'Pests and Climate Change'
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Abstracts

Basics of climate change

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Our climate receives al lot of attention these days. According to many researchers, the climate is changing and this change is mainly caused by human activities. The Intergovernmental Panel on Climate Change (IPCC) states in its latest report that “most of the increase in globally averaged temperatures since the mid-twentieth century is very likely due to the observed increase in anthropogenic greenhouse gas concentrations" through an enhanced greenhouse effect. The background of the climate change and the enhanced greenhouse effect will be briefly discussed.
If we accept the conclusion that our climate is changing, the next question is what the effects will be. A general warming of the climate can have effects in many different ways. Will the weather be of the same character or will we get structural changes in weather patterns. Depending on the outcome, this may increase or decrease the effects of climate change on a local scale. A few possibilities will be discussed.
Climate change also affects the daily life of all people, but it is very difficult to inform the public about this subject. Hardly anyone understands how the atmosphere works, let alone why climate change will become a problem in the next decades. Only a few people think ahead more then a few years. And now we ask them to change their daily life for a phenomenon that most likely will exceed this century. Some attention will be given to this subject.

Weather and climate change in relation to crop protection

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Recent studies have considered possible changes in the variability as well in the mean values of climatic variables. At middle latitudes of Europe, global warming will extend the length of the potential growing season, allowing earlier planting of crops in the spring and earlier maturation and harvesting, as long as the provided moisture is adequate and the risk of heat stress is low.

The atmospheric CO_2 concentration is predicted to increase and to generate a rise in the global surface temperature, and change of the precipitation pattern. This could aggravate the severity to summer drought and affect crop yield. Elevated CO_2 levels tend to result in changed plant structure. At multiple scales, plant organs may increase in size: increased leaf area, increased leaf thickness, higher number of leaves, higher total leaf area per plant, and stems and branches with greater diameter have been observed in a number of studies. These increased organ sizes favor disease circumstances.

Higher temperatures may have an important repercussion on the effectiveness of resistance genes and also elevated CO_2 and ozone levels could have an influence on the effectiveness of host resistance.

Climate change could firstly affect disease directly by either decreasing or increasing the encounter rate between pathogen and host by changing rates of the two species. Disease severity should be positively correlated with increases in virulence and aggressiveness of pathogens. However, both of these effects on disease will be mediated by host resistance and encounter rates, which in turn are potentially affected by climate. The range of many pathogens is limited by climatic requirements for overwintering or oversummering of the pathogen or vector. Asynchrony between pathogen, vector and host may be an effect of climate change.

The majority of the pest and disease problems are closely linked with their host crops. This makes major changes in plant protection problems less likely. Maybe climate change could be an ultimate possibility for decision support systems to improve their value in advising adjusted dosages, sprayed at the right moment.

Due to the higher mean temperatures, new (quarantine) organisms could be introduced, coming from southern regions.

Re-constructing evolution of fungicide resistance and disease dynamics of cereal pathogens from crop archives

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Between 1843 and 1856, Lawes and Gilbert started nine long-term field experiments with the main objective to measure the effects of inorganic fertilizers on crop yields. Eight of the nine ‘classical experiments’ are still continuing more or less as originally planned up to today. From each experiment, samples of crops and soils have been stored annually and successive generations of scientists at Rothamsted have continued to add samples to the archive which now comprises > 300,000 samples (Anonymous, 2006). In addition, meteorological measurements have been made since 1850 and mega-data sets are available through the Electronic Rothamsted Archive (e-RA).

Application of molecular techniques provides new opportunities to explore the archive samples to reconstruct the evolution of fungicide resistance and to measure fluctuations in cereal pathogen populations. We were able to construct a unique 160-year time series of the abundance of *Phaeosphaeria nodorum* and *Mycosphaerella graminicola* in both grain and leaf/stem samples from the Broadbalk continuous winter-wheat experiment (Bearchell *et al.*, 2005; Shaw *et al*., 2008). Changes in the ratio of the two pathogens were not correlated to climate or agronomic changes but, unexpectedly, to sulphur deposition. The archive samples of the Broadbalk and the long-term spring-barley experiment (Hoosfield) have also been used recently to study the evolution of fungicide resistance (e.g. resistance to benzimidazole carbamates (MBC), sterol 14α-demethylation (Cools & Fraaije, 2008) and QoI inhibitors (Fraaije *et al.*, 2005) in populations of *M. graminicola*, *Ramularia collo-cygni* and *Rhynchosporium secalis*. Results of this research and other topics using archive samples will be presented and discussed.

