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Economics of a decision–support system for managing the main fungal diseases of winter wheat in the Grand-Duchy of Luxembourg

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ABSTRACT

We evaluated the cost effectiveness of a decision–support system (DSS) developed for assessing in real time the risk of progression of the main fungal diseases (i.e., Septoria leaf blotch, powdery mildew, leaf rusts and Fusarium head blight) of winter wheat in the Grand-Duchy of Luxembourg (GDL). The study was conducted in replicated field experiments located in four agricultural locations (representative of the main agro-ecological regions of the country) over a 10-year period (2003–2012). Three fungicide spray strategies were compared: a single DSS-based system and two commonly used spray practices in the GDL, a double- (2T) and a triple-spray (3T) treatment; there was also a non-treated control. In years with a high disease pressure, the DSS-based recommendation resulted in protection of the three upper leaves comparable to that achieved with the 2T and 3T treatments, with significant grain yield increases ($P > 0.05$) compared to the control (a 4 to 42% increase, depending on the site and year). Overall, the financial gain in treated plots compared with the control ranged from 3 to 16% at the study sites. Furthermore, in seasons when dry weather conditions precluded epidemic development, the DSS recommended no fungicide spray, reducing use of fungicide, and thus saving the cost of the product. The gain in yield for the 2T and 3T plots (compared with control) did not necessarily result in a financial gain during the duration of the experiment. This study demonstrates the potential advantages and profitability of using a DSS-based approach for disease management.

1. Introduction

Winter wheat (*Triticum aestivum* L.) is the most important grain crop grown in the Grand-Duchy of Luxembourg (GDL). The area under winter wheat in 2013 was 13,410 ha, with a total production of circa 86,433 metric tons (Ministère de l'Agriculture, 2014). Wheat protection in the GDL largely relies on early fungicide applications before appearance of severe symptoms that might reduce yield. Fungicides are routinely applied to control fungal diseases so as to prevent yield losses due to pathogens, to delay the senescence of the upper leaves or in some cases, to comply with the recommendations from the mill industry, thereby maximising economic returns. Generally, two to three fungicide treatments are applied during crop growth. The first spray is applied early in the season (during stem elongation), and aims to control early season diseases including powdery mildew (WPM, caused by *Blumeria graminis* DC. f. sp. *tritici* em. Marchal) and eyespot (caused by *Pseudocercosporella herpotrichoides* (Fron) Deighton). This fungicide application is often done in combination with herbicide or fertilizer applications. A second fungicide application typically aims to protect the flag leaf from Septoria leaf blotch (SLB, caused by *Zymoseptoria tritici* (Desm.) Quaedvlieg & Crous). Since early-developing epidemics of *Z. tritici* (approximately 245 days after sowing) are more destructive than late epidemics (with epidemic outbreaks around 270 days after sowing (approximately 270 days after sowing), an accurate forecast of infection for early epidemics is of particular concern (Beyer et al., 2012). A third application is sometimes applied at early flowering in order to protect the wheat crop against infection by *Fusarium* head blight (FHB, primarily caused by *Fusarium graminearum* Schwabe). Apart from these targeted fungal diseases, rusts [i.e., leaf rust (WLR) and stripe rust (WSR), caused by *Puccinia triticina* Roberge ex Desmaz. and *P.*

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striiformis Westend, respectively] have become of increasing economic concern over the last decade (El Jarroudi et al., 2009b, 2012b).

Decision–support systems (DSS) based on plant disease forecast models are increasingly used in integrated disease management programs (Knight, 1997; Moreau and Maraite, 2000; Verreet et al., 2000; Wegulo et al., 2011; El Jarroudi et al., 2014b). DSS help by limiting potentially harmful side effects of fungicide applications while ensuring economic benefits (Fabre et al., 2007; Shtienberg, 2013). Indeed, a major incentive in adoption of DSS by farmers is related to the cost advantages over conventional strategies (Wearing, 1988; Langvad and Noe, 2006; Fabre et al., 2007). Decision rules (i.e., tactical models) designed to provide farmers with binary advice ("treatment is needed" or "it is not worth the cost") are considered to be cornerstones for the implementation of DSS in integrated disease management programs (Hughes, 1999; Way and van Emden, 2000; McCown, 2002).

In Europe, including the GDL, the main fungicide groups used to control foliar fungal pathogens of wheat include the strobilurins and triazoles (EUROSTAT, 2007), both of which have a broad spectrum of activity. Chlorothalonil (a nitrile) has multi-site activity and good efficacy against the main pathogen *Z. tritici* (Beyer et al., 2011), and it is used in tank mixtures to delay the emergence of fungicide resistance. Recently, a new generation of succinate dehydrogenase inhibitors with excellent efficacy towards *Z. tritici*, but poor performance against *F. graminearum* (Dubos et al., 2013) and *Fusarium culmorum* (Pasquali et al., 2013), became available. A DSS based on different models for infection and progress was developed and validated for the main fungal diseases in the GDL [e.g., SLB (El Jarroudi et al., 2009a), WPM (El Jarroudi et al., 2011), and WLR (El Jarroudi et al., 2014a,b)]. This DSS determined (1) whether fungicide use was needed at all, and if so determined, (2) the best application time for a single treatment based upon the models' outputs and expert knowledge. Considering public awareness concerning environmental pollution (water quality, ecosystem sustainability, environmental pressure exerted by agriculture, climate change), and the increasing regulatory demand from national and international institutions and policy makers (national governments, non-governmental organisations, The European Commission, etc.), the assessment of the profitability of any crop protection strategy is of great importance. The main objective of this study was to assess the profitability of a single fungicide treatment recommended through the DSS, by protection provided to the three upper leaves of winter wheat, compared with conventional two or three spray fungicide regimes.

