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# Multifactorial spatial analysis of mycotoxin contamination of winter wheat at the field and landscape scale

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ABSTRACT

An assessment of contamination of cereals with the *Fusarium* mycotoxins deoxynivalenol (DON) and zearalenone (ZEA) is difficult because of the complexity and interactions of various driving factors. We study the mycotoxin accumulation in winter wheat growing after maize or oilseed rape at different topographic positions within fields consisting of alternating hilltop and depression positions across a transect in the Uckermark region in the Northeast of German Lowlands. A linear mixed-effects model and censored regression are used to account for spatial autocorrelation and non-detects in determining factors controlling DON content in 304 samples from 19 fields in 2006 and 2007. Environmental factors (actual rainfall during the anthesis, long-term mean annual precipitation), topographic factors (relief position, topographic wetness index TWI) and management factors (tillage, preceding crop, susceptibility ranking of wheat cultivars to *Fusarium* spp.) as well as the year of investigation were included as explanatory factors in this analysis.

The spatial linear mixed-effects model indicates that DON on wheat fields with maize as preceding crop was one order of magnitude higher than in wheat grown after oilseed rape (significant at the 5% level). Tillage had a similar effect: Ploughing significantly reduced DON by more than one order of magnitude. Humid areas (mean annual precipitation >550 mm) showed a significantly higher DON contamination (3.7-fold increase) than the drier areas. TWI and topographic position had significant influences on DON levels. Their combined effect lead to a 68% higher DON at depressions with high TWI compared to hilltops with low TWI. The results of the censored regression were very similar to those of the mixed model. The susceptibility ranking score of the wheat cultivars to *Fusarium* infection did not have a significant influence on DON in these models. Overall, the statistical models revealed a combined influence of climatic, topographic, and crop management factors on DON concentration in winter wheat on different spatial scales for the environmental setting of our study area.



## 1. Introduction

Infections of cereals with phytopathogenic strains of *Fusarium* species cause serious foot rot and head blight diseases of small-grain cereals (Parry et al., 1995; Bottalico and Perrone, 2002). The intense development of these fungi in plants results in substantial losses in grain yield and a considerable deterioration of the grain quality. Therefore, Fusarium head blight (FHB) is one of the most economically important diseases of wheat (Placinta et al., 1999; Windels, 2000). Furthermore, the majority of *Fusarium* species isolated from wheat, barley and rye are capable of produce many toxic metabolites, including several trichothecenes and zearalenone (Bottalico and Perrone, 2002). The species *Fusarium* (*F.*) *culmorum* (W.G. Smith) Sacc. (teleomorph unknown) and *F. graminearum* Schwabe (teleomorph: *Gibberella zeae*) are widespread producers of the mycotoxins deoxynivalenol (DON), nivalenol (NIV) and zearalenone (ZEA) in northern humid temperate climates (Visconti et al., 1992; Mirocha et al., 1995). Their occurrence in feeds and foods is often associated with acute or chronic mycotoxicosis in

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farm and pet animals (Dänicke et al., 2004; Seeling et al., 2005; Séguin et al., 2010).

Toxin production by *Fusarium* species occurs mainly in the field. In general, the production of DON and ZEA by *F. culmorum* and *F. graminearum* is greatly influenced by genetic, environmental and agricultural management factors.

Minimum or no-tillage, introduction of crop rotation with high portion of cereals and maize, increased monocrop farming and low resistant level among the widespread wheat cultivars have been considered to be promotional factors which can dramatically increase the mycotoxin content of wheat (Sturz et al., 1997; Dill-Macky and Jones, 2000; Bateman et al., 2007; Maiorano et al., 2008).

The initial infection of a floret, following the spread to the spikelets on the same head, is preferred by humidity and temperatures favourable for hyphal growth (Ryu and Bullerman, 1999; Bateman, 2005; Xu et al., 2007). During the anthesis and the grain filling stages, humid conditions within the field could encourage the mycotoxin accumulation in grains and could originate from rainfall as well as from wet soils.

The infection behaviour and the mycotoxin production by Fusaria strains in crops is a multifactorial process. On the one hand, different driving factors could influence the risk for *Fusarium* infection and mycotoxin contamination, on the other hand the dispersal of the fungi determines the pathogen patterns within a field (Campbell and Noe, 1985; Chellemi et al., 1988). An understanding of its epidemiology in micro- and macroscale approaches should be combined with knowledge about the effects of several abiotic influences.