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New challenges to crop pest management in traditional Central African agroecosystems under a changing climate

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By the end of the 21st century, global average air temperatures are projected to rise by 1.8–4.0°C (IPCC, 2007). This alters the hydrological cycle as the water-holding capacity of air increases by about 4% per degree Celsius. For West and Central Africa, Boko *et al*. (2007) project increased precipitation, although the distribution will not be even. Dry areas will become drier and humid zones wetter, resulting in more abrupt ecoregional transitions and closer isopluvials.

In West and Central Africa, smallholder farmers manage a plethora of diverse, albeit low-yielding perennial, annual, cash crops and subsistence agroecosystems, which are predominantly rainfed. So what risks will climate change pose for traditional systems and how will farmers adapt? Here, the impacts of changing temperature and humidity on pest, disease and weed dynamics in some traditional cropping systems will be considered at both the field and the landscape level.

Plantain (*Musa* spp AAB) is both an important staple and cash crop throughout the West/ Central African humid forest zone. Major yield constraints are root nematodes, particularly *Radopholus similis*, the foliar diseases *Mycosphaerella fijiensis* and *M. musicola,* and weevils (*Cosmopolites sordidus*). Data from lab and field experiments demonstrate higher nematode population densities and greater plantain root damage at the projected temperature increases. *Radopholus similis*, currently absent from cooler, higher altitude areas is likely to expand its range. *Mycosphaerella fijiensis* is also likely to expand its range and replace the less virulent *M. musicola* at higher altitudes.

At the landscape level, CLIMEX$_{\text{TM}}$ (Sutherst *et al*., 2007) uses IPCC models plus data on rainfall, humidity and temperature data to project climate change surfaces for global weeds, including *Chromolaena odorata*, a dominant weed in West and Central Africa. Its range is projected to expand east to Central Africa and beyond (Kriticos *et al*., 2005). It is an attractant for the African grasshopper *Zonocerus variegatus*, a defoliator of maize, cassava and other food crops, which sequesters the pyrrolizidine alkaloids of *C. odorata*, protecting itself from antagonists and increasing its population with the spread of *C. odorata*.

The impacts of these and other emerging pest problems on smallholder farmers and potential adaptation strategies, including biological, and cultural controls, and the use of tolerant crop varieties will be discussed.

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Vulnerability of crops - the influence of climate change and altered cultural practices

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During the last years agriculture and horticulture are exposed to strong external influences, e.g. from higher food and feed demand to consequently increased global trade. These economic constraints have lead to changes in cultural practices. Also the production of bioenergy has become a further factor to change agricultural practices. These already high challenges are further more influenced by global climate change – an increase of temperatures, changes of rainfall in amount and distribution and as a consequence the general changes in availability of water will furthermore influence the productivity of various crops, but will highly influence the incidence of pests and diseases.

The vulnerability of crops depends on the particular importance of these in distinct areas: examples will be presented from diseases and pests on food and feed crops as well as bioenergy plants. Additionally, the introduction of invasive pests like *Diabrotica* on maize will be taken into account. Especially the awareness of arising problems and the scenarios for new problems will be presented as well as possible counter measures.

Climate change: opportunity or difficulty for farmers?

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The climate is changing. Your business too?

This question was asked in three groups of arable farmers and three groups of dairy farmers during workshops in different parts of The Netherlands. We asked them if they already experience effects of climate change on their farms. We also discussed which climate-related difficulties they face now and expect in the near future. Besides difficulties, farmers also see opportunities. As an arable farmer from the province of Groningen stated: "*For Global Warming we farm at the Gold Coast: fertile soil, enough water available, warmer weather and –in Groningen- above sea level*."

Farmers differ in their opinion on the relation between climate change, pests and crop protection. Some dairy farmers relate the increase in flies and insects causing diseases as Bluetongue and Q fever to climate change. Furthermore, they expect more weeds in their crops when temperature rises. Arable farmers expect an increase in fungal diseases and state that they already have more troubles with insects. The consequences for their crops and cattle are uncertain. They expect more pests, but also new natural enemies. Some farmers think pests and weeds will become a bigger challenge, while others think the situation will not change that much. "*As farmers, we are used to changes*." Overall, most farmers think their business eventually will benefit from climate change due to improved climatic conditions for crop growth.

