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SCIENCE DIRECT
Crop Protection 25 (2006) 1013–1023
Crop Protection
www.elsevier.com/locate/cropro

Characterization of multiple disease systems and cultivar susceptibilities for the analysis of yield losses in winter wheat

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Received 18 October 2005; received in revised form 23 December 2005; accepted 30 January 2006

Abstract

The relationship between winter wheat (*Triticum aestivum* L.) cultivar susceptibility to four main fungal diseases, multiple disease systems, and yield loss (YL) levels was studied. Data from 276 wheat cultivar trials carried out in major wheat-growing areas in France over 12 years (1991–2002) were analyzed. Two variables were defined for each disease: actual disease intensity, referring to individual cultivar and potential disease intensity for each trial, calculated from the disease intensities measured on susceptible cultivars. Cultivar was represented by its level of susceptibility to each disease, previously given by GEVES and based on a semi-quantitative scale. YL was estimated for a given cultivar as the difference between the mean yield of fungicide-protected and of untreated plots. Nonparametric multivariate analysis provided a characterization of relationships among variables. Eight cultivar susceptibility profiles (CP), five potential disease profiles (PDP), and six actual disease profiles (ADP) were determined by cluster analysis. Correspondence analyses led to a good description of variation in YL when potential or ADP were considered. General linear models were developed for each of the five PDP, which involved a significant interaction between CP and PDP on YL. These empirical models provided a means of quantifying the effects of CP on YL. These models represent a practical tool to support choices for multiple-disease resistances in a given area, depending on the prevailing disease profile. Results from this study can also be used to improve the disease module of an agronomic model for wheat aimed at designing "cultivar × crop management" combinations for a given environment and cost/price ratio.

Keywords: Winter wheat; Multiple disease system; Host plant susceptibility; Cluster analysis; Correspondence analysis; Yield loss assessment

1. Introduction

Owing to the cost of fungicide and their perceived negative environmental impact, the use of cultivars resistant to diseases can represent a major tool for reducing yield losses (YL) due to diseases. Major efforts are therefore devoted to the development, release and use of wheat cultivars resistant to one or several diseases worldwide (Line and Chen, 1995; Lonnet, 1997; Bockus et al., 2001). The responses of cultivars to diseases are routinely assessed in research or extension trial plots subject to the prevailing diseases (see, e.g., Wagoire et al., 1998; Kurt, 2002). In such plots, YL of resistant cultivars may be dramatically lower than those of their susceptible counterparts. However, each of these trials is a particular case. YL due to diseases depend on the combinations of diseases occurring, which may depend on trial-specific crop management and year-specific climatic conditions. It is therefore difficult to use results from these trials to predict the yields (and YL) of cultivars.

Interactions between patterns of multiple diseases and cultivar susceptibility profiles (CP) on YL should be considered when choosing the cultivars best adapted to specific areas or cropping systems. Here, we define a CP as a group of cultivars that share common susceptibilities to diseases. Four main fungal diseases are prevalent in winter wheat in France: septoria tritici blotch (*Mycosphaerella graminicola*), brown rust (*Puccinia triticina*), yellow rust (*Puccinia striiformis*), and powdery mildew (*Blumeria*

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doi:10.1016/j.cropro.2006.01.013

graminis). The maritime climate of much of France and the large proportion of arable land under wheat favour the development of these diseases. The wheat cultivars grown differ in terms of the proportion of total area they represent and their levels of resistance to diseases. Furthermore, the dominant combination of diseases may differ markedly between regions and between years.

A variety of approaches may be used to assess the effects of multiple-disease systems on crop losses, including principal component analysis, canonical correlation and multiple regression analysis, discriminant analysis, analysis of variance from experiments with a factorial design, and correspondence analysis (Madden, 1983; Madden and Nutter, 1995). Savary et al. (1995) discussed the usefulness of correspondence analysis for studies of crop YL. This type of analysis is applied to categorised data (e.g. low, moderate, high disease severity). It is particularly useful if some variables cannot be determined on a continuous scale (Savary and Zadoks, 1992). This method has been used in rice-based systems, to achieve an overview of relationships between pest profiles, patterns of cropping practices and yield levels (Savary et al., 2000a, b). In this article it is proposed to use it on winter wheat in order to predict the YL due to diseases in France by considering CP and combinations of foliar diseases.

