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Examination of meteorology-based predictions of Fusarium head blight of wheat grown at two locations in the southern Pampas region of Argentina

M. R. Carranza[A,E], *R. C. Moschini*[B], *G. Kraan*[C] *and J. H. Bariffi*[D]

[A]Centro de Investigaciones de Fitopatología (CIDEFI), Facultad de Ciencias Agrarias y Forestales, UNLP, 60 y 119, La Plata, CP: 1900, Buenos Aires, Argentina y Comisión de Investigaciones Científicas (CIC), Provincia de Buenos Aires.

[B]Instituto de Clima y Agua, CNIA, INTA Castelar, V. Udaondo, Buenos Aires, Argentina.

[C]Chacra Experimental Integrada Barrow, CC 216, CP 7500, Tres Arroyos, Buenos Aires, Argentina.

[D]EEA INTA Balcarce, CC 276, CP 7620, Balcarce, Buenos Aires, Argentina.

[E]Corresponding author. Email: carranza@net-alliance.net.ar

Abstract. In Argentina, head blight or scab is a highly risky disease (caused by *Fusarium graminearum*) of wheat, although its occurrence is sporadic depending on prevalent environmental variables. These traits stimulated the development of predictive models of head blight epidemics, which would help growers in the selection of control strategies. Regression models for predicting head blight incidence were developed at Pergamino (33°56′S, 60°30′W), associating temperature and moisture variables with mean disease data (empirical approach). Recently a new fundamental–empirical approach for estimating *Fusarium* index (incidence% × severity%/100) was developed using data from Pergamino and Marcos Juarez (32°41′S, 62°07′W). Validation studies of both empirical and fundamental–empirical approaches were carried out at northern and southern locations showing good results after making a few changes. The objective of this work was to examine the goodness of fit of the predicted values from both approaches (original and including some of the changes derived from previous validation studies) in comparison with median disease data in two southern locations of the Pampas region: Balcarce (37°45′S, 58°18′W) and Barrow (38°19′S, 60°15′W), for the 2002, 2003 and 2004 wheat seasons. Partial and mean deviation values between observed and predicted data were calculated. In accordance with previous validation studies, successful *Fusarium* index estimations were achieved decreasing the heat accumulation defining the length of the wheat critical period for infection to 450 degree days [base mean daily temperature (Td) = 10°C]. Reducing the critical period length [450 degree days (base Td = 0°C) instead of 530] and increasing maximum and minimum temperature thresholds (30° instead of 26°C and 11°C instead of 9°C) of the empirical equation thermal variable led to satisfactory *Fusarium* incidence predictions. This study showed that both approaches developed at northern locations of the Pampas region can be portable and useful for predicting disease intensity at more southern locations, making only a few changes. Differences in wheat cultivar behaviour regarding the disease were observed in the analysed data but this effect was not considered in this study.

Introduction

Fusarium head blight (FHB), caused by several species of *Fusarium*, is a disease affecting wheat, barley, oats, rye, corn, triticale, canary seeds and some forage grasses. In Argentina, 90% of the pathogens isolated from blighted heads were *Fusarium graminearum* (teleomorph *Gibberella zeae*) (de Galich and Galich 1994; Carranza *et al*. 2002). The disease has a worldwide distribution, being common in humid and semihumid wheat growing areas.

Previous research at Pergamino led to the development of regression equations (empirical approach) for predicting wheat FHB incidence based on temperature and moisture (rainfall and relative humidity) (Moschini and Fortugno 1996). Two of these meteorology-based empirical equations satisfactorily predicted head blight incidence at two more northern locations than Pergamino, changing the maximum temperature threshold of the model temperature variable (Moschini *et al*. 2001). At locations south of Pergamino, FHB incidence values were correctly predicted by changing the length of the critical period for infection [450 degree days (base daily temperature (Td) = 0°C) instead of 530], combined with changes in the maximum and minimum temperature thresholds (30° instead of 26°C and 11°C instead of 9°C) (Moschini and Carmona 1998). Recently successful *Fusarium* index (incidence% × severity%/100) estimations (fundamental–empirical approach) were achieved at Pergamino and M. Juarez, using a meteorology-based system which combined elements derived from the fundamental (Andersen 1948) and empirical approaches (Moschini *et al*. 2002). Decreasing the length of the critical period for infection to 450 degree days (base Td = 10°C),

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accurate predictions of *Fusarium* index were obtained at three southern locations for the 2001 wheat season (Moschini *et al*. 2004).

The objective of the present study was to examine the performance of original and changed meteorology-based equations and the fundamental–empirical system for predicting FHB incidence and *Fusarium* index at Balcarce and Barrow, for the 2002–04 crop seasons.

