Forecasting of Fusarium head blight and deoxynivalenol content in winter wheat with FusaProg*

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Fusarium head blight is one of the most serious cereal diseases of the world. Epidemics of Fusarium head blight can lead to a decline in grain quality and yield. In addition, grains often become contaminated with mycotoxins, which are harmful to humans and animals. In a field survey of winter wheat in Switzerland, *Fusarium graminearum* proved to be the most prevalent species responsible for head blight and deoxynivalenol the most common mycotoxin. To elucidate and quantify single or combined effects of cropping factors on *F. graminearum* infestation and to reduce the risk of mycotoxin contamination of wheat under conservation tillage, we developed the decision support system FusaProg. Our model takes into account the effects of cropping factors, previous crops, soil and straw management, as well as the *F. graminearum* susceptibility of the planted variety. These factors are used as driving variables and are combined with the prevailing weather conditions and growth stage in order to predict the deoxynivalenol content of a specific wheat plot before harvest. To use FusaProg as a threshold-based tool to control *F. graminearum* with optimized timing of fungicide applications, forecasts of deoxynivalenol contents are conducted during the flowering period. FusaProg is an Internet-based decision support system which not only provides information about the local and regional *F. graminearum* infection risks; it also forecasts plot-specific deoxynivalenol contamination of winter wheat. In 2006, the system was evaluated by Swiss cantonal plant protection officers, and in 2007, the system will be made available to Swiss wheat producers.

Introduction

Fusarium head blight, caused by different Fusarium species, is one of the most serious cereal diseases worldwide (Parry *et al*., 1995; McMullen *et al*. 1997; Bottalico & Perrone, 2002). Fusarium head blight infection can lead to a decline in grain quality and yield (Parry *et al*., 1995). In addition, grains may be contaminated with mycotoxins, which are harmful to humans and animals (McMullen *et al*., 1997; Bennett & Klich, 2003). In Switzerland, Fusarium head blight is mainly caused by *Fusarium graminearum* Schwabe (Schachermayr & Fried, 2000).

Harvest residues of host plants, especially maize debris, are an ideal substrate for the development of fruiting bodies of *Gibberella zeae* (Schw.) Petch, the sexual stage of *F. graminearum* Schwabe. These perithecia develop under wet and relatively warm weather conditions and release ascospores which are dispersed by air or rain splash to wheat ears. Anthesis is a period of increased susceptibility of ears to *Fusarium* infection. Ascospores germinate and hyphae penetrate the wheat floret, colonize the seed and may produce mycotoxins. The most common toxin associated with *F. graminearum* infected grains is deoxynivalenol.

To avoid substantial mycotoxin contamination, farmers need a combination of efficient cultivation measures to prevent infections by *Fusaria* and to control *F. graminearum* with fungicides if necessary. Fungicide trials have shown that efficient control of Fusarium head blight depends not only on the active components of the fungicide and the dose rate used, but also on the time of application (Parry *et al*., 1995; Forrer *et al*., 2000; Pirgozliev *et al*., 2003; Hecker *et al*., 2004). Decision support systems are useful tools for a targeted control of pathogens (Schepers, 2002). In order to learn more about the influence of cropping factors on *F. graminearum* infestation and deoxynivalenol contamination in winter wheat and thus, to improve cropping systems, we developed the Internet-based decision support system FusaProg. FusaProg is an aid to assess the risk of *F. graminearum* infestation and deoxynivalenol contamination in winter wheat on a local and regional scale.

Materials and methods

Collection and analysis of weather data

Hourly measured and forecasted (24 h) data from 60 stations of the national weather service 'MeteoSwiss' and private weather

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Table 1 Example of weather conditions, which define a high (1) or medium (0.25) weather-based infection risk in the FusaProg system.

	Model 1	Model 2	Model 3–6*
Current day			
Ø mean temp.	≥ 15 C°	≥ 15 C°	...
Ø mean rh percentage	≥ 85%	≥ 75 C°	...
sum of precipitation	≥ 3 mm	≥ 0 mm	...
Day before			
Ø mean temp.	≥ 10 C°	≥ 10 C°	...
sum of precipitation	≥ 0 C°	≥ 3 mm	...
risk of infection	1	0.25	...

*Model 3–6: other weather models, which are included in our system, but not shown in this table.

stations are transferred on a daily basis to our server. On the server, data are automatically analyzed for periods conducive for *F. graminearum* infection according to our FusaProg weather rules. The processed data is then forwarded to and stored on a public server via FTP.

