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Review

Predicting winter wheat yields by comparing regression equations

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A B S T R A C T

The aim of this study was to determine a statistical model described by regression equations as a tool for predicting the reduction in winter wheat yields as a function of the degree of pathogenic damage to the flag leaf and first leaf under the flag leaf at the stage of full heading, at growing sites with varied conditions. The study was carried out in the years 2007–2009, at two locations in the Wielkopolska region of Poland. The research was based on one-factor experiment on winter wheat, variety Tonacja. The method is based on the adaptation of the procedure of comparing of parallelism and separation for regression equations. These results indicated that expressing the yield as a function of the degree of infection by pathogens by means of a single regression equation is a process that requires several stages, entailing comparison of the regression coefficients and, independently of that, comparison of the intercepts (distances between hyperplanes). Determination of regression equations may be used as a tool for determining yield reduction, but it requires the consideration of factors including habitat conditions, leaf type and location. The program package R (3.0.2) was used for the calculations.

Contents

1. Introduction

Increasing concerns about the adverse environmental effects of fungicides mean that alternative substances and methods for combating diseases and pests are being sought, in addition to other solutions enabling a reduction in the use of fungicides and in expenditure on plant protection products. Wheat is affected by numerous agricultural pests, which every season cause reductions in yields and grain quality (Bottalico and Perrone, 2002). According to published data (Afzal et al., 2007; Bailey at al., 2000; Blandino and Reyneri, 2009; Cooke, 2006; Haidukowski et al., 2005; Murray et al., 1998; Verreet et al., 2000; Mercer and Ruddock, 2005; Bockus et al., 2010), estimated crop losses resulting from lack of protection or its inappropriate application range from several to several dozen percent. Significant diseases of wheat include eyespot (*Oculimacula* spp.), fusarium ear blight and blight of the stalk base and roots (*Fusarium* spp.), blight of the stalk base caused by *Gaeumannomyces graminis*, powdery mildew

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Table 1
Analysis of variance to test the parallelism and separation of c regression lines.

Source of variation	DF	Sum of squares	Mean squares	F-ratio
Combined regression	1	$\hat{\mathbf{y}}^{*\prime}\hat{\mathbf{y}}^{*}$ - G	$\hat{\mathbf{y}}^{*\prime}\hat{\mathbf{y}}^{*}$ - G	
Between intercept	c-1	G-S_2	(G-S_2)/(c-1)	F_2 or F_3
Between regression	c-1	S_2−S_1	(S_2−S_1)/(c-1)	F_1
General regression	N-2	G	G/(N-2)	
Common regression residuals	N-c-1	S_2	S_2/(N-c-1)	
Combined regression	N-2c	S_1	S_1/(N-2c)	
for kth group	N_k-2	$SS_{e,k}$	$SS_{e,k}$/(N_k-2)	
Total	N-1	$\hat{\mathbf{y}}^{*\prime}\hat{\mathbf{y}}^{*}$		

(*Blumeria graminis*), brown rust (*Puccinia triticina*), tan spot (*Pyrenophora tritici-repentis*), Septoria leaf blotch (*Mycosphaerella graminicola*), Septoria nodorum blotch (*Phaeosphaeria nodorum*), and locally also yellow rust (*Puccinia striiformis*) (Murray et al., 1998; Verreet et al., 2000; Santos et al., 2013; Bockus et al., 2010). The environment in which the plant grows may significantly affect its susceptibility to attack by pathogens and the level of their activity (Walters and Bingham, 2007). Knowledge of the environmental factors that influence infection and subsequent Fusarium development is essential for assessing the potential disease risks and for developing efficient disease management strategies (Moschini et al., 2001). Crop rotation is a fundamental control measure to counter plant diseases because it reduces the monoculture of one crop species over large areas (Kutcher et al., 2011; Lori et al., 2009). High concentration of nitrogen often increases susceptibility of plants to diseases (Agrois, 1997; Krnjaja et al., 2015), e.g., high soil nitrogen promoted Fusarium species in wheat and supplementary nitrogen applied as ammonia, increased the disease (Martin et al., 1991). When planning the combating or reduction of pathogenic fungi, it is necessary to take account of multiple factors which may increase the effectiveness of the treatment (Finckh, 2008; Strange and Scott, 2005). The determination of damage thresholds in relation to various agricultural pests, including pathogens, is a very important element of integrated plant protection, which involves the parallel application of a full set of available methods. The main idea behind integrated plant protection is to limit the introduction of foreign chemical compounds into the environment, thus helping to protect it and also to improve soil fertility (Swanton and Weise, 1991; Boller et al., 2004). In the context of the development of sustainable agriculture and integrated plant protection, the development of mathematical models to forecast yield losses resulting from pathogenic infection in plants may prove a fundamental tool in decision-making concerning methods of protection. The choice of an appropriate mathematical model will very likely enable a grain producer to predict potential crop losses resulting from the infection of plants by fungal diseases.