Methods

Observed FHB incidence and Fusarium index

FHB incidence and severity observations were obtained from regional wheat trials conducted at Balcarce (37°45′S, 58°18′W) and Barrow (38°19′S, 60°15′W) experiment stations (southern Pampas region), for the 2002–04 (only Balcarce) crop seasons. In these trials, many commercial wheat cultivars are sown on different dates every year, phenological data are registered and grain yield are determined. The original disease observations recorded under the 0–9 scale, were proportionally transformed to percentage, being 9 equal to 100%. Observed *Fusarium* index values were calculated as incidence × severity, divided by 100. Medians of the available disease observations for the cultivars grouped by similar heading dates (heading date ±1 day) were calculated by location and crop season (Table 1).

Predicted incidence (empirical approach)

Meteorology-based predictive wheat FHB incidence equations were previously developed for Pergamino (Moschini and Fortugno 1996). These equations were originally developed based on mean observed incidence values from many wheat cultivars, grouped by their similar heading dates. Using daily records of maximum (MaxT) and minimum (MinT) temperature (Td: daily average temperature calculated as half the sum of the daily MaxT and MinT), precipitation and relative humidity (average of the 0800, 1400 and 2000 hours observations) obtained from a standard weather station, independent meteorological variables were calculated. These variables were processed in a time period beginning 8 days before heading date (emergence of first heads) and ending when 530 degree days (base Td = 0°C) were accumulated. This period was regarded as the critical period length (CPL). From the study in Pergamino, one of the original adjusted equations for predicting FHB incidence (PI %) was the following:

$$\text{PI\%} = 20.37 + 8.63 \times NP_2 - 0.49 \times DD_{926} \qquad (1)$$

where NP_2 is the number of 2-day periods with precipitation ($\geq$ 0.2mm) and relative humidity >81% in the first day and relative humidity $\geq$ 78% in the second day; DD_{926} resulted from adding DDMaxT and DDMinT, which were calculated by the next procedure: if MaxT >26°C then $\text{DDMaxT} = \sum^{d}(\text{MaxT} - 26)$; if MinT <9°C then $\text{DDMinT} = \sum^{d}(9 - \text{MinT})$, summed over d (days of the CPL).

For the present study, the original empirical approach was used to predict PI% at meteorological conditions of Balcarce and Barrow. Also, the following changed Eqn 1 was used: $\text{PI\%} = 20.37 + 8.63 \times NP_2 - 0.49 \times DD_{1130}$, in which maximum and minimum temperature thresholds of the variable DD_{926} were increased to 30°C and to 11°C, respectively (DD_{1130}). CPL was reduced to 450 degree days (base Td = 0°C). These changes were determined from a previous successful validation study (Moschini and Carmona 1998). Daily meteorological data for calculating model variables were obtained from standard weather stations located in the experimental fields of the two locations (Balcarce and Barrow). Observed wheat heading dates (when 50% of the heads were fully emerged) were specified in each location in order to perform estimations with the original and changed Eqn 1 (Table 1).

Predicted Fusarium index (fundamental–empirical approach)

In a recent study (Moschini *et al*. 2002), a total of 84 values of *Fusarium* index registered in commercial wheat cultivars (susceptible and moderately susceptible) at Pergamino and M. Juárez (10 crop seasons) were satisfactorily contrasted with predicted values. In that study, predicted *Fusarium* index values were obtained by following the next steps:

(1) Daily progress of wheat heads with exposed anthers (%): from field observations in a single wheat cultivar, a polynomial function between the logit of the proportion of head with anthers (Anther, values from 0 to 1) and the time in degree days (DD_{12} : base Td = 12°C) was fitted.

$$\text{LogitAnther} = -6.765052912 + 0.136395967 \times DD_{12} - 0.000694621 \times DD_{12}^2 + 0.000001384 \times DD_{12}^3 - 0.000000001 \times DD_{12}^4 \qquad (2)$$

where LogitAnther is the natural logarithm of (Anther/1 − Anther); $DD_{12}^2 = DD_{12} \times DD_{12}$; $DD_{12}^3 = DD_{12}^2 \times DD_{12}$; $DD_{12}^4 = DD_{12}^3 \times DD_{12}$. Solving [EXP(LogitAnther)/1 + EXP(LogitAnther)] × 100, the daily percentage of heads with anthers were obtained. The critical period for the infection (CPL) began 4 days before the observed heading date and finished when 530 degree-days (base Td = 12°C) were accumulated.