Weather rules

To assess the weather-based infection risk for a particular day, weather data from this day and also the day before is analyzed (Table 1). For the plot-specific deoxynivalenol risk assessment, weather conditions during the last three days as well as the weather forecast are taken into account. The following three parameters are taken into consideration: daily mean temperature, sum of precipitation and daily mean of relative humidity (at 2 m height).

Programming and funding

The programming was performed in collaboration with the Swiss company 'MSI Dr Wälti AG Buchs (SG)'. The program was installed on a public Internet server to facilitate access to all users (*www.fusaprog.ch*).

Definition of key factors for the development of *Fusarium graminearum*

A Swiss *F. graminearum*/deoxynivalenol survey conducted in the canton Aargau (AG) in winter wheat from 2001 to 2004 served as background for the definition of key factors which are important for the development of *F. graminerarum* (Forrer *et al*., in preparation).

Results of morphologically-based seed health tests obtained from this study showed that *F. graminearum* was the most prevalent *Fusarium* species, followed by *F. poae* and *F. avenaceum* (Forrer *et al.,* in preparation). Furthermore, previous crop, type of tillage and susceptibility of the variety are important factors for the infestation by *F. graminearum* and subsequent deoxynivalenol contamination (Hecker *et al*., 2004; Vogelgsang & Forrer, 2006). Disease incidence with *F. graminearum* and deoxynivalenol contamination was highest in samples from fields with maize as previous crop, no-tillage, and varieties with medium to high *F. graminearum* susceptibility. The deoxynivalenol content was closely correlated with the incidence of *F. graminearum* in wheat grains.

Based on these findings, results from our own straw management and fungicide trials, and literature, we defined different key factors referred to in our FusaProg model as: last two previous crops, susceptibility of the variety, soil and straw management, growth stage and weather conditions. To predict the risk for *F. graminearum* infection and deoxynivalenol contamination, the system considers these key factors as well as the prevailing weather conditions.

Results and discussion

FusaProg model

To calculate a plot-specific risk of deoxynivalenol contamination, all factors mentioned above have to be considered. First a specific field is classified to one of the four types of cropping systems: with or without maize in the previous crop; with ploughing or minimal tillage. Deoxynivalenol values, typical for each of these four cropping systems were derived from the Swiss survey and are used as primary input for the field-specific deoxynivalenol calculation. These basic deoxynivalenol values are subsequently corrected by the different factors influencing the disease and deoxynivalenol contamination such as previous crops, as well as straw, soil, and seedbed management. Consequently, the predicted deoxynivalenol contamination is a function of the basic deoxynivalenol value, field-specific crop management, growth stage of the wheat and weather conditions (Fig. 1).

We developed FusaProg as an Internet-based information system. Plant protection officers and farmers will have access at *www.fusaprog.ch* and will be able to register at the beginning of the growing season (Fig. 2).

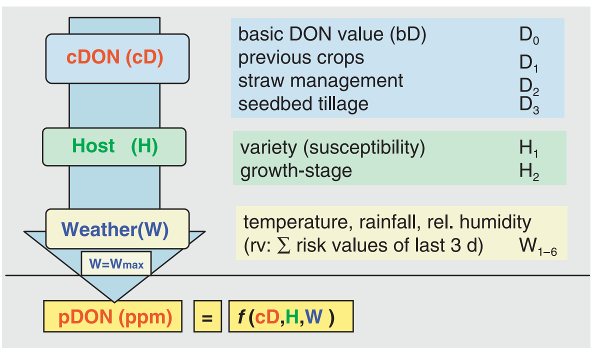

Fig. 1 Flow chart of the key factors and parameters which are considered in the Internet-based FusaProg system. bD = basic DON value: values derived from Swiss *F. graminearum*/DON survey, cDON = cropping system-related DON value, pDON = predicted DON value, rv = risk value.

