Prediction Model for Deoxynivalenol in Wheat Grain Based on Weather Conditions

Marie VÁŇOVÁ[1], Karel KLEM[1], Pavel MATUŠINSKÝ[1] and Miroslav TRNKA[2]

[1]Agrotest Fyto, Ltd., Kroměříž, Czech Republic; [2]Mendel University of Agriculture and Forestry in Brno, Brno, Czech Republic

Abstract: Environmental factors influence the growth, survival, dissemination and hence the incidence of *Fusarium* fungi and the disease severity. The knowledge of the quantitative and qualitative effects of environmental factors and growing practices on initial infection, disease development and mycotoxin production is important for prediction of disease severity, yield impact and grain contamination with mycotoxins. The objective of this study was to design a model for prediction of deoxynivalenol (DON) content in winter wheat grain based on weather conditions, preceding crop and soil cultivation. The grain samples from winter wheat field experiments conducted in 2002–2005 to determine the effect of preceding crop in combination with soil cultivation on Fusarium head blight infection were analysed for the DON content. Average daily weather data (temperature, rainfall, relative humidity) were collected using an automated meteorological station and analysed separately for April, May and a 5 days period prior to the beginning of flowering and 5 days after the beginning of flowering. The correlation coefficients of DON content to weather data were calculated for monthly data prior to heading and 5 days data prior to and after the beginning of anthesis. Highest positive correlation coefficients were found for sum of precipitation in April, average temperature in April, and sum of precipitation 5 days prior to anthesis. Significant negative correlation was found for average temperature in May and average relative humidity 5 days prior to anthesis. Using the data from this experiment, we trained neural networks for prediction of deoxynivalenol content on the basis of weather data and preceding crop. The most appropriate neural network model was then coupled with AgriClim model to simulate spatial and temporal variation of DON content in wheat samples for south Moravia and north-east Austria area.

Keywords: prediction model; mycotoxin DON; winter wheat; weather conditions

In compliance with guidelines of good agricultural practice principles, farmers are compulsory to produce health safe raw materials for food and feeding use. Meeting this requirement depends on thorough control and providing optimum production and technological conditions that eliminate potential accumulation of health hazardous substances in raw material for production of foods or feeds. However, agroecosystem is an open system in which the presence of filamentous microscopic fungi is a common and inevitable fact. Under certain conditions, these fungi are able to produce secondary metabolites with significant impact on human health that are generally called mycotoxins. At present, the most important fungi from this point of view are species of the genus *Fusarium.* The knowledge of the quantitative and qualitative effects of environmental factors on initial infection, disease development and subsequent mycotoxin production is important for predicting the disease risk and mycotoxin contamination. Environmental factors influence the growth, survival, dissemina-

Supported by the Ministry of Agriculture of the Czech Republic, Projects No. QF 3121 and QG 50041.

tion and hence the incidence of *Fusarium* fungi and the disease severity. In wheat, environmental effects accounted for 48% of the variation in deoxynivalenol (DON) content, followed by variety (27%) and preceding crop (14–28%) (Schaafsma *et al.* 2005).

Hooker *et al.* (2002) have shown that for *F. graminearum* infection the environmental parameters are crucial in determining infection and contamination with DON. Two key periods for Fusarium head blight (FHB) infection could be indicated during spring vegetation. The first one is important for production and dispersal of asexual conidia and sexual ascospores of *F. graminearum* and includes early spring period up to anthesis initiation. The second one is much shorter and covers the time of flowering. This period is important for spike infection. In both cases higher temperatures and higher relative humidity or rainfall are favourable for final disease severity. Sometimes abundant rainfall during grain filling can considerably contribute to heavy FHB infection (Lacey *et al.* 1999).

Several groups have tested prediction models based on meteorological observations to manage FHB (Hooker *et al.* 2002; De Wolf *et al.* 2003), but these models often underestimate effect of early spring weather conditions which are in the Czech Republic highly variable and often limiting for both conidia and ascospores production.

The objective of this study was to design a model for DON prediction in winter wheat grain based on weather conditions and preceding crop.

MATERIALS AND METHODS

Grain samples from winter wheat field experiments conducted in 2002–2005 to determine the effect of soil cultivation in interaction with preceding crop on Fusarium head blight (FHB) infection were analysed for the DON content. Small-plot field experiments with winter wheat were conducted at the location of Ivanovice in 1994–2007. Three soil cultivation systems were used prior to sowing:

– tillage to the depth of 22 cm,
– shallow cultivation with discs (10 cm),
– and no-till sowing.

The experiments were sown following two preceding crops:

– lucerne as non-host crop,
– and maize as host crop.

