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Critical yield-point model to estimate damage caused by brown spot and powdery mildew in barley

Modelo do ponto crítico para estimar danos causados pela mancha-marrom e oídio em cevada

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ABSTRACT

*Barley (**Hordeum vulgaris** L.) is the second most important winter crop in Southern Brazil. The excessive rainfall in this region during the crop-growing season increases the frequency and intensity of foliar fungal diseases. The research aimed to determine the damage function equations (DFE) for the multiple pathosystem of barley brown spot and powdery mildew based on the relationship between grain yield and diseases intensity at different 'BRS Cauê' cultivar growth stages (GS) during 2009 and 2010 growing seasons in Southern Brazil. The experiments were arranged in a randomized complete block design with nine treatments and four replicates. The disease gradients were generated by strobilurins and triazols fungicides rates and number of applications on barley cv. Cauê. The fungicide applications and disease incidence and severity assessments were performed at the 22, 31, 39, 45 and 56 plant GS. The DFE were obtained by variance analysis and linear regression between grain yield and diseases intensity. Significant and negative DFE were obtained and the damage coefficients (DC) varied from 29.48 to 100.08 (2009) and from 36.08 to 113.57kg ha^{-1} (2010) for incidence, and from 219.5 to 6,276.6 (2009) and 102.3 to 5,292.5kg ha^{-1} (2010) for severity. The largest damage coefficients were obtained when diseases assessments were made on GS 22 and 31 on both growing seasons evaluated. DFE were used to calculate the economic damage threshold (EDT) as a criterion to indicate the fungicide application moment to control the diseases in cultivars similar to 'BRS Cauê' in Southern Brazil.*

Key words: ***Bipolaris sorokiniana***, ***Blumeria graminis*** *f. sp.* ***hordei***, ***Hordeum vulgare***, *multiple pathosystem, economic damage threshold.*

RESUMO

*A cevada (**Hordeum vulgaris** L.) é a segunda mais importante cultura de inverno no Sul do Brasil. Nessa região, o excesso de chuvas durante a estação de crescimento da cultura favorece o aumento na frequência e intensidade de doenças foliares. O trabalho objetivou determinar as equações de função de dano (EFD) para o patossistema múltiplo mancha-marrom e oídio da cevada pela relação entre rendimento de grãos e intensidade foliar das doenças em diferentes estádios fenológicos da cultivar de cevada 'BRS Cauê', nas safras 2009 e 2010 no sul do Brasil. O delineamento foi em blocos casualizados com nove tratamentos e quatro repetições. Os tratamentos foram constituídos de diferentes doses e número de aplicações dos fungicidas triazóis e estrobilurinas para gerar os gradientes de intensidade das doenças. As aplicações de fungicidas e as avaliações da incidência e severidade foliar foram realizadas nos estádios fenológicos (EF) 22, 31, 39, 45 e 56. As equações foram obtidas pela análise de variância e regressão linear entre rendimento de grãos e intensidade das doenças. As EFD foram significativas e negativas e os coeficientes de danos variaram de 29,48 a 100,08kg ha^{-1} (2009) e 36,08 a 113,57kg ha^{-1} (2010) para a incidência e de 219,5 a 6.276,6kg ha^{-1} (2009) e 102,3 a 5.292,5kg ha^{-1} (2010). Os maiores coeficientes de dano foram obtidos nos estádios EF 22 e 31em ambas as safras. As EFD foram usadas para calcular o limiar de dano econômico, que é um critério que indica o correto momento de aplicação de fungicidas para o controle das doenças em cultivares similares a 'BRS Cauê' no sul do Brasil.*

Palavras-chave: ***Bipolaris sorokiniana***, ***Blumeria graminis*** *f. sp.* ***hordei***, ***Hordeum vulgare***, *patossistema múltiplo, limiar de dano econômico.*

INTRODUCTION

Barley (***Hordeum vulgaris*** L.) is the fourth most important crop in the world after maize, wheat and rice (MEUSSDOERFFER, 2009). Barley

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is cultivated as a summer crop in temperate areas and as a winter crop in tropical areas for malt production. Brazil is one of the largest barley-importing countries, producing only 30% of the national brewing industry's demand. Brazil's 2011 barley production was approximately 305 thousand tons in 88,4 thousand ha (CONAB, 2012).