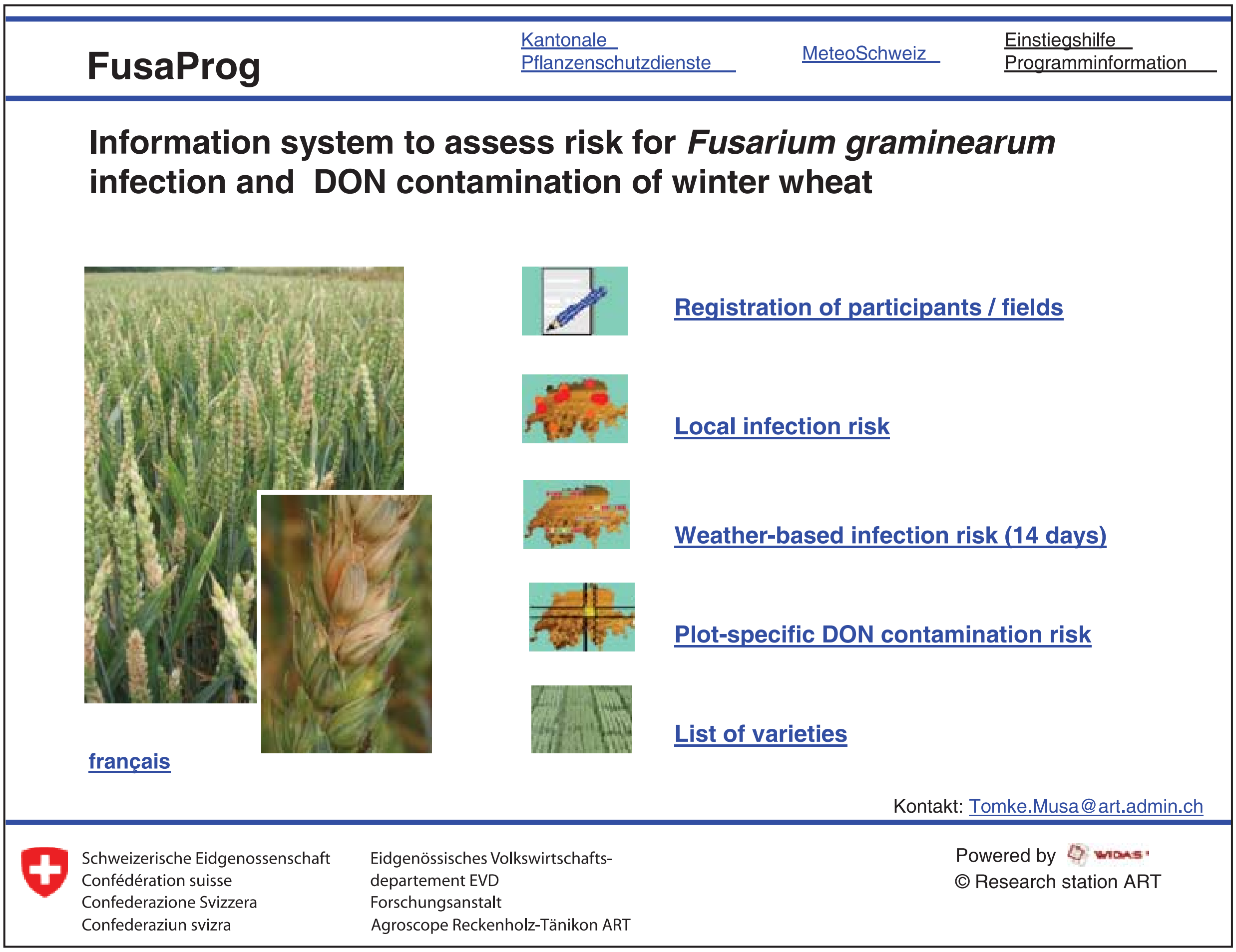

Fig. 2 Homepage of the information system FusaProg (www.fusaprog.ch).

To predict a plot-specific *F. graminearum* infection and deoxynivalenol contamination risk, plot-specific characteristics as mentioned above have to be entered into the FusaProg system during the first log-in. Fixed parameters, for example the location of the field and the wheat variety, have to be entered only once. However, the changing parameter 'growth stage' has to be updated on a regular basis, since the risk of infection depends strongly on this aspect.

The system automatically allocates a weather station to each registered field to assess the weather-based infection risk. This allocation is based on geographical distances between the weather station and a particular wheat field. If desired, the allocated weather station can be manually changed by the user.

FusaProg outputs

After registration, a variety of information is offered to the participants. They can view a map of Switzerland showing the regional weather-based infection risk. For each meteorological station, this infection risk is presented for the last three days (Fig. 3). In addition, an overview of the daily weather-based infection risk within the last 14 days for each single weather station is available. Furthermore, a forecast of the infection risk for the current day is also included in this overview (Fig. 4).