However, most of the studies are laboratory, plot trials and small-field experiments which reported a correlation between a single factor and the FHB infection rate and/or mycotoxin production (Beck and Lepschy, 2000; Lemmens et al., 2004; Heier et al., 2005; Bateman et al., 2007; Xu et al., 2007). Only a few studies in Europe (Bauer, 2000; Koch et al., 2006) and some DON forecast models in Canada (Hooker et al., 2002; Schaafsma and Hooker, 2007) examine the combined effects of several driving factors, the interaction between them or the relative importance of driving factors in a quantitative manner. Our study aims at filling this gap. We focussed on combined effects of different crop management practices (crop rotation, tillage, cultivar) with presumed most important abiotic drivers, i.e. climate, weather and topography. We chose the mycotoxin content in the harvested kernels as the dependent variable without consideration of the FHB disease incidence because mycotoxin concentration in unprocessed cereals are limited by the European Commission (EU, 2006) and an excess of the regulatory limits implies an economic loss for the farmers. Finally, we included field and landscape scale relationships in our study, both of which are of importance not only for better ecosystem understanding, but for practical purposes as well, e.g., precision agriculture.

## 2. Materials and methods

### 2.1. Study sites, soils, management and growing conditions

The study fields are located in the Uckermark region, in the Northeast Lowlands of Germany (state of Brandenburg). The glacial drift area is characterized by a hummocky terrain with ambient closed depressions. Soil landscapes of the study area show a complex soil pattern mainly influenced by relief and type of parent material, i.e. sands or marly glacial tills. A typical soil sequence (catena) shows Haplic or Stagnic Luvisols at ridges and slopes, Mollic Gleysols and Terric Histosols in depressions. This natural sequence is modified due to intense erosion–deposition processes, mainly by tillage and water. As a consequence eroded soils, like Haplic Regosols (calcaric), developed at hilltops and Colluvic Regosols found at footslopes, small depressions and hollows of the landscape (Schmidt, 1991; Sommer et al., 2008; Deumlich et al., 2010; soil classification according to WRB, 2006). Gleysols and Histosols often are covered by mineral topsoil material deposited from erosional processes in the catchment (Sommer, 2006).

Sampling took place at a total of 19 fields (10 locations) distributed along a 40 km west-east transect (Fig. 1a), which reflects a climatic gradient from wetter to drier conditions. Five locations were investigated each in 2006 and 2007. Two adjacent winter wheat fields (*Triticum aestivum L. emend. Fiori et Paol.*) were selected at each location: the preceding crop on one field was winter oilseed rape (*Brassica napus L.*), on the other maize (*Zea mays L.*). Within each field, eight sampling sites were placed at hilltop positions and in small topographic depressions, respectively (Fig. 1b).

The tillage treatments consisted of (i) mouldboard ploughing 30 cm deep or (ii) non-inverting soil techniques including shallow mixing 15 cm deep up to no-tillage or direct drilling (summarized as minimum tillage). The crops were managed according to standard agricultural procedures and good professional practice. Site-specific management (SSM) or precision farming procedures were not applied in any of the fields. Information on management procedures, the winter wheat varieties and their susceptibility to *Fusarium* infection is displayed in Table 1.

Each plot of 4 $m^2$ was harvested by hand at the ripening state Z92 (Zadoks et al., 1974). The grain was threshed by a mechanical threshing machine (HEGE-Parzellen-Mähdrescher, Wintersteiger Ried Austria). The amount of harvested kernels averaged from 2 to 3.5 kg at each plot.

### 2.2. Climate and weather conditions

The Uckermark is one of the driest regions in North-Central Europe (Wessolek and Asseng, 2006) with long-term annual precipitation between 450 and 600 mm. We used data on mean annual precipitation (1961–1990) as well as actual precipitation during anthesis (month of June) in each year of our study to characterize long-term and short-term humidity patterns across the study area (Table 1). Precipitation was interpolated from data measured at the nearest weather stations operated by Deutscher Wetterdienst (Germany) and by the Research Station of the Leibniz-Centre for Agricultural Landscape Research at Dedelow (Germany).

### 2.3. Topography

In a given climatic region topographic factors mainly determine the distribution of soil and air humidity at field scale. We chose two of them, i.e. topographic position and topographic wetness index. Sampling sites were situated between 17 and 170 m a.s.l. (2006) and 6.7 and 114.9 m (2007). Altitudinal differences within the fields ranged from 4.2 (Wit_maize06) to 88.3 m (Ded_maize06) in 2006, and from 6.7 (Pas_rape07) to 68.2 m (Ded_rape07) in 2007 (see Table 1).

The topographic wetness index (TWI) was used as an explanatory variable that characterizes the topographic position of the sampling sites and their potential soil humidity. It is derived from a digital elevation model (DEM) at a resolution of 25 m × 25 m provided by the Land Surveying Offices of the states of Brandenburg and Mecklenburg-Vorpommern. The TWI is intended to identify topographic conditions favouring flow accumulation and water infiltration (Beven and Kirkby, 1979; Sørensen et al., 2006). It is based on the local slope angle and the size of the topographic catch-