(2) Predicted severity: in controlled environment studies, Andersen (1948) established the percentage of infection (severity %) in wheat heads inoculated with *Fusarium graminearum* conidia, exposed to different wet period lengths (W: from 18 to 72 h) and temperatures (t = 15, 20,

Table 1. Median of Fusarium head blight incidence and *Fusarium* index values observed on commercial wheat cultivars at two southern locations (Balcarce and Barrow) of the Pampas region, Argentina, for the 2002–04 crop seasons

	Incidence median (%)	Fusarium index median (%)	Heading date	No. of wheat cultivars
Balcarce				
2002	27.5	13.3	11/1	14
2003	5.5	1.2	11/4	12
2004	22.0	7.3	10/31	12
Barrow				
2002	19.0	9.8	11/1	14
2003	0	0	11/4	12

25 and 30°C). A polynomial function was fitted between the logit of the severity (S, from: 0 to 1) and W (h) and T (°C), including individual and interactive effects.

$$\text{LogitS} = 38.77166158 - 0.53815698 \times \text{W} - 6.02985565 \times \text{T} + 0.26849793 \times \text{T}^2 - 0.00396097 \times \text{T}^3 + 0.04990941 \times \text{IT} - 0.00092343 \times \text{IT}^2 \qquad (3)$$

where LogitS is the natural logarithm of (S/1 − S); $\text{T}^2 = \text{T} \times \text{T}$; $\text{T}^3 = \text{T}^2 \times \text{T}$; $\text{IT} = \text{T} \times \text{W}$; $\text{IT}^2 = \text{T}^2 \times \text{W}$. Values of predicted severity were obtained solving $\text{EXP(LogitS)}/[1 + \text{EXP(LogitS)}] \times 100$.

In order to use Eqn 3, equivalence rules defining W values and mean T during wet periods from daily precipitation (Prec), maximum and minimum temperature and relative humidity (RH%) registered at standard weather stations, were established. Using criteria derived from the empirical approach (Moschini and Fortugno 1996), it was defined that:

1 day with Prec ($\geq$ 0.2 mm) and RH $\geq$ 81% is equal to W = 24 h.

2 consecutive days with Prec and RH $\geq$ 81% is equal to W = 48 h.

3 consecutive days with Prec and RH $\geq$ 81% is equal to W = 72 h.

A maximum W period of 72 h was analysed. If before or after W period of 24 and 48 h, Prec and RH < = 77% are registered, 3 h of wet are added. If Prec and RH >77% and <81% (before or after) are registered, 6 h of wet are added. Occurrence of RH >77% and <81% after W periods, 3 h are added. The temperature during the wet period, calculated by averaging the mean daily temperatures (t = MaxT + MinT/2), was weighted for the wet duration of each day involved. If T is <15°C, severity values are only calculated for wet periods > = 48 h.

(3) The final predicted *Fusarium* index value resulted from the sum of the partial products between the percentages of heads with exposed anthers (a) and predicted severity (b) (divided by 100), calculated for all the wet periods found throughout the wheat critical period for the infection.

For the present study, the original preceding fundamental–empirical approach for estimating *Fusarium* index values was used under the weather conditions of Balcarce and Barrow. As described in a previous validation paper (Moschini *et al.* 2004), the present study included some changes to the original version: CPL ended when 450 degree-days (base Td = 10°C) were accumulated. Also, if W period is lower than 48 h and T is lower than 15°C, 90% of the calculated *Fusarium* index value for W = 48 h was considered.

Validation

The correspondence between predicted incidence and *Fusarium* Index values (using original and changed meteorology-based approaches) and the observed ones in the two locations for the 2002–04 crop seasons, was analysed comparing the signs and magnitudes of the partial deviations and mean deviations.

Results

Partial deviations between median FHB incidence observations and values predicted by the original empirical approach (Eqn 1, CPL: 530 degree days, base Td = 0°C) were much higher than those calculated using the changed approach (changed Eqn 1, CPL: 450 degree days, base Td = 0°C) (Table 2). Predominance of negative partial deviation values (4 out of 5 values) showed a tendency to overestimation when the original approach was used. Much lower mean deviations resulted from using the changed (2.7%) than the original approach (−14.5%) for predicting FHB incidence.

Unlike FHB incidence predictions, slight differences between the original and changed fundamental–empirical approach for estimating *Fusarium* index values were obtained, when deviations from the observed values were analysed (Table 2). Nevertheless, a mean deviation of only 0.4% was produced using the changed approach, compared with −1.1% using the original one. It is worth pointing out that the wide range of *Fusarium* index values observed in the commercial cultivar was not predicted using the changed fundamental–empirical approach. During the FHB epidemic of 2002, the observed *Fusarium* index values ranged from 33.9– 3.6% at Balcarce and 49–0% at Barrow, respectively. The corresponding predicted extreme values were 15.4–17.9% and 5.7–8.2% for both locations (Table 2).