By selecting the menu item 'plot-specific deoxynivalenol contamination risk', FusaProg will predict the risk of deoxynivalenol contamination for a chosen wheat field by considering the key factors and weather conditions as described above. In order to relate the predicted deoxynivalenol value to the calculation, the impact of each single factor is graphically depicted (Fig. 5). Furthermore, deoxynivalenol contamination risk during the whole flowering period is summarized in a separate webpage.

So far, recommendations for fungicide treatments have not been integrated, as our overall goal is to reduce deoxynivalenol contamination risk mainly by optimizing cultivation measures. For 2007, a fungicide application threshold was defined at 0.5 ppm deoxynivalenol, i.e. should FusaProg predict a deoxynivalenol contamination risk equal to or higher than 0.5 ppm, a fungicide treatment is recommended.

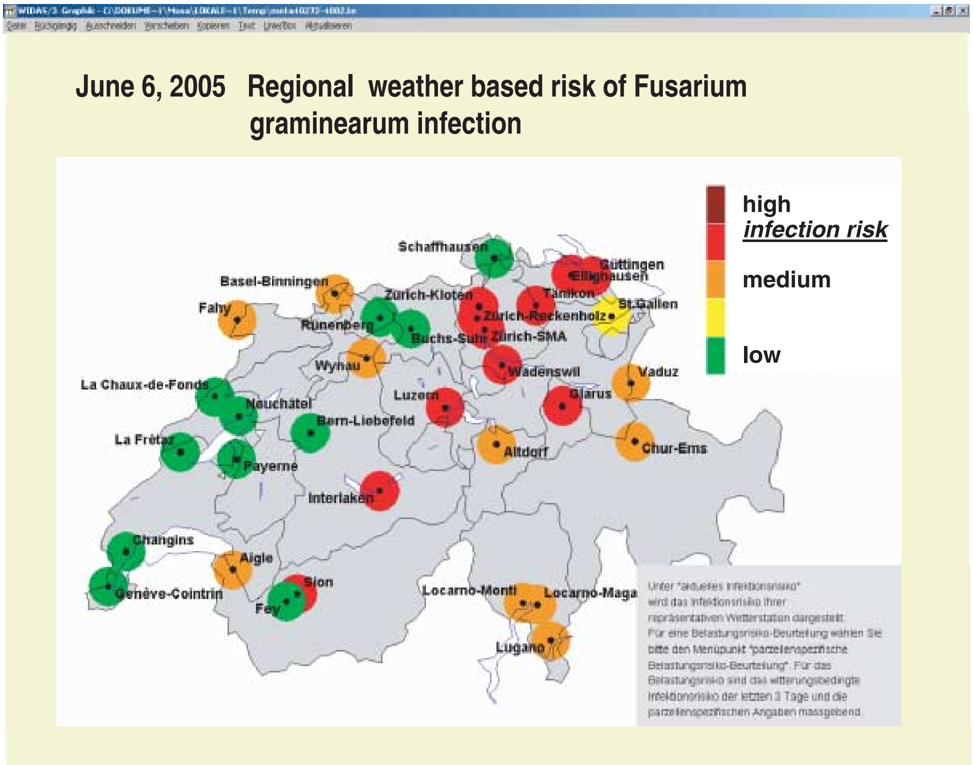

Fig. 3 Regional weather-based infection risk displayed on a map of Switzerland.