The excessive rainfall in Southern Brazil during the crop-growing season increases the frequency and intensity of foliar fungal diseases (REIS & CASA, 2007). The main foliar fungal diseases are brown spot (***Bipolaris sorokiniana*** (Sacc.) Shoemaker), net blotch (***Drechslera teres*** (Sacc.) Shoem.) and powdery mildew (***Blumeria graminis*** DC. f. sp. ***hordei*** Em. Marchal.). These diseases intensities depend on cultivar susceptibility, crop systems, tillage practices and environment conditions (MATRHE, 1997). Barley diseases can be controlled by genetic resistance and management practices such as seed treatment, aerial fungicide application, seeding date and seeding rate, balanced fertility, weeds and volunteer crop-plant control and harvest management (MATRHE, 1997; KUMAR et al., 2002). Aerial fungicide applications have been one of the most important strategies in some countries, such as Brazil, to control most diseases in winter cereal crops (PICININI et al., 1996; LENZ et al., 2011).

The indicative criteria for the timing of aerial fungicide applications to barley crops are not yet clearly based on the research data. Normally, the fungicide applications are preventive and/or performed according to the crop growth stage (REIS & CASA, 2007). The indicative criteria to control barley brown spot and powdery mildew based on disease intensity are 3% foliar severity or 20% foliar incidence and 2-3% foliar severity, respectively (REUNIÃO, 2011). Fungicide applications aiming higher yields without considering economic and technical criteria like disease intensity and damage, and cost and efficiency of disease control can increase production costs. There is a certain amount of information regarding fungicide application based only on disease intensity associated to losses, control costs or fungicide efficiency. These factors can induce unnecessary or late fungicide applications when the disease intensity has already overcome the economic damage threshold (EDT) (CASA et al., 2009).

The EDT is the term used to define the disease intensity that can cause losses equal to the control cost, and it consists of rational and scientific indicative criterion for fungicides' applications (REIS & CASA, 2007). In Brazil, there are many barley crop damage function equations (DFE) for simple pathosystems, such as powdery mildew (REIS et al., 2002), brown spot (REIS & CASA, 2007) and net blotch (REIS et al., 1999). These equations were obtained for isolated and independent diseases without considering the situation of multiple pathosystem such as when more than one disease affects a crop simultaneously. In Brazil, barley is normally grows in the non-tillage system after wheat or oat (***Avena sativa*** L.) rotation, increasing the brown spot occurrence because the pathogen can survive in the plant debris of the previous crop (MATHRE, 1997; REIS & CASA, 2007). Many epidemiological models, such as the critical yield-point model, have been used to estimate crop DFE for plant diseases. The critical-point model is particularly useful for identifying a specific host plant growth stage in which the disease intensity is closely correlated with the future crop damage (BERGAMIN FILHO & AMORIM, 1996). From the DFE, damage coefficients are obtained , and they vary according to each plant species growth stages and cultivars (REIS & CASA, 2007).

The objectives of this study were (i) to estimate the DFE for the multiple pathosystem of barley brown spot and powdery mildew using the critical-point and experimental parcel models relating the disease intensity to the grain yield, and (ii) to determine the EDT using the model-generated damage coefficient from the DFE.

MATERIAL AND METHODS

The experiments were carried out during the 2009 and 2010 growing seasons at the NBN Seeds Company in the Muitos Capões Municipality in the State of Rio Grande do Sul, Southern Brazil (28º15'51 S and 51º10'54 W), at an 937m above sea level. The experiments were conducted using the barley cultivar 'BRS Cauê', which is susceptible to brown spot and powdery mildew and is widely cultivated, due to its high productivity, agronomic type and malt quality (REUNIÃO, 2011). The climate of the region is humid mesothermic (Cfb), according to the Köppen classification. Higher rainfall in Muitos Capões occurs from October to March, and during this period, the average monthly precipitation is approximately 166mm. The region's soil has a basaltic rock origin, classified as brown latosol aluminic cambic (Oxisol - class A) with clay texture (EMBRAPA, 1999).

The experiments were carried out in a no-tillage area with oat crop rotation system and soybean succession. Sowing dates were on June 27th 2009 and June 12th 2010, and the experimental units were composed of 380 plants per m^2 density, spaced 0.17m between rows. The seeds were treated with 100mL iprodione (Rovral), 80mL carbendazim (Portero) and 60mL imidacloprid (Gaucho) per 100kg of seeds. The soil was fertilized with 204kg ha^{-1} of MAP (11% of N and 52% of P_2O_5) and 187kg ha^{-1} of KCl (60% of K_2O). Insect control (caterpillars and aphids) was performed using 30mL ha^{-1} triflumuron (Certero) and 500mL ha^{-1} imidacloprid + betaciflutrin (Connect), and weed control was achieved using 70g ha^{-1} iodosulfuron-methyl (Hussar).

