Crop Protection 106 (2018) 182–189

Contents lists available at ScienceDirect

Crop Protection

journal homepage: www.elsevier.com/locate/cropro

Fungicide treatments in winter wheat: The probability of profitability

A. Djurle*, E. Twengström[1], B. Andersson

Dept. of Forest Mycology and Plant Pathology, Swedish University of Agricultural Sciences, Box 7026, SE-750 07 Uppsala, Sweden

ARTICLE INFO

Keywords:
Leaf blotch diseases
Logistic regression
ROC curves
Field trials

ABSTRACT

The marginal return of fungicide applications against leaf blotch diseases in winter wheat fields were analysed based on data from field trials performed in 1996–2011 in Sweden. Yield increases from fungicide treatments were compared with data on growing conditions (precipitation, previous crop, nitrogen fertilization, soil type, and disease severity) using logistic regression. After identification and quantification of single factors with good predictive ability, multiple factor models were analysed. A model with five factors; rain days in April/May and three weeks before ear emergence, disease severity at ear emergence, soil type and previous crop, identified situations when a fungicide treatment gave a positive marginal return. The sensitivity and specificity of the model was evaluated by using receiver operating characteristic (ROC) curves.

1. Introduction

Leaf spot or leaf blotch fungi are often used as common names for the fungi causing tan spot; *Pyrenophora tritici-repentis* (Died.) Drechs. (Syn. *Drechslera tritici-repentis*), septoria tritici blotch; *Zymoseptoria tritici* (Desm.) Quaedvlieg and Crous (Syn. *Mycosphaerella graminicola, Septoria tritici*) and stagonospora nodorum blotch; *Parastagonospora nodorum* (Berk.) Quaedvlieg, Verkley and Crous (Syn. *Phaeosphaeria nodorum, Stagonospora nodorum*) in wheat. In Europe, leaf blotches are among the most economically important diseases in winter wheat, and yield losses up to 5–15 dt per hectare have been recorded (Jørgensen et al., 2014). In Sweden, septoria tritici blotch is the most widespread of these three diseases, and the main target for fungicide applications between stem extension and ear emergence (Wiik, 2009a). Tan spot dominated in the middle central parts of the country in the 1990's, but comes second to septoria tritici blotch nowadays. Stagonospora nodorum blotch was more common in the 1980's, and after playing a minor role for several years, an increased incidence is reported in the last five years. Wheat cultivars commonly grown in Sweden lack good resistance to leaf blotch diseases.

Humid weather provides favourable conditions for the development of leaf blotch diseases (Eyal et al., 1987; Djurle et al., 1996). Conidia of *Z. tritici* and *P. nodorum* are dispersed by water splash while dispersal of *P. tritici-repentis* conidia may be through both wind and water splash. The major sources of inoculum are infected crop residues in the field and wind-borne ascospores (Duczek et al., 1999; Mehra et al., 2015; Sommerhalder et al., 2010; Suffert et al., 2011). For *P. tritici-repentis* and *P. nodorum* seed borne inoculum is an additional source (Schilder and Bergstrom, 1995; Shah et al., 1995). In Sweden chemical seed dressing of winter wheat is done as a routine in conventional agriculture resulting in seed borne inoculum having minor importance. For management of the leaf blotch complex the growers' options are cultivation practices such as crop rotation, choice of resistant cultivars (if available), tillage, adjustment of sowing time in the autumn, and fungicide applications. The use of fungicides still remains an important, acute, control measure when preventive disease management tools have not had sufficient effect. In Sweden one fungicide treatment at ear emergence is often enough to control leaf blotch diseases. In Southern Sweden two treatments are done in some years.

Due to large variations in net return from fungicide treatments, between fields and years (Djurle and Bommarco, 2014; Jørgensen et al., 2017; Wiik and Rosenqvist, 2010), it is difficult to make decisions on the need of fungicide application in individual fields. Growers want reliable information for their decision making. This points to a need for reliable disease forecasts, or other tools, in order to direct the use of fungicides to situations when it is biologically and economically justified. For the growers' marginal return, in the long run, and as part of a strategy to reduce the risk of substantial problems with fungicide resistance, these justifications are necessary. This is also a corner stone of integrated pest management as expressed in the EU directive on the sustainable use of pesticides (Anon, 2009). Without tools that can capture the variability at a satisfactory level, there is a risk that fungicides will be applied as a routine, ignoring other concerns.

Analysis of field and disease data from field trials, in combination with weather data, have a big potential in contributing to a better understanding of the pathosystem, and to more accurate predictions of

---

* Corresponding author.
E-mail address: Annika.Djurle@slu.se (A. Djurle).

[1] Present address: Hemse Sindarve 310, SE-623 50 Hemse, Sweden.

https://doi.org/10.1016/j.cropro.2017.12.018
Received 27 June 2017; Received in revised form 13 December 2017; Accepted 14 December 2017

the need for fungicide treatments. Systems for disease prediction are often based on disease, incidence or severity, or weather factors (Jørgensen et al., 2014), but aside from that, methods and tools for decision support are designed in many different ways, and the predictions are calculated from various additional factors. A common characteristic is that the prediction models are empirically based which reduces their reliability, especially if used in areas with conditions different from those where the system was developed (Yuen et al., 1996).

Objective valuations of qualitative and quantitative factors, their importance to the outcome of the dependent variable, and the relationships between factors in their respective effects on the dependent variable, can be quantified by using logistic regression. A logistic regression model relates the odds of an event to the various factors. This is done by relating the logarithm of the odds of the predicted outcome (i.e. the logit of the predicted probability of the outcome) to a linear combination of the different factors. Depending on how the model is parameterized, this method predicts either the odds or the odds ratio of the outcome being studied (Yuen et al., 1996). The aim of this project was to objectively identify qualitative and quantitative factors, and different combinations thereof, that describe when a fungicide treatment at ear emergence against leaf blotch diseases in winter wheat could be profitable, i.e. the marginal return (yield increase) should cover the costs of a treatment. Important factors were identified and their relative importance estimated. The factors were combined in a multiple factor model which could be used in the development of decision tools.