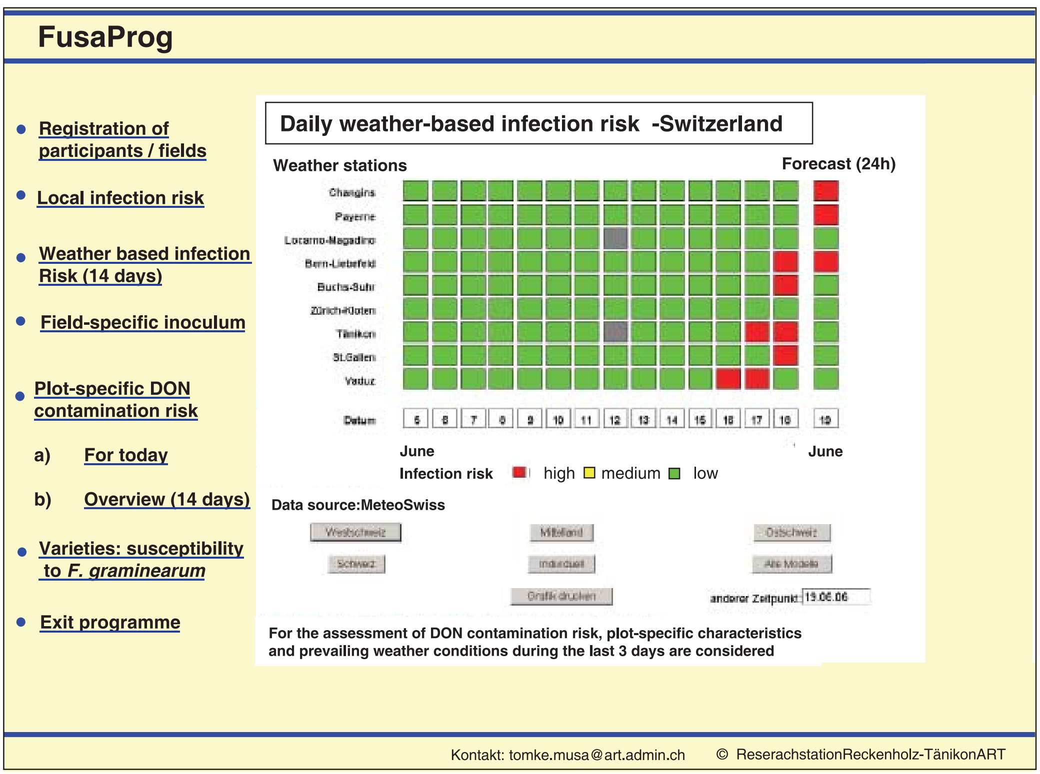

Fig. 4 Daily weather-based infection risk for single weather stations. Colour index: green = no risk, yellow = medium risk, red = high risk.

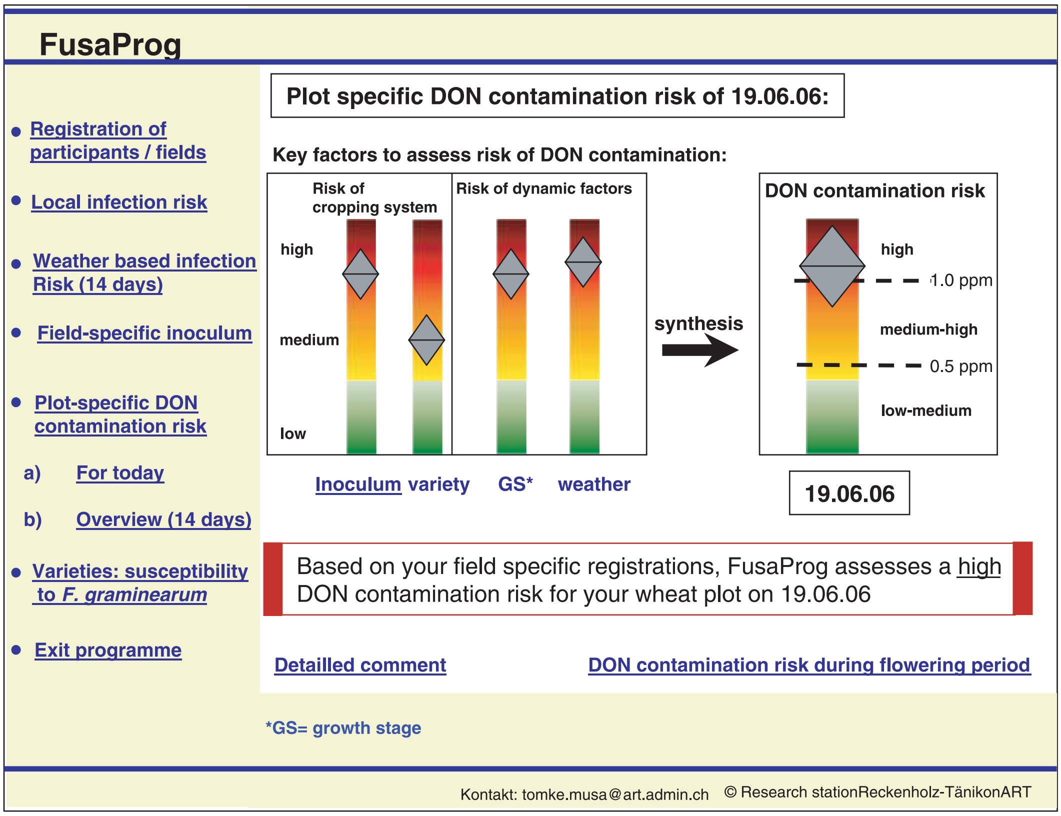

Fig. 5 Example of a plot-specific DON contamination risk with the single depicted key factors.

