDTxn in the nine-year period evaluated in La Aguada. To predict populations accumulated until November 15 and to estimate possible insect vector migrations, the variables DDTxn and DPr were analyzed, both processed from July 1 to different dates: September 9, September 19, October 1 and October 15. The best regression model (selected by Stepwise, R^2=0.99, optimal performance when validated with independent data from Chaján, Sol de Mayo and Espinillo) was the following:

$$Dkma=379.2+12.8\ DDTxn - 20.27\ DPr \qquad \text{(Model C)}$$

where DDTxn is processed from July 1 to September 19, and DPr from July 1 to October 15.

Population values above 80% estimated by model C (813 wing forms) and model B (1204 wing forms) might be used for early warnings of probable migrations of the vector insect from the endemic area. For Río Cuarto, these threshold values were only reached or exceeded in 1971, 1982, 1986, 1990, 1996, 1997, 2004, and 2006 (Figure 3).

Precipitation

Precipitation records from June through November in Río Cuarto (1981, 1982, 2004, 2006) and La Aguada (1996, 1997) are shown in Figure 4. Precipitation from June through September (oat and wheat growth period) in 1981, 1996 and 2006, when the main epidemics occurred, amounted to 18, 41 and 11 mm, respectively; whereas during the same period in the years 1982, 1997 and 2004, rainfall amounted to 119, 107 and 69 mm, respectively.

DISCUSSION

Understanding the relationship between virus insect vector populations and their movements is necessary to determine the vector's role in virus spread (Raccah & Irwin 1988). This is especially important in the case of MRCV, because its main insect vector, *D. kuscheli*, migrates from oat or wheat to corn crops, which it does not colonize because corn is not a suitable host for feeding, oviposition or breeding (Virla & Remes Lenicov, 1991).

Population dynamics of planthoppers is influenced by several factors, such as crowding, temperature, host

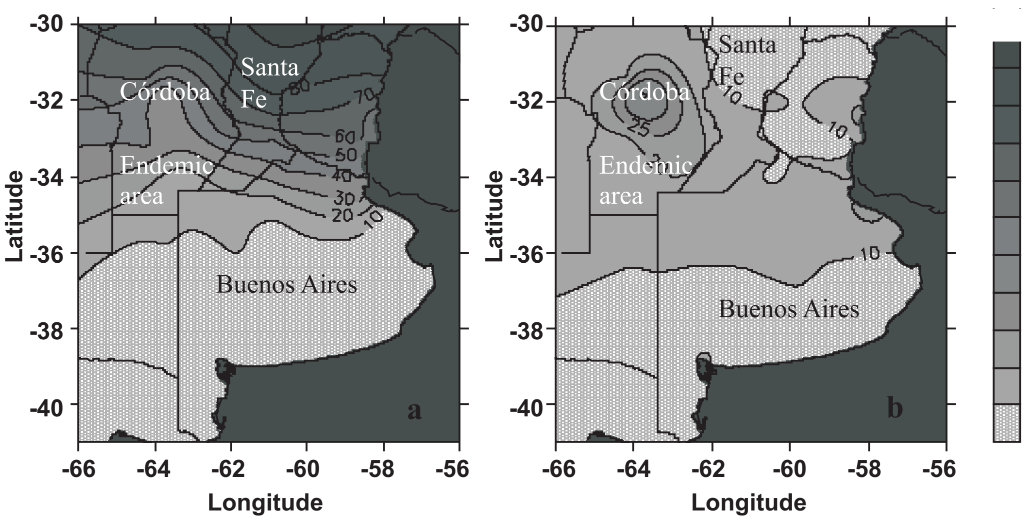

FIGURE 1 - Climate risk level (% of years) with "High" (a) and "Intermediate" (b) population level of *Delphacodes kuscheli* macropters (Dkma) accumulated until November 30 predicted by model B, in the Argentina Pampas region. Model B: Dkma=528.2+16.98 DDTxn-34.49 DPr, being DDTxn: total accumulation of degree-days above 10°C (base daily mean temperature), when maximum temperature and minimum temperature are greater than 24.5°C and 11°C, respectively; DPr: number of days with precipitation (Pr>0mm). Variables are processed from July 1 to September 19.