The aims of this study were (1) to characterize representative cultivar profiles based on their susceptibility to diseases, (2) to define common combinations of diseases that may be found in wheat fields in France, (3) to use correspondence analysis to explore relationships among the variation in YL, multiple disease profiles, and CP, and (4) to generate estimates of quantitative YL in relation to varying patterns of multiple diseases and different CP.

2. Material and methods

2.1. Field trials and the winter wheat database

Data were obtained from the wheat cultivar trials carried out by GEVES (the Research and Control Group for Cultivars and Seeds, France) from September 1990 to August 2002. Each year, 99–142 cultivars (including six–nine reference cultivars tested over several successive years, and 90–133 new cultivars tested for only 1 or 2 consecutive years) were tested in 56–99 trials across most of the major wheat-growing areas in France. These experiments typically involved split–plot designs with two or three replicates, with the main plots corresponding to fungicide treatment/nontreatment and the subplots corresponding to cultivars. Fungicide treatments were designed to suppress all disease attacks. Individual plots were 8–10 m^2 in area.

For each cultivar, the grain yield at 85% dry matter was measured in each plot for all replicates, with and without fungicide. Disease intensities for brown rust were measured at the milky to dough stage (GS 75–85 (Zadoks et al., 1974)), whereas septoria tritici blotch, yellow rust and powdery mildew intensities were measured between heading and flowering (GS 50–69). As cultivars differed in earliness, observations for a given disease were made on the same date, once more than half the cultivars in a trial had reached the growth stage concerned. Both disease severity (% diseased leaf area) and incidence (% diseased plants) were considered when assessing disease intensity, which was scored from 0 (no disease) to 8 (very high disease intensity) (Crespin and Soyer, 2002).

The database includes four groups of variables (Table 1): (1) cultivar susceptibility to each disease, from 0 (very resistant) to 8 (very susceptible); (2) potential intensity of each disease in each trial, from 0 (no disease) to 8 (very high); (3) actual intensity of each disease on each cultivar, from 0 (no disease) to 8 (very high); and (4) YL.

Cultivar susceptibilities to brown rust, yellow rust and powdery mildew were measured by GEVES, using inoculation trials, and trials with main plot corresponding to fungicide-free/fungicide trials in major wheat-growing areas for two successive years (Mistou, 2001). For cultivar susceptibility to septoria tritici blotch, inoculation trials have only been carried out by GEVES since 2000. Susceptibility to septoria tritici blotch was thus estimated

Table 1
List of variables in the database of winter wheat trials

Variable type	Symbol	Variable description
Cultivar	Ses	Cultivar susceptibility to septoria tritici blotch
	Mis	Cultivar susceptibility to powdery mildew
	Brs	Cultivar susceptibility to brown rust
	Yrs	Cultivar susceptibility to yellow rust
Potential diseases	Sep	Score of the intensity of septoria tritici blotch on susceptible cultivar[a] in a trial
	Mip	Score of the intensity of powdery mildew on susceptible cultivar[b] in a trial
	Brp	Score of the intensity of brown rust on susceptible cultivar[c] in a trial
	Yrp	Score of the intensity of yellow rust on susceptible cultivar[d] in a trial
Actual diseases	Sea	Score of the intensity of septoria tritici blotch on every cultivar in a trial
	Mia	Score of the intensity of powdery mildew on every cultivar in a trial
	Bra	Score of the intensity of brown rust on every cultivar in a trial
	Yra	Score of the intensity of yellow rust on every cultivar in a trial
Yield loss	Yl	Yield loss

[a]Sidéral and Trémie were firstly selected as susceptible cultivars. If both cultivars were present in the same trial, disease intensity was then characterized by taking the higher of the scores for these two cultivars. Récital was used as a susceptible cultivar only for the trials in which Sidéral and Trémie were not tested.
[b]Récital.
[c]Soissons.
[d]Thésée, Ami and Récital.