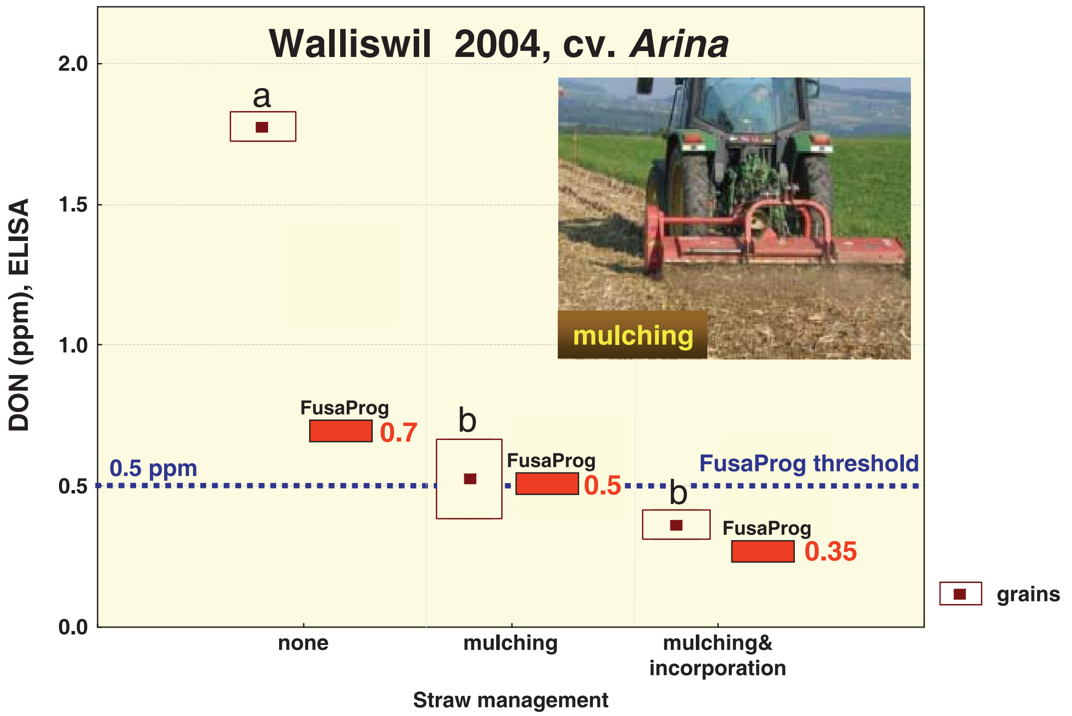

Fig. 6 Comparison of forecasted DON contamination by FusaProg and ELISA-measured DON values in wheat grains of a field trial with different residue and soil management practices at Walliswil (Kt. BE) in 2004. ■ measured DON values, ■ forecasted DON content with FusaProg.

With one of the menu items, users have the possibility of changing key factors: for example, they can look at their potential field situation if they would have used a less susceptible wheat variety or another soil management. Hence, growers can discover how to minimize deoxynivalenol contamination risk and use FusaProg as a support tool.

Validation of FusaProg

During the growing seasons 2004 and 2005, winter wheat fields with different residue and soil management practices, including no-tillage, fine mulching with or without surface incorporation, were used to validate FusaProg. The system proved to be a useful tool for daily forecasting of the regional weather-based infection risk. In 78% out of 23 cases, FusaProg accurately predicted a deoxynivalenol content below or above the critical threshold of 0.5 ppm (Fig. 6). The first validation of FusaProg was very promising; however, the number of trials was small. On-farm trials with different straw and soil management practices were repeated in 2006. In addition, a greater number of grain samples from commercial wheat fields were collected. Seed samples are currently analysed by morphological and ELISA tests to determine the *Fusarium* species present. Moreover, spore traps were placed in wheat fields to evaluate the correlation between ascospore sampling and weather conditions in our weather-based infection risk model. These results will be used to adapt weather rules if necessary.