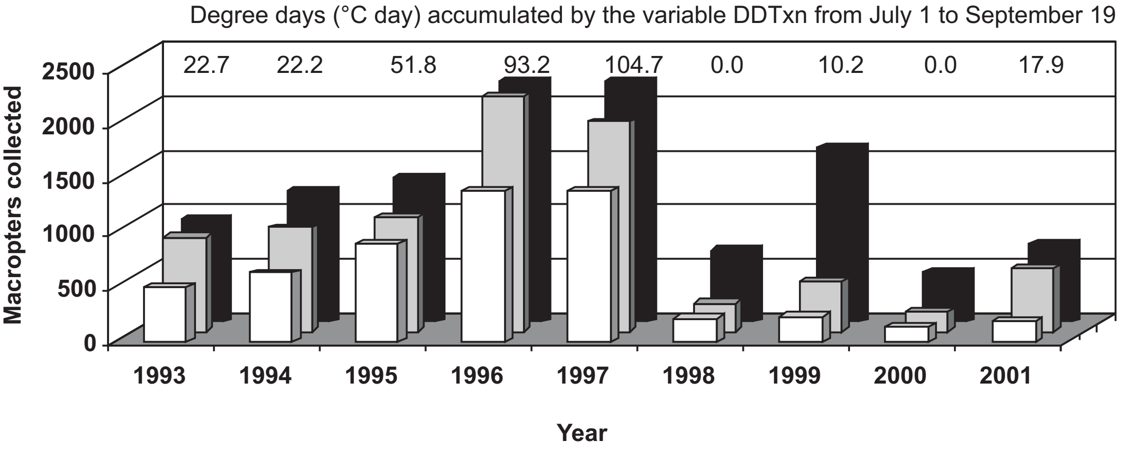

FIGURE 2 - *Delphacodes kuscheli* macropters collected until November 15 (white bars), until November 30 (gray bars) and until December 30 (black bars) from 1993 to 2001 in La Aguada (Río Cuarto, Córdoba) and the corresponding degree days (°C day) accumulated by the variable DDTxn. DDTxn: total accumulation of degree-days above 10°C (base daily mean temperature), when maximum temperature and minimum temperature are greater than 24.5 °C and 11°C respectively. The variable is processed from July 1 to September 19.

conditions and photoperiod (Denno et al., 1986; Iwanaga et al., 1987). The present work demonstrates the importance of temperature (DDTxn) and precipitation (DPr) in population dynamics of *D. kuscheli*. On the basis of both variables, the best linear bivariate model obtained (Model C, R^2=0.99) allows us to predict total macropters accumulated until November 15 by October 15, usually when most corn crops are still to be planted in the endemic area of the disease; the second best bivariate model (Model B, R^2=0.97) allows us to predict total macropters accumulated until November 30, 26 days earlier (September 19), often when corn planting has not started in this area. The statistical method applied for developing these models has often been used in the generation of disease forecasting systems in Argentina (March et al., 1995; Moschini & Fortugno 1996; Moschini et al., 2006).

The climate risk maps generated in this work show that in the endemic area of the disease and in the main growing areas of Argentina (east of Córdoba, south of Santa Fe, north of Buenos Aires), climate risk values are