A new method employing high-performance liquid chromatography coupled with tandem mass spectrometry (LC-MS/MS) was used for the determination of trichothecene mycotoxin DON.

Average daily weather data (temperature, rainfall, relative humidity) were collected using an automated meteorological station and analysed separately for April, May and a 5 days period prior to the beginning of flowering and 5 days after the beginning of flowering.

The weather data were correlated to DON content in grain separately for each parameter. To analyse a multiple effect of several weather parameters on DON content, the artificial neural network was trained on the dataset using neural network procedure in Statistica 7.0 software. The neural networks were trained using back propagation learning algorithms. The winning neural network was selected on the basis of minimised sum of square deviations between predicted and observed data. The most appropriate neural network was coupled with AgriClim model enabling to calculate predicted values of DON content for individual years at 50 locations in south Moravia and north-east Austria from known meteorological data.

RESULTS

The correlation of DON content to weather data was done for monthly data prior to heading and 5 days data prior to and after the beginning of anthesis (Table 1). The highest positive correlation coefficients were found for sum of precipitation in April, average temperature in April, and sum of precipitation 5 days prior to anthesis. Significant negative correlation was found for average temperature in May and average relative humidity 5 days prior to anthesis.

Using the data from this experiment, we trained neural networks for prediction of DON content on the basis of weather data as continuous and preceding crop as categorial input variables. The winning neural network with architecture ZRNS 5:5-12-2-1:1 works with five input variables: categorial variable preceding crop and continuous variables average April temperature, sum of April precipitation, average temperature 5 days prior to anthesis, sum of precipitation 5 days prior to anthesis. Reliability of prediction using neural network can be seen from Figure 1, representing

Table 1. Correlation coefficients for individual weather variables and DON content in grain (experiment with soil cultivation)

Weather variable		*P*	Weather variable	*P*
Average temperature	April	0.53*	Average temperature 5 days prior to anthesis	0.27
	May	–0.42*	Sum of precipitation 5 days prior to anthesis	0.52*
Sum of precipitation	April	0.66*	Average relative humidity 5 days prior to anthesis	–0.57*
	May	0.40	Average temperature 5 days after anthesis	–0.31
Average relative humidity	April	–0.01	Sum of precipitation 5 days after anthesis	0.31
	May	–0.23	Average relative humidity 5 days after anthesis	0.25

*$P < 0.05$

fit of observed and predicted data. One of the most important input parameters is categorial preceding crop and continuous variable sum of precipitation 5 days prior to anthesis. The effect of sum of precipitation 5 days prior to anthesis starts from the limit of 15 mm. Other two important parameters critical for perithecia formation are average temperature and sum of rainfall in April. Generally the DON content is increasing with temperature and precipitation rise. The production of DON is suppressed at average April temperatures below 9.5°C with continuous increase in DON content up to average temperatures around 11°C. The simulation on 50 locations and two years (2003 and 2004) shows that simulated data have higher spatial variability of DON content in year with generally higher DON contamination (Figures 2 and 3), and the results of simulation are in good coincidence with real situation of individual year.

DISCUSSION

The efforts to manage losses in grain quality, caused by *Fusarium* species producing mycotoxin DON, through soil cultivation have been proven not to be entirely successful and the effect of crop rotation is only supplemental to effect of environmental conditions. The DON content in wheat grain was mainly influenced by year. Such annual variation and dependence on weather conditions increase demand for qualified decision based on prediction models. FHB is well known as a disease strongly influenced by environmental conditions during flowering and grain filling (Lacey *et al.* 1999). Similarly, the environmental conditions play a leading role in the perithecia development on crop debris and ascospore release during spring vegetative period (Gilbert & Fernando 2004). The effect of soil cultivation was very small in

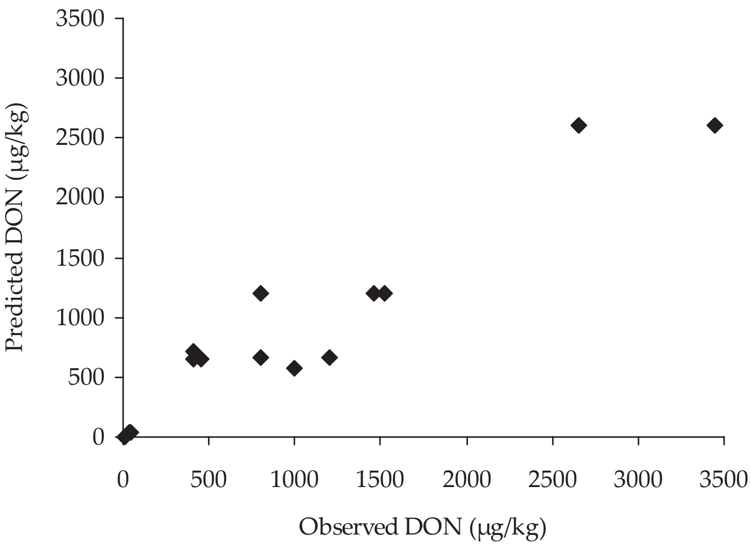

Figure 1. Graph of fit between observed and predicted (using neural network with weather input variables ZRNS 5:5-12-2-1:1) DON concentrations in grain