Climate change exacerbates the oak processionary caterpillar problem in The Netherlands

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Since its first observation in the south of The Netherlands in 1991, the geographical range of the Oak processionary caterpillar (*Thaumetopoea processionea*, “OPC” in the following text) has increased steadily over the years, moving in north-eastern direction. Figure 1 shows that it now occurs in the whole southern part of The Netherlands. During its expansion, the observed numbers clearly peaked in 1996 and in 2004. Both peaks were followed by severe decreases in 1997 as well as in 2005. The spreading of the caterpillar causes considerable health problems as each caterpillar has over 1.8 million urticating hairs.

The causes of the observed change in occurrence as well as potential future changes are unknown. The OPC is an egg-overwintering insect, a group of insect species that as a whole has become increasingly successful over the years. As the OPC is mainly found on solitary oaks and then mainly on the southern side of the trees we hypothesise that the OPC prefers warm conditions. Therefore, it is likely that the observed 1°C increase in temperature and the corresponding increase in growing season length in the recent decades have stimulated the spreading.

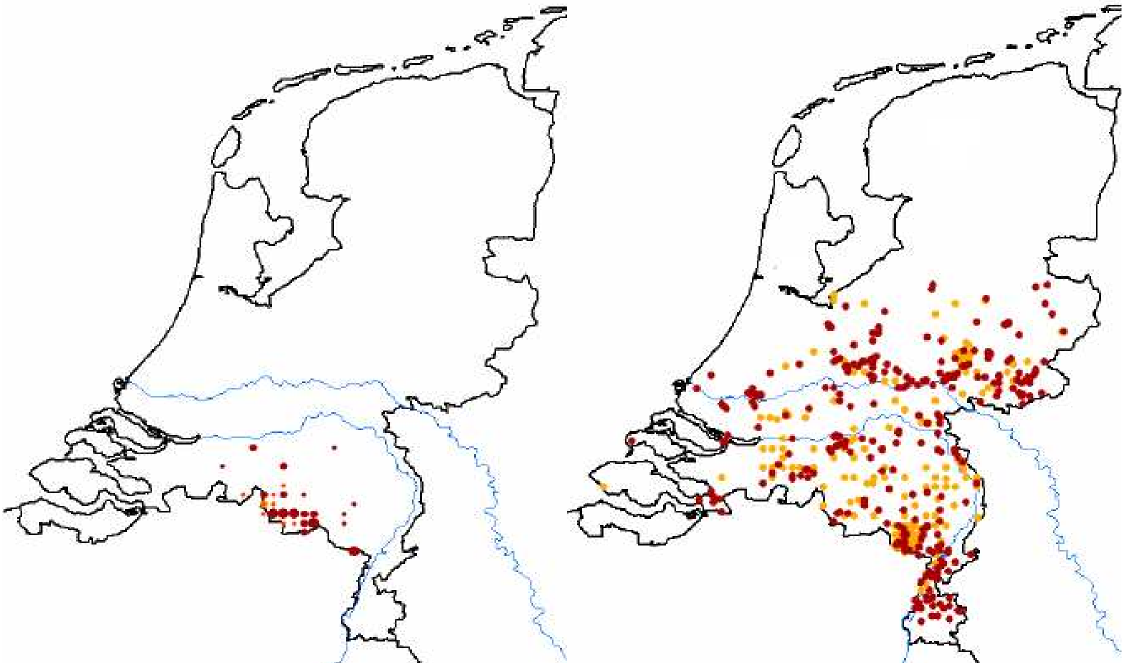

Figure 1: Oak processionary caterpillar (OPC) distribution maps of the periods 1991/1993 and 2006/2007 in The Netherlands. The darker dots represent the more recent years. Since the OPC’s first appearance in 1991 its distribution area has moved in north-eastern direction, expanded rapidly as well.

The first objective of our study was to determine which climate variables could explain the observed changes in the spatial distribution and changing population dynamics of the OPC. Our second objective was to determine the potential future changes in its distribution under different climate scenarios.