The experiments were arranged in a randomized complete block design with nine treatments and four replicative. Each plot had an experimental unit area of 5.0x2.5m. To generate the disease gradients, strobilurin and triazol fungicide rates (one half and full recommended rates) and numbers of fungicides sprays (once, twice, third and fourth) were applied, according to REIS et al., (2000, 2002, 2007, 2008), BOHATCHUK et al. (2008) and NERBASS et al. (2010). The fungicide applications were performed at the plant GS 22 (Main shoot and 2 tillers), GS 31 (Swelling 1st node detectable), GS 39 (Flag leaf ligule just visible), GS 45 (Full-boot, boot above ligule of 2nd last leaf) and GS 56 (50% of spikes visible), according to the diagrammatic scale of ZADOKS et al. (1974). Spraying was performed at 21 days intervals using a knapsack atomizer with CO_2-generated pressure, a 2.0m-wide boom and a delivered volume of 200L ha^{-1}.

The methodology used to obtain the disease gradients to estimate yield loss was the experimental plot method, using the critical-point model described by BERGAMIN FILHO & AMORIM (1996). The critical-point model is particularly useful when it can identify a specific plant growth stage in which disease intensity is most closely correlated with the future damage. Thus, in practice, a simple model may be applied to estimate the damage caused to the host by a specific disease in function of the host's GS and disease intensity. This model is represented by the equation: $y=b_0+b_1x$. Where, 'y' represent the crop productivity rates and 'x' represent the disease intensity rates (incidence/severity) of the host's growth stage (BERGAMIN FILHO & AMORIM, 1996).

The brown spot and powdery mildew disease incidence and severity were assessed in ten tillers of ten plants per plot, which were sampled randomly at the five different plant GS 22 (main shoot and 2 tillers), 31 (swelling 1st node detectable), 39 (Flag leaf ligule just visible), 45 (Full-boot, boot above ligule of 2nd last leaf) and 56 (60% of spikes visible). The incidence of the diseases was defined by number of leaves with diseases symptoms divided by the total number of leaves evaluated. The diseases severity was assigned according to the wheat leaf spot diagrammatic scale of JAMES (1971). Distrain applicative of TOMERLIN & HOWELL (1998) was used to train the raters. Plants from the central rows of each plot were harvested manually and threshed and cleaned by a stationary machine. Grain yield was expressed in kg ha^{-1}.

The plots yield rates were submitted to mathematical model of presupposition test followed by variance analysis ($P \leq 0.05$). The cultivar, plant GS and growing season interaction were significant by F-test ($P \leq 0.05$) and consequently, linear regression analysis among diseases intensities (independent variable) and grains yields (dependent variable) was conducted using Statistical Analysis System (SAS®) version 9.1, generating the DFE for each plant GS and growing seasons. The damage coefficients were obtained from the DFE, represented by 'b_0' of the equation $y = b_0 + b_1x$ described previously. The linear regression used was due to the critical-point model adopted and the DFE was calculated according to REIS et al. (2001) by the following equation:

$$I = Cc/ (Bp \times Dc) \times Ce$$

Where I = foliar disease incidence, Cc = fungicide control cost ha^{-1}, Bp = barley commercial grain price, Dc = damage coefficient from the DFE and Ce = fungicide control efficiency compared among severity of the control and 4 replicates treatments.

RESULTS AND DISCUSSION

The brown spot and powdery mildew intensities were similar during both 2009 and 2010 growing seasons, occurring predominant between the barley GS 22 and 45 (tillering and heading). The low variation of climatic condition between both growing seasons was responsible for these results, where the average temperature and rainfall during both growing seasons were 26°C and 1.113mm, respectively (AGRITEMPO, 2012). In neither growing seasons leaf rust and net blotch were recorded.