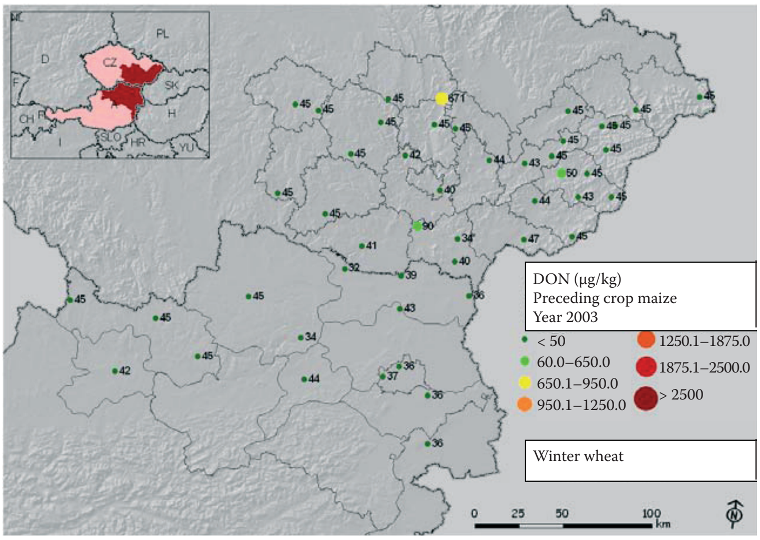

Figure 2. Values of deoxynivalenol content in wheat grain simulated by coupling of models for DON prediction and AgriClim for 50 locations in south Moravia and north-east Austria in 2003 and maize as preceding crop

most experimental years. These results show that the burial of crop residues plays a significant role only if the infection level is generally high. Dill-Macky and Jones (2000) found out only small differences in DON content between mouldboard plough, chisel plough, and zero till plots.

The correlation analysis shows that under relatively dry conditions of continental climate in the Czech Republic, one of very important factors for FHB infection and resulting DON formation, is the development of infection potential on preceding crop residues during early spring (April). Warm and humid early spring supports increasing infection and DON formation in winter wheat grain. Such conditions in the spring favour perithecial development and maturation on plant debris in time to produce ascospores concomitantly with the flowering of cereal crops (Suty & Mauler-Machnik 1996). Some studies (e.g. Fernando *et al.* 1997) concluded that FHB infection results mainly from primary infection and the secondary spread is of minor importance. Therefore, conditions favourable for perithecia development (relative humidity and temperature in April) could have higher impact than weather conditions around anthesis.

There is an interesting paradox in the correlation coefficients for relative humidity and sum of precipitation 5 days prior to anthesis. For the first parameter, the correlation is positive and for the second negative. This can be easily explained by optimum conditions for ascospore release from perithecia, i.e alternately wetting and drying. Paulitz (1996) suggested that perithecial drying during the day followed by sharp increases in relative humidity may provide the stimulus for release of ascospores.

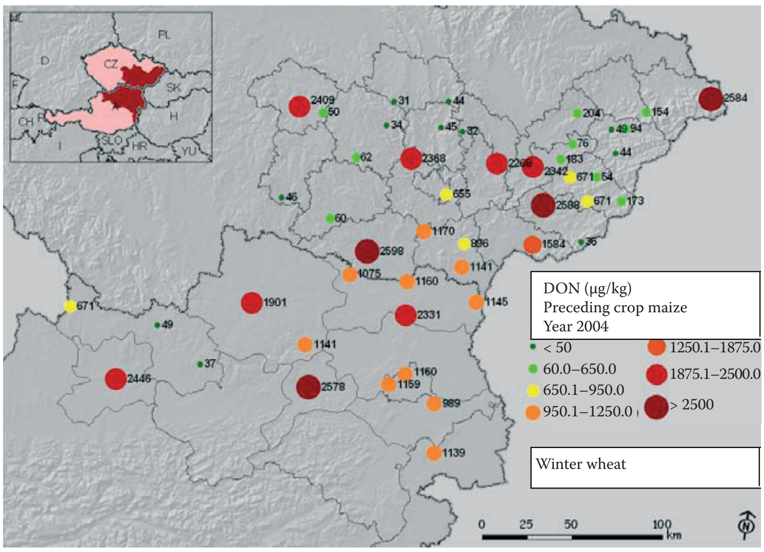

Figure 3. Values of deoxynivalenol content in wheat grain simulated by coupling of models for DON prediction and AgriClim for 50 locations in south Moravia and north-east Austria in 2004 and maize as preceding crop