As a conclusion, we believe that FusaProg is a useful and practical tool for the development of cropping strategies to reduce *F. graminearum* infection and deoxynivalenol contamination risk under conservation tillage. By using the Internet system, participants can obtain information in an easy and rapid manner about the *F. graminearum*/deoxynivalenol situation of their own wheat fields. In the near future, we will focus on further improvements in terms of practicability and accuracy.

Acknowledgements

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Prévoir l'occurrence de la fusariose des épis et la teneur en déoxynivalénol du blé d'hiver avec FusaProg

La fusariose des épis est une des maladies des céréales les plus importantes dans le monde. Les épidémies de fusariose des épis peuvent conduire à une diminution de la qualité du grain et du rendement. En outre, les grains sont souvent contaminés par des mycotoxines, qui sont dangereuses pour l'homme et les animaux. Au cours d'une étude au champ sur blé d'hiver en Suisse, *Fusarium graminearum* s'est révélé l'espèce responsable de la fusariose la plus fréquente et le déoxynivalénol la mycotoxine la plus commune. Pour élucider et quantifier les effets simples des facteurs culturaux et leurs interactions sur une attaque de *F. graminearum* et pour réduire le risque de contamination du blé par des mycotoxines en culture sans labour, nous avons développé le système d'aide à la décision FusaProg. Notre modèle prend en compte les effets des facteurs culturaux, des cultures précédentes, de la gestion du sol et des pailles, ainsi que la sensibilité de la variété à *F. graminearum*. Ces facteurs sont utilisés comme variables d'entrée, combinées avec les conditions climatiques dominantes et les stades de développement afin de prédire la teneur en déoxynivalénol d'une parcelle de blé avant sa récolte. Afin d'utiliser FusaProg pour définir des seuils d'intervention contre *F. graminearum* avec une optimisation de la période des applications fongicides, des prévisions des teneurs en déoxynivalénol au cours de la période de floraison ont été proposées. FusaProg est un système d'aide à la décision disponible sur Internet qui ne donne pas seulement des informations sur les risques locaux et régionaux d'infection par *F. graminearum* mais prévoit aussi la contamination du blé d'hiver en déoxynivalénol pour des parcelles spécifiques. En 2006, le système a été évalué par les agents des services cantonaux de la protection des végétaux en Suisse ; le système sera rendu accessible aux producteurs de blé suisses en 2007.

Прогнозирование фузариоза колосьев и содержания деоксиниваленола на озимой пшенице с помощью системы FusaProg

Во всем мире фузариоз колосьев считается одним из наиболее серьезных заболеваний злаковых культур. Эпидемии фузариоза могут приводить к снижению качества зерна и урожайности. Кроме того, зерно зачастую заражается микотоксинами, которые вредны для людей и животных. В ходе полевого обследования озимой пшеницы в Швейцарии *Fusarium graminearum* оказался наиболее распространенным видом, вызывающим фузариоз колосьев, а деоксиниваленол оказался наиболее распространенным микотоксином. Для прояснения ситуации и количественной оценки индивидуальное или совместное воздействие факторов выращивания на заражение *F. graminearum* и снизить опасность засорения микотоксином пшеницы, выращиваемой с противоэрроозионной обработкой почвы, была разработана система содействия принятию решений FusaProg. Модель этой системы включает факторы выращивания, предыдущие сельскохозяйственные культуры, обращение с почвой и соломой, а также восприимчивость сорта к *F. graminearum*. Эти факторы используются как определяющие переменные и сочетаются с преобладающими погодными условиями и стадиями роста культуры для прогнозирования содержания деоксиниваленола на конкретном участке пшеницы перед жатвой. Для использования системы FusaProg в качестве основанного на пороговом значении средства для борьбы с *F. graminearum* при оптимизированном времени применения фунгицидов уже на стадии цветения были проведены прогнозы

содержания деоксиниваленола. FusaProg представляет собой систему содействия принятию решений на базе интернета, предоставляющую не только информацию о местных и районных рисках заражения *F. graminearum*, но и прогноз заражения озимой пшеницы деоксиниваленолом на уровне конкретного участка. В 2006 г. проводилась оценка этой системы кантональными сотрудниками швейцарской фитосанитарной службы, а, начиная с 2007 г., эта система поступит на вооружение швейцарских производителей пшеницы.

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