Five incidence and severity DFE were generated for the 2009 and 2010 growing seasons with their respective coefficients of determination (R^2), totaling 20 linear equations (Figure 1 and 2). All damage function equations were significant ($P<0.05$) and negative, where the increase of diseases symptoms

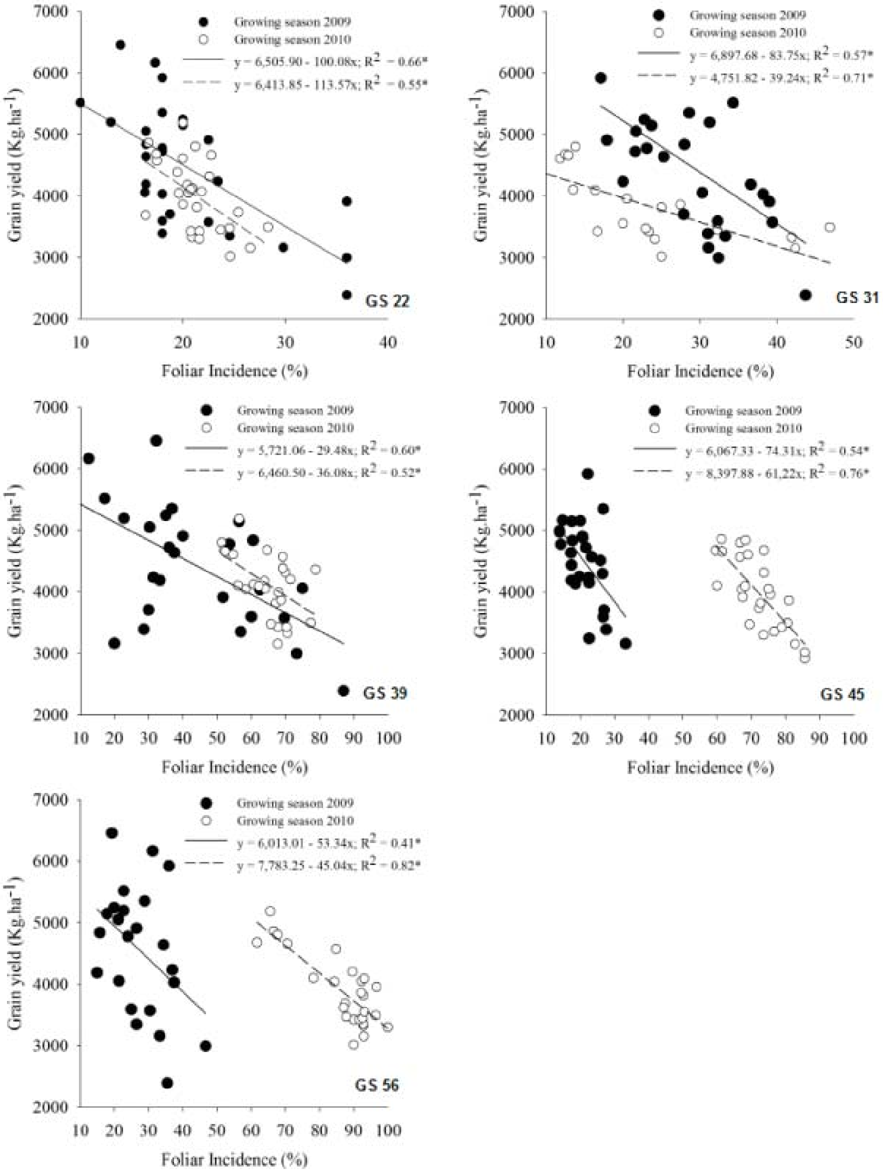

Figure 1 - Relationship between foliar incidence and grain yield of the multiple pathosystem of brown spot and powdery mildew of the barley Cauê cultivar in different plant growth stages of GS 22, GS 31, GS 39, GS 45 and GS 56, during the 2009 and 2010 growing seasons in Muitos Capões, RS Municipality.* Significance Level (P<0.05).

reduced the grains yield according to the GS. DFE have been described for simple pathosystems in barley like brown spot for cv. BR-2 (REIS & CASA, 2007) and for powdery mildew for cv. Antarctica-5 (REIS et al., 2002). These equations were obtained for isolated and independent diseases without considering the situation of multiple pathosystems which consider more than one disease occurring simultaneously. In addition, these equations were developed for cultivars which no longer are cultivated in Brazil.