2. Materials and methods

2.1. Overview of the decision–support system

The DSS relies on (i) the mechanistic PROCULTURE model to simulate the emergence of the five last leaves as well as the availability of *Z. tritici* inoculum to infect those leaves (Moreau and Maraite, 1999, 2000; El Jarroudi et al., 2009a); (ii) an approach for predicting WLR and WSR infection and progress based on night weather variables (El Jarroudi et al., 2004, 2014a), and (iii) a model for simulating the progress of WPM (El Jarroudi et al., 2011). The inputs used for simulating the infection periods and progress of SLB, WLR, WSR and WPM are hourly meteorological data (i.e. maximum and minimum air temperatures, relative humidity, and rainfall) and observed disease incidence and severity. Meteorological variables were collected during the growing season using automatic meteorological stations located near each study site (≤1 km). The assessment of severity of fungal diseases was conducted weekly throughout the growing season. The need for and timing of the single fungicide spray using the DSS was based on the observed disease severity earlier in the cropping season [i.e., at growth stages (GS) 31–37 (Zadoks et al., 1974), or on the lower leaves L5–L4, L1 being the flag leaf], the susceptibility of the cultivars, past and forecasted weather conditions, and the predicted development of leaves based on the output of the PROCULTURE model. Furthermore, historical data (weather and disease incidence and severity) were used as a basis for similarity analysis to further evaluate the risk of severe disease development. Given a threshold level of observed disease severity (on the lower leaves) and weather conditions (actual and forecasted), an advice for fungicide treatment was taken and fungicides applied if required to protect the upper leaves. For example, for 5% emergence of L3 coinciding with SLB symptoms on L5 and a rainfall event, there is an increased risk that L3 will become diseased with SLB by full emergence. Thus a fungicide treatment for SLB is recommended if 75% of a latency period is completed combined with favourable weather conditions forecasted. When different fungal diseases are observed, the relative importance in severity of each of the diseases is first evaluated. A combined treatment (i.e. tank mixtures) is recommended for protecting the upper leaves against the predominant diseases, if required. For example, if SLB and WLR are observed on L5 at the emergence of L3, or moderate to high severity of SLB is observed on L5, associated with at least 5% severity of WLR on L3, a tank mixture (triazoles and strobilurins in this case) is advised and should be applied to susceptible cultivars when forecasted weather is favourable for disease. If different diseases develop at different times, or there is a second outbreak, a risk assessment is made based on the field management practices (previous crop), the susceptibility of the cultivar to the disease, and historical examples, taking into account any effect of the remaining fungicide from the first application. If there is a high risk of the new disease outbreak affecting grain yield, a second fungicide treatment may be advised (thus in this situation two treatments will be recommended using the DSS).

2.2. Experimental fields and data collection

Experiments were carried out in fields of winter wheat at four locations in the GDL [Burmerange (50°3′N, 6°1′E), Christnach (49°47′N, 6°15′E), Everlange (49°29′N, 6°19′E), and Reuler (50°11′N, 5°15′E)] during the 2003–2012 growing seasons. Agronomic details of the trials are given in Table 1. The experimental design was a complete randomized block with four replicates (one replicate plot = 12 m^2). Each fully randomized replicate block consisted of fungicide treated and non-treated (control) plots. The different fungicides applied, and the wheat GS when treated (each treatment was associated with a specific GS) are given in Table 2. The GS were assessed according to the Zadoks' decimal code (Zadoks et al., 1974). The fungicides used were commercially available and applied according to the manufacturer's recommendations. Crop management (sowing and harvest methods, fertilisation and weed control) was done as described previously (El Jarroudi et al., 2009a, 2012a).

During the 2003–2012 cropping seasons, two to three fungicide treatments were tested at each site (Table 2). They included a single DSS-based treatment, a double (2T) spray treatment, and a triple (3T) spray treatment. The 2T and 3T treatments represent common practice for fungicide use in winter wheat in the GDL (Guy Reiland, Personal comm.). Note that 3T was included after the 2005 cropping season in order to protect the wheat crop against infection by FHB and was not tested during the 2003–2005 period.

The meteorological data, recorded at 10 min intervals, were automatically retrieved from a web-based database system (www.agrimeteo.lu) and processed using an automatic data processing chain for quality check and gap filling. As hourly intervals were needed for running the disease forecast models, the 10-min