The aim of this study was to determine a statistical model described by regression equations as a tool for predicting the reduction in winter wheat yields as a function of the degree of pathogenic damage to the flag leaf and first leaf under the flag leaf at the stage of full heading, at growing sites with varied conditions.

2. Materials and methods

In the years 2007–2009, at two locations in the Wielkopolska region of Poland – the PSD IOR PIB Winna Góra experimental station and the Strzelce Borowo Plant Breeding Centre – a controlled micro-field (1 m^2) experiment was carried out with the Tonacja variety of winter wheat. The wheat was grown at sites with soil in different agronomic categories (Borowo: IIIa, Winna Góra: IVa). In the single-factor experiments with four replications the dependence of the yield on the degree of damage to the first leaf under the flag leaf (F2 leaf) and flag leaf (F1 leaf) in BBCH stages 55–59 (from the stage with half inflorescence emerged up to the end of the heading stage) was observed. The dependence of the yield on the degree of damage was analysed based on four degrees of damage (0%, 30%, 50%, 100%). The control consisted of healthy plants with full leaves. The analysis was in fact performed using the proportion of the leaf surface area which was not affected by fungal disease, respectively 100%, 70%, 50% and 0%. At BBCH stages 31 and 49 standard fungicidal protection was applied to all plants. To simulate fungal damage to plants, mechanical reduction of the F2 and F1 leaves was carried out, which has largely the same effect as the natural reduction in assimilative surface area caused by pathogens infecting the leaves. Either 30% or 50% of the leaf surface area was removed as appropriate, or the leaves in question were removed completely, for all plants in the field.

The weather conditions in the study years were variable, and a particularly unfavourable distribution of rainfall in the period of critical water requirement for cereals, compared with the long-term average, was recorded in 2008. Rainfall in May of that year amounted to 38% of the long-term average at both Borowo and Winna Góra. On the other hand, the rainfall in June 2009 was very high, reaching 115% of the long-term average for Borowo and 198% for Winna Góra.

At the full maturity stage (BBCH 92) the yield of wheat grain was determined for each micro-field. Based on the yields recorded at both locations and the simulated reduction in the degree of damage done to the plants by fungal disease, a statistical analysis was carried out on the results.

The analysis consisted of three stages, of which the aims were: (i) to determine the particular regression equations; (ii) to compare the regression coefficients; and (iii) to compare the intercepts (see Caliński and Malec, 1976; Pereira et al., 2012), see Table 1. In the first stage, the regression relations for the degree of damage to the F2 and F1 leaves, depending on the location of the experimental site, were considered separately. By a method of backward stepwise

Table 2
Coefficients of the regression equation $y = \beta_{0k} + \beta_k x$ and their significance.

		Year	β_{0k}	β_k	R^2
Series 1	Borowo	2007	765.876 ***	220.047	0.226
	F2 leaf	2008	948.522 ***	132.172	0.057
		2009	740.094 ***	307.783 *	0.306
Series 2	Borowo	2007	727.146 ***	192.689	0.178
	F1 leaf	2008	907.483 ***	162.359·	0.202
		2009	739.033 ***	173.349 *	0.251
Series 3	Winna Góra	2007	530.566 ***	50.865 *	0.343
	F2 leaf	2008	715.843 ***	79.794	0.139
		2009	845.104 ***	115.148	0.047
Series 4	Winna Góra	2007	519.638 ***	68.082	0.169
	F1 leaf	2008	715.063 ***	97.428	0.077
		2009	761.564 ***	167.499	0.144

Significance codes: 0***, 0.001**, 0.01*, 0.05, 0.1.