The foliar diseases incidences and severities were higher in the 2010 than in 2009 growing season (Figures 1 and 2) mainly in stages GS 45 (Full-boot, boot above ligule of 2nd last leaf) and GS 56 (60% of spikes visible) (Figures 1A and 1B). This result may be attributed to the more severe levels of powdery mildew in these plant GS, which was favored by the low rainfall during this period. Powdery mildew reduces the active foliar photosynthetic area by reducing of light absorption

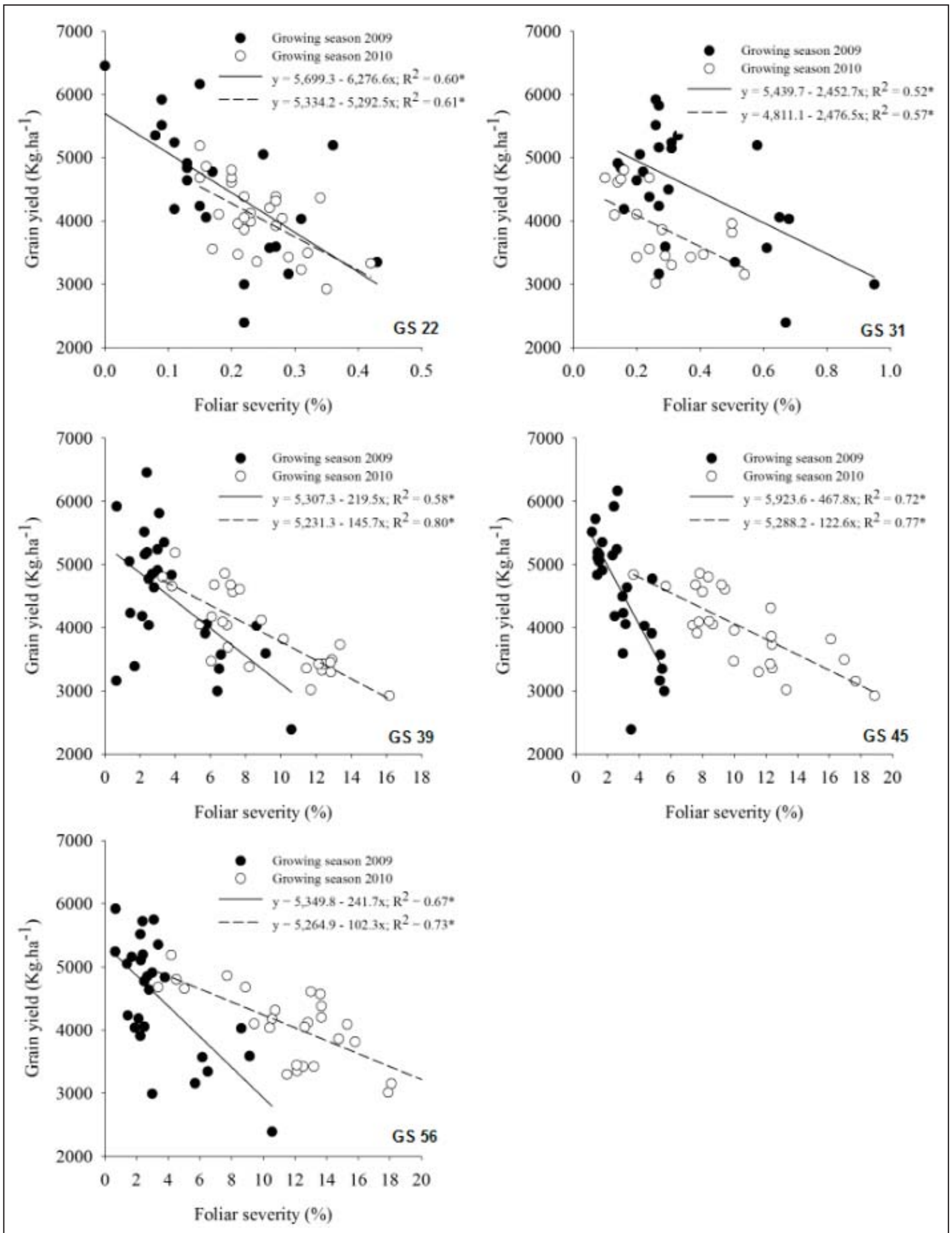

Figure 2 - Relation between foliar severity and grain yield of the multiple pathosystem of brown spot and powdery mildew of the barley Cauê cultivar in different plant growth stages of GS 22, GS 31, GS 39, GS 45 and GS 56, during the 2009 and 2010 growing seasons in Muitos Capões, RS Municipality.* Significance Level (P<0.05).

and consequently plant photoassimilation conversion, hindering the formation and grain filling (MATHRE, 1997; CZEMBOR, 2002). FUNCK et al. (2009) showed a low dry matter weight of wheat at vegetative dough growth stage in growing seasons with powdery mildew predominance.