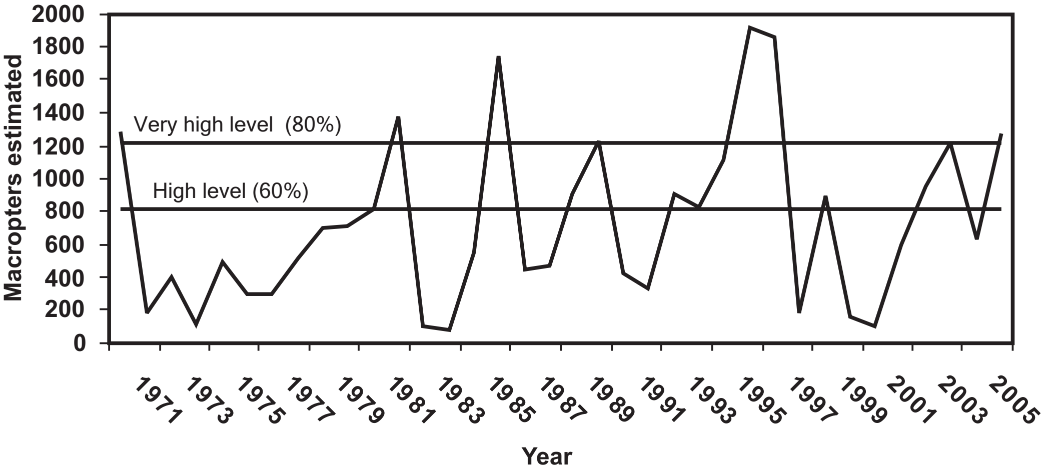

FIGURE 3 - Total annual number of *Delphacodes kuscheli* macropters accumulated until November 30 estimated by model B in Río Cuarto (department of Río Cuarto, Córdoba, Argentina) for the 1971-2006 series. To classify the annual total of macropters into categories, total values with 60% (High level) and 80% (Very high level) of probability were identified (818 and 1204 respectively) and used as category thresholds.

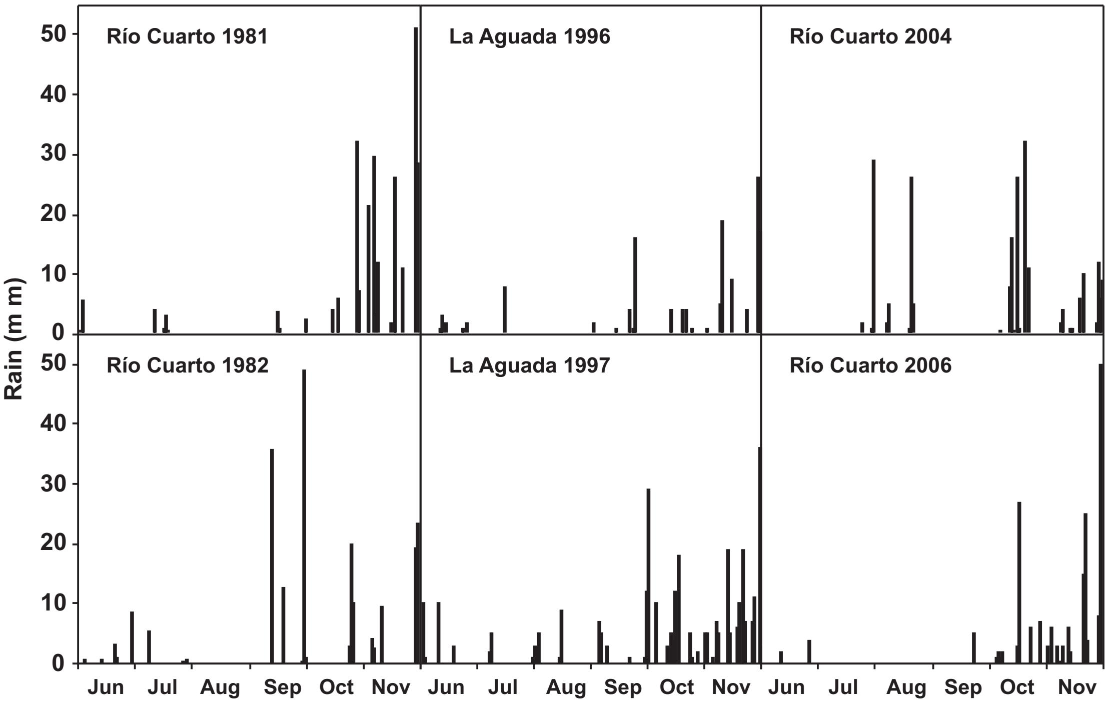

FIGURE 4 - Rains recorded from June to November in Río Cuarto and La Aguada (department of Río Cuarto, Córdoba, Argentina) in the years when the most important epidemics occurred (1981, 1996, 2006) and in the closest years with similar characteristics of *Delphacodes kuscheli* macropterous population.

similar. However, the agroecosystem structure favors the development of high population densities in the endemic region and low densities in the growing areas mentioned, because *D. kuscheli* populations are closely associated with their preferred host crops, wheat and oats (Grilli & Gorla, 2002).