Artificial neural networks have recently gained popularity in plant pathology mostly in forecasting models (De Wolf & Francl 1997; Chakraborty *et al.* 2004). The neural network prediction model developed in this study is based on categorial input variable preceding crop and continuous variables average April temperature, sum of April precipitation, average temperature 5 days prior to anthesis and sum of precipitation 5 days prior to anthesis. The main advantage of our model is that it integrates the effect of preceding crop, weather conditions on inoculum formation and weather conditions on ascospore release and infection process. Similar FHB epidemics forecasting model, based on hourly weather data (relative humidity, air temperature and rainfall) collected during the 7-day interval before flowering was developed by De Wolf *et al.* (2004). Based on our experimental results and indices in literature, we can summarise that variables representing the environment prior to anthesis may provide models with information about potentially limiting factors for inoculum production simultaneously with the direct effect on spike infection. High variation in local weather conditions shortly prior flowering and shift in flowering time is main reason for high spatial variation in DON content. This was well documented on simulations for 50 locations in south Moravia and north-east Austria and two consecutive years. While in 2003 simulated DON concentrations were low at all locations, in 2004 which was much favourable for FHB infection, simulated values varied from low to high concentrations. Such simulated variation shows need for location-based prediction of DON content generated from local weather data, timing of anthesis and preceding crop.

References

Chakraborty S., Ghosh R., Ghosh M., Fernandes C.D., Charchar M.J., Kelemu S. (2004): Weather-based prediction of anthracnose severity using artificial neural network models. Plant Pathology, **53**: 375–386.

De Wolf E.D., Francl L.J. (1997): Neural networks that distinguish infection periods in an outdoor environment. Phytopathology, **87**: 83–87.

De Wolf E.D., Madden L.V., Lipps P.E. (2003): Risk assessment models for wheat Fusarium head blight epidemics based on within-season weather data. Phytopathology, **93**: 428–435.

De Wolf E., Lipps P., Miller D., Knight P., Molineros J., Francl L., Madden L. (2004): Evaluation of prediction models for wheat Fusarium head blight in the U.S. In: Canty S.M., Boring T., Wardwell J., Ward R.W. (eds): Proceedings 2nd International Symposium Fusarium Head Blight, Orlando, 11–15 December, 2004.

Dill-Macky R., Jones R.K. (2000): The effect of previous crop residues and tillage on Fusarium head blight of wheat. Plant Disease, **84**: 71–76.

Fernando W.G.D., Paulitz T.C., Seaman W.L., Dutilleul P., Miller J.D. (1997): Head blight gradients caused by *Gibberella zeae* from area sources of inoculum in wheat field plots. Phytopathology, **87**: 414–421.

Gilbert J., Fernando W.G.D. (2004): Epidemiology and biological control of *Gibberella zeae/Fusarium graminearum.* Canadian Journal of Plant Pathology, **26**: 464–472.

Hooker D.C., Schaafsma A.W., Tamburic-Ilincic L. (2002): Using weather variables pre- and post-heading to predict deoxynivalenol content in winter wheat. Plant Disease, **86**: 611–619.

Lacey J., Batemann G.L., Mirocha C.J. (1999): Effects of infection time and moisture on development of ear blight and deoxynivalenol production by *Fusarium* spp. in wheat. Annals of Applied Biology, **134**: 277–283.

Paulitz T.C. (1996): Diurnal release of ascospores by *Gibberella zeae* in inoculated wheat plots. Plant Disease, **80**: 674–678.

Schaafsma A.W., Hooker D.C., Miller J.D. (2005): Progress and limitations with respect to pre-harvest forecasting of *Fusarium* toxins in grains. Phytopathology, **95**: S123.

Suty A., Mauler-Machnik A. (1996): Fusarium head blight on wheat – New findings on the epidemiology and control of *Gibberella zeae* the teleomorph of *Fusarium graminearum* with Folicur. Pflanzenschutz-Nachrichten Bayer, **49**: 55–70.

Corresponding author:

Ing. Marie Váňová, CSc., Agrotest fyto, s.r.o., Havlíčkova 2787/121, 767 01 Kroměříž, Česká republika
tel.: + 420 573 317 130, e-mail: vanova.marie@vukrom.cz