The DFE of GS 22 showed the largest damage coefficient (Figures 1A and 2A) in both growing season, corroborating with BOHATCHUK et al. (2008) and REIS et al. (2008) wheat and oat data, respectively. The authors indicated that early disease onset in winter cereal in Southern Brazil has an impact on the grain yield, due to interference with the grain number per m^2, which is determined by the tiller development (COOK et al., 1999). However, NERBASS et al. (2010), studying the same multiple pathosystem in oat, showed that the greatest damage occurs at the flowering (anthesis) stage, rather than tillering. Foliar incidence and severity are parameters used for diseases quantifications. Incidence is an objective variable while severity a subjective variable. However, both are correlated and incidence can be used to estimate severity and vice-verse. The relation between foliar incidences and severities was higher at the beginning of epidemics and, as the diseases develop, this relation becomes lower because the diseases were occurred over most of the leaves while the severities were still variable. Therefore, in the early epidemics stages the incidences and severities increased until all leaves were infected and for this point on the increase of diseases intensities occurred only by severities. The incidences were useful to evaluate the diseases when the epidemics were still in the early stages and in this situation, can be correlated with the severity.

For each 1% of foliar incidence, the economic damage threshold (EDT) for the multiple pathosystem of brown spot and powdery mildew generated a variable damage coefficient between 29.48kg ha^{-1} and 100.08kg ha^{-1} (2009 growing season) and between 36.08 and 113.57kg ha^{-1} (2010 growing season) of the grain yield (Figure 1 and 2). For each 1% of foliar severity, the damage coefficient was between 219.5kg ha^{-1} and 6,276.6kg ha^{-1} (2009 growing season) and between 102.3 and 5,292.5kg ha^{-1} (2010 growing season) of the grain yield (Figures 1 and 2). The damage coefficient obtained for different GS was used to calculate the EDT according to REIS et al. (2001). The EDT may be an useful criterion to indicate the moment for the fungicides applications to control the diseases. An example of such EDT calculation can be found in REIS & CASA (2007), where, based on these relationships, a barley field with an estimated fungicide control cost of US$ 48.00ha^{-1} (COOPERATIVA AGRÁRIA/ENTRE – RIOS, 2012), barley commercial grain price US$ 323.00t^{-1} (HGCA, 2014), 70% fungicide efficiency and the damage coefficient obtained from the 2010 DFE (Figure 1) for GS 31 would have GY=4,751.82-39.24 I with R^2=0.71 (GY = grain yield; I = incidence). In this case, for each 1% of disease incidence, the damage potential will be 39.24kg ha^{-1} or 0.03924t. A field with 4,500kg ha^{-1} as its estimated yield would have a damage potential of 37.16kg ha^{-1} or 0.03716t. Applying these values to the EDT formula would produce a foliar incidence of 2.8%, indicating that fungicide applications for the control of brown spot and powdery mildew control must begin when the disease incidence reaches 2.8%. The EDT considers the disease monitoring in the field. In the above example, the fungicide applications decisions only happens with 2.8% of brown spot and powdery mildew foliar incidence in the GS 31. The EDT is a technical and economic criterion for technological decision-making, indicating the better moment for fungicide application. According to REIS & CASA (2009), EDT is an integrated disease management tool to valorize the professional works in the field. The EDT value generally is not fixed and therefore varies according to the commercial price of barley grain, the fungicide control price and the fungicide efficiency. Therefore, it is important to continue research in different locations, growing seasons and cultivars to generate more DFE for barley foliar diseases to assist in fungicide decision making based on the EDT.

CONCLUSION

The relation between foliar incidence and severity by simultaneous occurrence of brown spot and powdery mildew and the barley BRS Cauê cultivar grain yield generated five incidence and severity DFE with their respective coefficients of determination (R^2), totaling 20 linear equations in 2009 and 2010 growing seasons in Southern Brazil. The incidence was useful to evaluate the diseases when the epidemics were still in the early stages and, in this situation, could be correlated with the severity. All DFE were significant and negative, where the increase of diseases symptoms reduced the grains yield according to the GS. DFE were used to calculate the EDT as a criterion to indicate the fungicide application moment to control the diseases in cultivars similar to 'BRS Cauê' in Southern Brazil.

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