We created annual distribution maps of the OPC based on observations gathered by Alterra Wageningen UR, the Dutch Butterfly Conservation and the Dutch phenological network Nature’s Calendar. The period covered was 1991 to 2007. We correlated the distribution maps of the OPC with weather data that were based on data from thirty to fourty MeteoConsult weather stations, comparing the region where the OPC occurred to regions without OPC observations. The large number of weather stations gave us a unique insight in regional climate differences. By combining the found relation between climate and occurrence with the four climate change scenarios of the KNMI, we assessed the potential future distribution of the OPC.

We conclude that the temperatures in May, June, July, September and October are significantly higher in the OPC region. May, June and July are the months in which the eggs hatch and the caterpillars grow, September and October is the period of flight and reproduction of the OPC. The summer temperature in the OPC region currently averages 17.6°C. In the north of the country this is 16.7°C. Our analysis also showed that September on average was significantly drier in the OPC region. This suggests that much rain during the flight period has a negative impact on reproduction.

Our scenario analysis showed that the average summer temperature in the north of The Netherlands will be between 16.6 and 17.6°C in 2020 and between 17.0 and 19,0 in 2050 (depending on the scenario). Therefore, we conclude that the OPC distribution area is likely to expand further; in 2020 the entire country could become an “OPC region”.

The need for more detailed information about the OPC and the locations has become clear. By improving the level of detail in the information as well as the cooperation in the management the nationwide risk posed by the OPC could be contained or prevented more efficiently. Moreover, attention must be paid to the distribution of potentially infected oak trees throughout The Netherlands. Important for the management of the OPC (locations) is the coupling between reported observations on the one hand and information about the confirmation and management practices on the other hand.

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Climate change and bioinvasiveness of plant pathogens: comparing pathogens from wild and cultivated hosts in the past and the present

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Shifts in the distribution of organisms occur permanently and worldwide, involving organisms from all taxonomic groups. Shifts towards previously uncolonized areas are now commonly referred to as biological invasions. Invasions by pests and pathogens have a huge impact on agriculture. The successfulness of these invaders has been ascribed to absence of their natural enemies, but the successfulness of many invaders is also comfortably explained by lack of sufficient resistance in many crop/pathogen combinations, the area cropped in monoculture, and narrow rotations.

Many plant pathogens of agricultural crops made a great shift in their geographical distribution due to simple enlargement of the area cropped to hosts, mostly in combination with the oblivious transportation of these pathogens in plant material. However, it is also interesting to consider cases where invasion has not yet occurred. This can be due to inability of the pathogen to bridge large distances or to unfavourable climatic conditions. For example, although their host ranges are excessively large, the soilborne pathogens *Sclerotium rolfsii* and *Macrophomina phaseolina* do not occur in temperate climates due to their high temperature optimum and frost sensitivity. Likewise, the distribution of *Verticillium dahliae* is limited because it is relatively intolerant to high temperatures. Comparative spread of pathogens and their hosts will be exemplified for rust fungi occurring in the Netherlands and reasons for the various distribution patterns, including climate change, will be discussed. Some other examples of dispersal of plant infecting fungi will be given.

Climate change can affect pathogen and pest dynamics in multiple ways. Crucial is the question whether the effect of climate change outnumbers other factors affecting the epidemiology of pests and pathogens, and if so, how pathosystem management should be modified. Although impossible to quantify, it is believed that in the majority of cases, potential invaders do not successfully settle. This success rate of introduced, potential invaders might be sensitive to climate change. For airborne pathogen and pest organisms, higher temperatures may lead to faster disease cycles, leading to an increase in disease spread, and to increased survival due to shortened and less severe frost periods. For soilborne pathogens, reduced frost may lead to increased survival of those species that do not tolerate frost. For soilborne pathogens that do tolerate frost, decreased exposure to frost could lead to germination during frost-free periods in the absence of hosts or, alternatively, triggered by the presence of weed hosts. As a result, new strategies to manage soilborne pathogens would be needed. Climate change will also invoke changes in farm management, which in turn may affect epidemiology of pests and pathogens. The already existing trend to advance planting crops to bring crops early in the season to the market is done because prices are then still high, but is done also to escape plant diseases. Such practices are currently carried out by organic growers to temporarily avoid potato late blight. This trend will continue when temperatures raise. The

consequence will be that plant disease epidemics will start earlier, have a longer season, and, thus, polycyclic epidemics will show more disease cycles in one vegetation season.
Summarizing, it could be useful to separate various kinds of effects of climate change on plant pests and diseases leading to:

- changed probability of a pathogen to settle in a hitherto uncolonized area.
- changed epidemiologic characteristics such as duration of the life cycle and survival during the host-free season.
- changed farm management, such as a prolonged vegetation season.