Discussion

The original empirical approach developed for predicting FHB incidence at Pergamino satisfactorily predicted disease incidence at the two locations analysed during the 2002–04 wheat seasons when the thresholds of the temperature variable of Eqn 1 and the length of the critical period for infection were slightly modified. At more southern locations than Pergamino such as Balcarce and Barrow, more accurate FHB incidence predictions were obtained by reducing the length of the critical period for infection [450 degree days (base Td = 0°C) instead of 530] and increasing the maximum and minimum temperature thresholds (30°C instead of 26°C and 11°C instead of 9°C) in Eqn 1. For the fundamental–empirical approach, the original length of the critical period for infection (530 degree days, base Td = 12°C) was slightly long for these colder locations (31–37 days), unlike the new critical period (450 degree days, base Td = 10°C), which lasted 27–30 days.

It should be emphasised that both meteorological variables in Eqn 1 (original and changed) are calculated after the entire wheat critical period for infection has completed. Therefore, the predicted FHB incidence at this stage is too late to be useful for decision making with regard to application of a chemical control. However, the identification of meteorological variables highly associated with the disease could be helpful for analysis of short-range weather forecasts throughout the wheat critical period. Through the fundamental–empirical approach, the evolution of the multiple infection process (characteristic in areas with moderate and severe FHB outbreaks) can be quantified event by event. During the incubation period, a chemical disease control could be implemented based on the accumulated *Fusarium* index value of the last infective event analysed.

The present study demonstrated that meteorology-based systems for predicting FHB intensity (both empirical and fundamental–empirical approaches) developed for northern locations of the Pampas region needed only minor adjustments to predict FHB intensity at southern locations. In this study, the

Table 2. Deviations (%, partial and mean) between observed Fusarium head blight incidence and *Fusarium* index values and those predicted by the original and changed meteorology-based approaches at two southern locations (Balcarce and Barrow) of the Pampas region, Argentina, for the 2002–04 crop seasons. In addition, the corresponding observed and predicted (changed approach) extreme *Fusarium* index values are presented

	Deviation (original)[A]		Deviation (changed)[B]		Extreme Fusarium index[C]			
	Incidence	*Fusarium* index	Incidence	*Fusarium* index	Observed		Predicted (changed)	
Balcarce								
2002	−34.8	−5.4	−14.0	−2.8	3.6	33.9	15.4	17.9
2003	−3.6	−2.9	5.5	−1.9	0.0	3.6	4.2	6.7
2004	−18.9	1.6	−1.7	3.8	2.4	12.1	4.6	7.1
Barrow								
2002	−13.6	3.0	−3.5	5.0	0.0	49.0	5.7	8.2
2003	0.0	−1.9	0.0	−1.9	0.0	0.0	3.2	5.7
Mean/s.d.	−14.2/13.8	−1.1/3.4	2.7/7.1	0.4/3.6	–	–	–	–

[A]Original empirical approach for predicting Fusarium head blight incidence: Eqn 1. Critical period length (CPL) began 8 days before the observed heading date and finished when 530 degree-days [base daily temperature (Td) = 0°C] were accumulated. Original fundamental–empirical approach for predicting Fusarium index: CPL began 4 days before the observed heading date and finished when 530 degree-days (base Td = 12°C) were accumulated.
[B]Changed empirical approach for predicting Fusarium head blight incidence: changed Eqn 1. Critical period length (CPL) began 8 days to prior the observed heading date and finished when 450 degree-days [base daily temperature (Td) = 0°C] were accumulated. Changed fundamental–empirical approach for predicting *Fusarium* index: CPL began 4 days before the observed heading date and finished when 450 degree-days (base Td = 10°C) were accumulated.
[C]Extreme predicted *Fusarium* index (PFindex) values were calculated by the following regression equations: (a) PFindexMS = 1.5859 + 0.8588 × PFindex and (b) PFindexS = 4.0914 + 0.8588 × PFindex for moderately susceptible (MS) and susceptible (S) cultivars (Moschini *et al*. 2002). Extreme observed *Fusarium* index values: maximum and minimum disease values observed on the wheat cultivars analysed by location and year.

improvement of the disease predictions was sharply significant when the changed empirical approach was used for estimating FHB incidence.

The empirical meteorology-based approach validated in this study included real-world factors that accounted for the influence of environment on disease incidence, but the model (original and changed) did not take into account any factors associated with genetic behaviour of wheat cultivars regarding the disease. Unlike observations made by Moschini *et al*. (2004) for the 2001 FHB epidemic, *Fusarium* index values estimated for susceptible and moderately susceptible wheat cultivars failed to match the wide disease range observed by commercial cultivars during the more severe 2002 FHB epidemic.

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