Furthermore, the growth stage of oat and wheat crops, mainly determined by rains, influences age structure of *D. kuscheli* populations and consequent migration of macropters (Ornaghi et al., 1993). The two bivariate models selected include the variable DPr with negative slope, indicating that with a lower number of days with precipitation a greater population of macropters accumulated until November 30 is predicted. The absence of rains in winter would have a double effect: it would produce the deterioration of oat and wheat crops, favoring development of *D. kuscheli* macropters, and it would delay corn planting dates; thus, the most susceptible crop stages would coincide with insect vector migrations. Several authors indicate that system instability induced either by the end of the host cycle or by host quality decline due to adverse environmental factors, favor migration of delphacid macropters (Denno & Grissell 1979; Denno et al., 1980; Fernández-Badillo & Clavijo, 1990; Grilli & Gorla, 2002). Interestingly, it has been stated that dispersal of *D. kuscheli* would be determined by a mechanism that is independent of population density (Grilli & Gorla, 1999).

While habitat instability due to host natural senescence or decline has been indicated as favorable to production and migration of *D. kuscheli* macropters (Boito, 2005; Grilli & Gorla, 2002; Ornaghi et al., 1993; Remes Lenicov et al., 1991; Tesón et al., 1986), the key factor that would trigger this process has not been accurately identified. Nevertheless, because of the high losses produced by this insect vector, the most important epidemics (1981/82, 1996/97, 2006/07) are worth analysis. In the first epidemics (1981) *D. kuscheli* population level estimated by the bivariate model was "High", whereas in the following year (1982) it was estimated as "Very high"; however, while losses were high in the 1981/82 growing season, disease intensity in commercial crops in the following growing season was low. The absence of rainfall in the 1981 winter season jeopardized oat and wheat crops, favoring macropter migration to corn crops that had been planted as late as November, after the occurrence of rains in late October-early November. Thus, MRC average incidence was 60% for the entire Río Cuarto department (March et al., 1993). In contrast, in 1982, rains in September favored the development of winter cereals and early planting of corn. Thus, the large *D. kuscheli* populations would have found more suitable conditions for developing on oat and wheat, and gradually migrated to corn crops that were at advanced growth stages, since most of the crops had been planted in October; hence, the disease did not reach epidemic characteristics (Lenardon et al., 1986; March et al., 1993).

Similar situations were observed with epidemics that occurred in the 1996/97 and 2006/07 growing seasons, which spread outside the endemic area. While in 1996 and 1997 population levels of *D. kuscheli* macropters - actual and estimated by the model - were "Very High" due to optimum temperature conditions (DDTxn=93.2 and 104.7 degree days, respectively), the absence of winter rains in 1996 (DPr=3) favored oat and wheat deterioration, and consequently the migration of macropters to corn crops not only in the endemic area but also in the provinces of Santa Fe and Buenos Aires. In contrast, winter rains in 1997 (DPr=10) promoted growth of winter cereal; thus, migration of macropters was gradual and did not produce important losses, since corn crops were at advanced growth stages (Lenardon et al., 1998; Ornaghi et al., 2001). Also, as there had been a recent epidemic, growers in the endemic area included tolerant hybrids at planting in 1997.

Furthermore, while the bivariate B model predicted a "High" macropterous population level for Chaján (994 macropters), it underestimated the 2570 individuals collected to November 30, 1996. For this site and growing season, the predictive variable DDTxn reached 37.6 degree days, a lower value than that obtained in La Aguada; this would be indicating the important role of the status of winter host of *D. kuscheli* populations in regulating migrations of macropters.

In 2004 and 2006, two years for which the predicted population was also "Very high", the situation would have been similar to those previously mentioned: migration of macropters due to deterioration of oat and wheat crops as a result of absence of winter rains in 2006 (DPr=2) with corn planted in November; and gradual migration in 2004 due to the good cereal growth in winter, to corn crops that had been sown in September-October because of the occurrence of rains (DPr=8). Most of the recently introduced hybrids are of high production potential, but often susceptible to the disease (Lenardon et al., 2007). The results of this work contribute to understanding the influence of temperature and precipitation on population dynamics of *D. kuscheli*. The predictive models generated are useful tools to be included in disease management strategies.

ACKNOWLEDGMENTS

This work was supported by the Instituto Nacional de Tecnología Agropecuaria - INTA and the Universidad Nacional de Río Cuarto, Córdoba, Argentina.