The current fast changes in climate may lead to alike alterations in the epidemiology of pests and pathogens. To be able to better predict these changes, systems monitoring such alterations in an early stage could be of use.

Why is Dickeya spp. (syn. Erwinia chrysanthemi) taking over? – The ecology of a blackleg pathogen

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Potato blackleg caused by pectinolytic *Pectobacterium atrosepticum* (syn. *Erwinia carotovora* subsp. *atroseptica*), *P. carotovorum* subsp. *carotovororum* (syn. *E. carotovora* subsp. *carotovora*) and *Dickeya* spp. (syn. *E. chrysanthemi*) gives increasing damage in seed potato production in Europe. In the past, the blackleg pathogens contributed equally to the occurrence of blackleg, but in the last five years *Dickeya* spp. was responsible for 50-100% of the incidences in France and The Netherlands. In this paper, the diversity and some ecological aspects of *Dickeya spp.* are discussed, which may explain the increasing significance of this pathogen.

Dickeya spp. has been recently divided among six species, largely coinciding with seven biochemically distinct groups (biovars). In potato in Europe, before 2000 *D. dianthicola* (biovar 1 and 7) was almost exclusively found. This species is more adapted to temperate climates. Since 2000, a biovar 3 *Dickeya* spp. was isolated from potatoes grown in Israel, Finland, Poland and the Netherlands, which could not be classified in any of the six new species. Results from *dnaX* and 16S rDNA sequence analysis, rep-PCR and biochemical assays indicate that strains belonging to this biovar 3 variant are clonal. This variant has a higher temperature maximum than *D. dianthicola*. Possibly due to the increasing average temperature during the growing season, the *Dickeya* biovar 3 variant is taking over from *D. dianthicola*.
In contrast to a biovar 7 *D. dianthicola* strain, the biovar 3 variant efficiently colonizes plant material. Soil infestation with a GFP-tagged strain resulted in a systemic colonization of potato plants within 30 days after inoculation. The biovar 3 variant was also able to colonize roots, stolons and progeny tubers from infected stems.

Spread within a crop may also occur during crop production if bacterial cells of *Dickeya* spp. are disseminated via free water in soil from rotten tubers to tubers of neighbouring plants. We showed that plants adjacent to blackleg diseased plants both within a row and between rows became contaminated after heavy irrigation.
Dickeya spp. was able to cause disease symptoms even when present in seed at low densities. In field experiments with vacuum-inoculated tubers, a level of 40 cells per gram of potato peel was sufficient to end up with 30 and 15% diseased plants in 2005 and 2006, respectively. Such low levels of infection easily remain unnoticed during seed testing, even if sensitive detection methods are used. As for *Pectobacterium* spp., spread of contamination within and between seed stocks often occurs during harvesting and grading. In an experimental field, contamination with *Dickeya* spp. was spread by mechanical harvesting up to a distance of 80 m behind a zone with rotten tubers, with an average of 12 meter. Hand-harvested tubers from a disease-free crop remained clean.
Dickeya spp. seems to act like a biotrophic organism, which needs the host for long-term survival. *D. dianthicola* and the biovar 3 variant survived maximally for only three months in soil. Soil type, temperature and humidity only had a minor effect on survival.

In conclusion, a *Dickeya* spp. has become the dominant blackleg pathogen, probably due to its higher optimal growth temperature and its ability to colonize plant tissue more efficiently compared to *Pectobacterium* spp. The increasing importance of *Dickeya* spp. may be related to the increasing average temperature during the growth season due to global warming.

Impact of climate change on insect pests of trees

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In The Netherlands, insect pests on trees and shrubs are being monitored continuously since 1946. During these years, almost all insect pest populations showed marked changes, which may be the result of climate change, arrival of new pests, changes in forest management, shifts in forest composition etc.

In an earlier study, we analyzed the number of observations for all pest species in the database on deciduous trees. The results showed that since 1985, pest insects hibernating in the egg stage, numerically exceed insects hibernating as larva, pupa or adult. During the last 2-3 decades, the winters in The Netherlands have become relatively warm and more humid. In literature, it is stated that mild winter temperatures can reduce winter survival of adult, larval and pupal stages more than of the eggs, presumably because the first stages are more vulnerable for entomopathogenic nematodes and fungal activity. This phenomenon may be the cause of our observed increase of egg hibernators (Moraal *et al.* 2004).