2. Materials and methods

Data were collected from > 500 field trials in winter wheat 1996–2011. The trials were placed in farmers' fields and subject to the farmers' choice of cultivar, fertilization, and other management. The trials had a randomized complete block design with four replicates. The original aim of the trials was to study the effect of different fungicides on leaf blotch diseases and yield response depending on fungicide dose and application date. From each of these trials, the untreated control and one fungicide treatment with a standard product (used as a reference), at full recommended dose at DC 55–59 (Zadoks et al., 1974) were selected. The analysis was based on treatment means. All winter wheat growing areas in Southern and Central Sweden were represented. Field data consisted of information on disease records, cultivar, soil type, previous crops two years back in time, planting time, and nitrogen fertilization. All field factors available from the data set were grouped by assigning them to different levels related to their respective values or characteristics.

Disease, reported as disease severity of all leaf blotches combined, was recorded on the three uppermost leaves (F, F-1 and F-2) on plants at stem elongation between DC 32–37, at ear emergence (DC 50–59), and at the end of the season (DC 75–80) (Zadoks et al., 1974). Soil types were analysed in groups based on their clay content. The amount of applied nitrogen fertilizer (kg/ha) was differentiated at two to three levels with varying ranges. Agroecological zones in Sweden were used to define regions.

Winter wheat was the previous crop in 124 fields, barley or oats in 75 fields, spring wheat in 7 fields, and triticale in 1 field. In the remaining 139 fields, 13 different crops were represented, whereof 46 fields had legume crops and 54 had oilseed rape as the previous crop. The grouping of data was based on the relatedness between hosts and host range for the pathogens causing leaf blotch diseases. At least 23 wheat cultivars were represented in the data set. Among these, only 12 occurred in more than 10 trials. None of the cultivars were grown during the whole time period, and their distribution varied geographically. The majority of the cultivars were in the medium range of susceptibility to leaf blotch diseases. Due to lack of variation in cultivar susceptibility, and inconsistent information on planting date, no grouping of these factors was possible, and they were therefore not analysed.

Table 1
Precipitation factors summarised from the day of fungicide treatment and backwards in time, and used for analysis of the marginal return of fungicide treatments against leaf blotch diseases in winter wheat.

Factor, daily values	Factor, accumulated values
Precipitation, mm	Precipitation, mm over 7, 14, 21, 28 day windows
Precipitation > 0 mm	Precipitation, number of days with rain > 0 mm over 7, 14, 21, 28 day windows
Precipitation in April/May	Precipitation, number of days 2 and 3 weeks in April/May

Rainfall data was collected from weather stations run by the Swedish Meteorological and Hydrological Institute (SMHI) according to the location of the field trials. The weather data consisted of daily values of precipitation, and from these new factors spanning over longer time periods were created (Table 1). The time periods were shifted depending on the geographical location of the field trials. Thus comparisons could be made with the wheat being in the same development stage (or range of DC's) irrespective of location. The new precipitation factors, calculated from observed data, were the sum of rainfall and the sum of rain days over periods of 7–28 days going back in time from the day of fungicide application (DC 55–59). In order to account for effects on disease development due to early summer drought, precipitation data from 2 to 3 weeks in April–May, ending c:a one month before ear emergence, was used. The levels of rainfall and rain days currently used as a base for treatment recommendations by the Swedish extension service, 20–30 mm of rain or > 4–5 days with rain from the second node stage (DC 32), were included in the analysis for comparison (Gustafsson, 2017).

During the first years of the project, the analysis was based on yield increase from a single treatment with the fungicide Amistar, (azoxystrobine, 250 g/L) at a rate of 1 L per hectare at ear emergence (DC 55–59). This treatment was a standard treatment and applied in more than 250 of the trials. In several trials, during the latter part of the time period covered, reduced doses of Amistar were sometimes used. Analyses showed that the yield increases from using Amistar in the doses 1.0 l/ha, 0.8 l/ha, 0.75 l/ha and 0.5 l/ha were not significantly different from each other, while a significantly lower yield increase was obtained with the dose 0.25 l/ha. From each trial only the treatment with the highest dose of Amistar was included in the analysis. After year 2004, Amistar was no longer used unless in combination with other substances due to reports on problems with fungicide resistance. The triazole Proline (prothioconazole, 250 g/L) replaced Amistar as the standard treatment in the field trials conducted after 2004, and thus also in our analyses. During a short time period of overlap between these two fungicides in the field trials, no significant differences in effect on disease or yield were observed. Although the two fungicides belong to different groups, Amistar is a QoI (quinone outside inhibitor) fungicide and Proline is a DMI (demethylation inhibitor) fungicide, both have good effect on spore germination, penetration and mycelial growth.

The treatment costs were based on the costs for machinery, labour, fungicide, and wheel track damage. Machinery and labour cost were set to 163 SEK/ha, fungicide cost was 400 SEK/litre and wheel track damage 1% of yield. (www.agriwise.org, Folkesson and Twengström, 2003). These are the marginal costs for a single fungicide treatment, and thus other costs of growing wheat were not included. All calculations were made in Swedish crowns (SEK), where 100 SEK corresponds to c:a 10 Euro or 12 USD. The wheat price was set to 1 SEK/kg.

Treatment cost = (labour cost + (dose x fungicide cost) + yield x wheel track damage)) / wheat price in SEK per kg.

The data contained both quantitative and qualitative information,