REFERENCES

Boito GT (2005) Evolución temporal del insecto vector del "mal de Río Cuarto" *Delphacodes kuscheli* Fennah, sobre cereales invernales. In 'VIII Congreso Nacional del Maíz'.

Denno RF, Grissell EE (1979) The adaptiveness of wingdimorphism in the salt marsh-inhabiliting planthopper, Prokelisia marginata (Homoptera: Delphacidae). Ecology 60:221-236.

Denno RF, Raupp MJ, Tallamy DW & Reichelderfer CF (1980) Migration in heterogeneous environments: differences in habitat selection between the wing forms of the dimorphic planthopper Prokelisia marginata (Homoptera: Delphacidae). Ecology 61:859-867.

Denno RF, Douglass LW, Jacobs D (1986) Effects of crowding and hosts plant nutrition on a wing dimorphic planthopper. Ecology 67:116-123.

Fernández Badillo A, Clavijo SA (1990) Polimorfismo alar de la chicharrita del maíz, Peregrinus maidis (Homoptera: Delphacidae) en Venezuela. Revista Facultad de Agronomía 16:27-34.

Ferris RS, Berger PH (1993) A stochastic simulation model of epidemics of arthropod-vectored plant viruses. Phytopathology 83:1269-1278.

Grilli MP, Gorla DE (1999) The distribution and abundance od Delphacidae (Homoptera) in central Argentina. Journal of Applied Entomology 123:13-21.

Grilli MP, Gorla DE (2002) Variación geográfica de la abundancia poblacional de Delphacodes kuscheli (Fennah) en la región central de Argentina. Ecología Austral 12:187-195.

Heathcote GD (1987) Virus yellows of sugar beet. In: McLean GD, Garret RG, Ruesink WD (Eds.) Plant virus epidemics. Sydney. Academic Press. pp. 399-417.

Iwanaga K, Nakasuji F, Tojo S (1987) Wing dimorphism in Japanese and foreign strains in the brown planthopper Nilaparvata lugens. Japanese Journal of Applied Entomology Z 7:45-48.

Jeger MJ, Holt J, Van den Bosch F, Madden LC (2004) Epidemiology of insect-transmitted plant viruses: modeling disease dynamics and control interventions. Physiological Entomology 29:291-304.

Lenardon SL, March GJ, Beviacqua JE, Marinelli A, Ornaghi JA, Astorga EM (1986). Diferentes épocas de siembra del maíz como alternativa para disminuir la incidencia del Maize Rough Dwarf Virus agente causal del Mal de Río Cuarto. IDIA 441-444, 78-83.

Lenardon SL, March GJ, Nome SF, Ornaghi JA (1998) Recent outbreak of "Mal de Río Cuarto" virus on corn in Argentina. Plant Disease 82:448.

Lenardon SL, March GJ, Giuggia J, Boito GT, Giolitti F, Ornaghi JA (2004) Manejo integrado del mal de Río Cuarto. In 'Congreso Mundo Maíz'. Buenos Aires, Argentina, 24 y 25 de junio de 2004. (MAIZAR-CREA-AAPRESID).

Lenardon SL, Vallone P, Marcellino J, Giolitti F, De Breuil S, Salomón A (2007) Comportamiento de híbridos comerciales de maíz frente al virus del mal de Río Cuarto en el área endémica 2006/2007. Informe de Actualización Técnica Maíz **5.** EEA INTA Marcos Juárez, Argentina.

Madden LV, Knoke JK, Louis R (1983) The statistical relationship between aphid trap catches and maize dwarf mosaic virus inoculation pressure. In: Plumb RT, Thresh JM (Eds.) Plant Virus Epidemiology (Eds.) Oxford. Backwell Scientific Publications. pp. 159-168.

Madden LV, Raccah B, Pirone TP (1990) Modelling plant disease increase as a function of vector numbers: nonpersistent viruses. Researches on Population Ecology 32:47-65.

Madden LV, Jeger MJ, Van den Bosch F (2000) A theoretical assessment of the effects of vector-virus transmission mechanism on plant virus disease epidemics. Phytopathology 90:576-594.