In a later study, we have analyzed trends in 61 years of population development of the 91 most abundant species in our database, in such a way that frequently observed species did not bias the results. Of the observed species, only a minority occurred regularly over the entire observation period of 61 years. The remaining species showed population fluctuations that varied from single short-term outbreaks to long-lasting increases or decreases. On coniferous trees, most insect species showed decreasing numbers, while increasing numbers were found most on deciduous trees. In the increasing trend-group of Lepidoptera, more egg hibernating species were observed compared with the decreasing trend-group (Moraal & Jagers op Akkerhuis, in prep).

Future climate change models for our region, predict increasing temperatures, drought periods, and heat waves during the growing season. The European literature on pest outbreaks that followed after the exceptional drought of 2003, give us some indications of the impacts of extreme climatic conditions. Primary pest insects, mostly leaf-consuming larvae, are not dependant on the vitality status of the host trees. Secondary pests, mostly bark-boring species, are dependant on weakened trees e.g. by drought. In literature, some generalized predictions were made, based on current pest distributions and the severity of insect outbreaks in individual regions after the summer drought of 2003. The predictions are that tree mortality due to secondary pest insects may become more important in the future, because dry summers will reduce the resistance of trees. A combination of global trade and a changing climate makes it possible for new invasive species to establish in the EU and The Netherlands. In the absence of specific natural enemies, these species may cause tree mortality on a large scale (Moraal, in press).

There are many interactions and it is extremely difficult to predict the impact of climate change on insect pests in the future, but we may expect an increase of certain primary pests as well as secondary pests and invasive species.

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Are changes in the composition of the Fusarium Head Blight complex caused by climate change?

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Fusarium Head Blight (FHB) of wheat and barley is caused by a complex of species. Apart from yield losses, this disease has attracted much attention due to the capacity of many of the species in the complex to produce mycotoxins that are detrimental to humans and animals. In The Netherlands, until the late 1980s / early 1990s, *Fusarium culmorum* was the predominant species on wheat, but since then *F. graminearum* became the most important pathogen. This trend was first detected in 2000 and 2001 (Waalwijk *et al.*, 2003) and was confirmed in other countries in Western Europe. This finding can be explained in several ways, including the expansion of the acreage of maize, which is a good host of *F. graminearum*, but less for *F. culmorum*. Secondly, *F. graminearum* has the capacity to go through sexual development, resulting in airborne ascospores that can travel several hundreds of kilometers; a clear advantage in colonization of crops in virgin soils. Lastly, *F. graminearum* favors higher temperatures than *F. culmorum* and the observed shift might be an indication of changes in climate.

In China, the population structure of FHB pathogens occurring on barley was investigated by sampling at 23 counties along the Yangtze River. In contrast to the situation in Europe or North America, the vast majority of isolates belong to *F. asiaticum*. Analyses of the structure of this population showed a dramatic gradient in the trichothecene mycotoxins produced (Yang *et al.*, 2008). While the production of nivalenol (NIV) was primarily found among isolates collected in the western part of the country, deoxynivalenol (DON) producers were mainly from the eastern provinces. As NIV producers have been reported in Asia in the past, we hypothesized that NIV producers represent the ancient population that is being replaced in the lowlands in the east. The populations in the western parts of China are not (yet) replaced as these counties reside in mountainous areas which are more difficult to become colonized by the DON producers.
A similar gradient was observed in Canada, where populations from the FHB complex in the East appear to overtake the place of those in the West. Phenotypic analyses showed that the ‘invading’ population consisted of strains that produced more mycotoxin and were more vigorous (Ward *et al.*, 2008). To verify whether a similar situation is currently taking place in China, we analyzed the diversity within and between populations using neutral VNTR markers. Some alleles were observed exclusively in upper valleys of the Yangtze River (Zhang *et al.*) which is in agreement with the occurrence of genetic differentiation along environmental gradients.

These results will be discussed together with data from a novel survey performed in the Netherlands in 2008, to underline the previously observed temporal shifts in the composition of the FHB complex. To put this in a broader perspective, this will be compared with results from surveys in France and Germany, where similar analyses were also performed on maize (Görtz *et al.*)

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