March GJ, Ornaghi JA, Beviacqua JE, 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. Gaceta Agronómica 76:384-388.

March GJ, Balzarini M, Ornaghi JA, Beviacqua JE, Marinelli A (1995) Predictive model for "Mal de Río Cuarto" disease intensity. Plant Disease 79:1051-1053.

March G.J, Ornaghi JA, Beviacqua JE, Lenardon SL (1997) Manual Técnico del Mal de Río Cuarto. (MORGAN-MYCOGEN: Argentina).

March GJ, Ornaghi JA, Giuggia J, Rago A, Lenardon SL (2002) Systemic insecticides to control Delphacodes kuscheli, and the "Mal de Río Cuarto" virus on maize. International Journal of Pest Management 48:127-132.

Mora-Aguilera G, Nieto-Angel DM, Téliz D, Campbell CL (1993) Development of a prediction model for papaya ringspot in Veracruz, México. Plant Disease 77:1205-1211.

Moschini RC, Fortugno C (1996) Predicting wheat head blight incidence using models based on meteorological factors in Pergamino, Argentina. European Journal of Plant Pathology 102**:**211-218.

Moschini RC, Sisterna MN, Carmona MA (2006) Modelling of wheat black point incidence based on meteorological variables in the southern Argentinean Pampas Region. Australian Journal of Agricultural Research 57**:**1151-1156.

Ochoa-Martínez DL, Zavaleta-Mejía E, Mora-Aguilera G, Johansen N.M (1999) Implications of leed composition and thrips species for the epidemiology of tonato spotted kilt in chrysanthemum (*Dendranthema grandiflora*). Plant Pathology 48:707-717.

Ornaghi JA, Boito G, Sánchez G, March G, Beviacqua JE (1993) Studies on the populations of Delphacodes kuscheli Fennah in different years and agricultural areas. Journal of Genetics & Breeding 47:277-282.

Ornaghi JA, March GJ, Boito GT, Marinelli A, Beviacqua J, Giuggia J, Lenardon SL (1999) Infectivity in natural populations of Delphacodes kuscheli vector of Mal de Río Cuarto Virus. Maydica 44:219-223.

Ornaghi J, Giuggia J, Beviacqua J, Boito GT, March GJ (2001) Respuesta de híbridos de maíz susceptible y tolerante a infecciones naturales del Mal de Río Cuarto. Fitopatología Brasileira 26:540.

Plumb TT, Lennon EA, Gutteridge RA (1986) Forecasting barley yellow dwarf virus by monitoring vector populations and infectivity. In: McLean GD, Garret RG, Ruesink WD (Eds.) Plant virus epidemics. Sydney. Academic Press. pp. 387-398.

Raccah B, Irwin ME (1998) Techniques for studying aphid-borne virus epidemiology. In: Kranz J, Rotem J (Eds.) Experimental techniques in plant disease epidemiology. pp. 207-222. Berlin. Springer Verlag.

Remes Lenicov A.M.M. de, Virla E, Dagoberto E (1991) Cambios estacionales en la población del vector del Mal de Río Cuarto del maíz (Delphacodes kuscheli Fennah) en cultivos de avena y su maleza circundante en Sampacho, Córdoba (Insecta-Homoptera-Fulgoroidea). In: Taller de Actualización sobre Mal de Río Cuarto INTA-CIMMYT. Pergamino, Argentina.

Remes Lenicov AMM de, Virla E (1999) Delfácidos asociados al cultivo de maíz en la República Argentina (Inecta-Homoptera-Delphacidae). Revista Argentina de Agronomía 104:1-15.

Tesón A, Remes Lenicov AMM de, Dagoberto E, Paradell S (1986) Estudio de las poblaciones de Delfácidos sobre maíz, avena y maleza circundante (Homoptera-Fulgoroidea). Gaceta Agronómica 6:507-517.

Virla EG, Remes Lenicov AMM de (1991) Ciclo de vida de *Delphacodes kuscheli* criado sobre diferentes hospedantes em condiciones de laboratorio. In: Taller de Actualización sobre Mal de Río Cuarto INTA-CIMMYT. Pergamino, Argentina.

TPP 215 - Received 23 November 2010 - Accepted 27 June 2011
Section Editor: Alice K. Inoue Nagata