Climate change in Europe:
altered life cycles and spread of major pathogens in oilseed rape

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Abstract

The climate history of Europe in the past two millennia has been characterised by distinct warm and cold periods with an estimated temperature range shift of +/-3°C. Agricultural production systems have been continuously challenged to adapt to such changes. Pests and diseases are important determinants of crop production. Their sensitivity to climate is pronounced. Knowledge about the impact of climate on the present and future development of pests and diseases is an important part in adapting agriculture to local conditions. There is considerable data available from the past 30 to 40 years on climate-disease or climate-pest relationships, which have been used to develop weather-based forecasting models with the aim of predicting epidemic severity to maximise economic use of pesticides. A large number of such models have been constructed for specific pests and diseases in different countries to help farmers and advisers in making their decisions about crop protection to save unnecessary sprays. Such weather-based disease forecast models can be combined with climate change models to simulate epidemic severity and/or the geographic spread of a particular pathogen under future climatic change scenarios.

However, an important constraint is that results from climate prediction models currently vary considerably and have a low spatial and temporal resolution. Thus, the most uncertain factor in global change research on crop diseases is global change prediction itself. Further complicating factors arise from the fact that climate not only affects pathogen or pest populations directly but also induces changes in the crop production systems and cropping techniques (soil tillage, irrigation, sowing dates, cultivars, crop species) that indirectly alter the prevalence of pathogens or pests. It is difficult to separate direct from indirect climate effects.

Greater mean temperatures may be associated with spread of phoma stem canker further north and altered temporal pattern of the fungal life cycle and disease stages in the UK. There is also some indication that the sclerotinia life cycle may change; after mild winter conditions, a pre-seasonal sclerotial stage has recently been observed in France and Germany and root infection has occurred more frequently. Significant increases in yield losses are recorded from ascospore infections at early flowering stages compared to late infections. Soil temperature profiles will have a specific impact on soil-borne diseases, such as clubroot (*Plasmodiophora brassicae*) and *Verticillium longisporum*. After mild winters, *V. longisporum* caused greater yield losses in Germany. Clubroot has recently become a serious threat inGermany, but its relationship to recent climatic changes is still unknown.

Research is urgently needed to improve and combine climate and disease prediction models to provide a realistic forecast of disease risks associated with climate change. As climate models are likely to continue to lack sufficient accuracy, thorough surveillance of disease epidemics will be more crucial than ever before, in order to detect changes and adaptation in pathogen (and pest) populations and to establish the appropriate crop protection systems early enough.

Introduction

Climate change has been a consistent phenomenon throughout the earth's history over the past millions of years. Recent data from climatologists show that in the past climate has not only changed to a much larger extent than is occurring today but also this has happened within relatively short periods of time. A good example is the climate history of Europe in the past 11,000 years, the post-glacial era, in which distinct warm and cold periods have occurred, illustrated by the Little Ice Age in the 16th and 17th centuries or the increase in wine production in England in the warmest Roman or Medieval periods. Biological organisms are sensitive to climatic factors and thus all species always have had to cope with climate changes. This is specifically true for agriculture, which is a particularly climate-dependent and climate-driven industry. Adaptation of crop production systems to local conditions has always been a key prerequisite for successful crop production. Pests and diseases are important determinants for crop production. Their sensitivity to climatic factors is well known (Chakraborty et al., 2000; Boland et al., 2004; Garrett et al., 2006). Thus knowledge about the impact of climatic factors on pests and diseases is a key factor in adapting agricultural production technique to local conditions.

Crop pathologists have been interested in weather-disease relationships long before the present climate change debate started. Their aim was to predict severity of epidemics of diseases in order to spray pesticides at the optimal time and with the most suitable dose. Thus, there is a considerable amount of data available from the past 30 - 40 years that has been used to describe climate-disease relationships. More recently, much of this data has been utilized to construct weather-based forecasting models with the aim of epidemic prediction and decision support under practical conditions in crop protection (Kluge et al., 1996; Kleinhenz & Jörg, 1998; Kleinhenz & Rossberg, 2000; Delinxhe et al., 2003; Koch et al., 2007; Rossi & Giosue 2005; Racca & Jörg, 2007; Räder et al., 2007). Such disease forecast models can now be adapted to simulate the epidemic behaviour or geographic spread of a particular pathogen under hypothetical future climatic conditions.

However, there are some important complicating factors to be considered. Firstly, while biological responses to climate may be experimentally verified, the extent and kind of climate change itself remains speculative. Results from climate models still vary considerably and have a low spatial and temporal resolution (IPPC 2007). Thus the most uncertain factor in global change research with regard to crop diseases is global change prediction itself. Secondly, there are additional complicating factors which have to be considered. Climatic factors impact on crop production in at least two ways. There are short-term direct effects on the amount of damage (loss), pathogen inoculum production and the importance of specific diseases in a certain area, but this all relates to pre-existing pathogens and crops. In the long-term, if climate change is greater, it may induce the invasion and establishment of novel pathogen or pest species, causing significant changes in the species composition. These direct effects on diseases may all be influenced by indirect effects, which derive from a parallel adaptation of crop production techniques to climate change. In the short-term, this may result in altered sowing dates, reduced soil tillage or enhanced irrigation. All such changes will have an impact on diseases by themselves. In the long term, local crop production may adapt by changing to alternative crops or increasing the proportion of individual crops in the rotation scheme. Such changes will have a considerable impact on pests and diseases and are a response to climate change. In conclusion, direct and indirect effects of climate change are difficult to separate and will be affected by the technological changes in agricultural practices.

Alterations in life cycles of pathogens of oilseed rape: above-ground diseases

As examples, this paper will focus on some important oilseed rape diseases in Europe, two above-ground, *Sclerotinia* stem rot and *Leptosphaeria* phoma stem canker, and two soil-borne, *Verticillium longisporum* and clubroot (*Plasmodiophora brassicae*). It will attempt to estimate how their life cycles might be altered under expected climate change scenarios.

Sclerotinia stem rot is typically a monocyclic disease with sclerotia of *Sclerotinia sclerotiorum* ripening in early spring to produce apothecia which release sexual ascospores at the time of flowering; these ascospores initiate the process that leads to infection of stems of oilseed rape plants. Recently, there have been observations indicating that the sclerotinia life cycle may change in various ways. Firstly, due to mild winter conditions (e.g. in 2006/2007) a pre-seasonal epidemic in late winter/early spring (February/March) has been observed in France and Germany. This caused significant disease on the winter oilseed rape crops before flowering. As a result, early production of sclerotia occurred. This may significantly increase the local sclerotial inoculum and increase ascospore inoculum concentration during flowering. Therefore, milder winter weather under future climates may significantly extend the period of time for infection and thus increase the disease incidence and damage potential of this pathogen.

Secondly, there may be changes in the timing of infection during flowering. The environmental requirements for infection to occur have recently been studied in order to develop sclerotinia stem rot forecasting systems such as SkleroPro (Koch et al., 2007). If conditions for infection are fulfilled earlier during flowering, infection may happen earlier and cause greater damage. In a recent study, regressions of disease incidence against yield loss differed between early and late infections. Early infections caused twice as much yield loss per unit disease incidence (% plants affected, DI) as late infections (0.45% vs. 0.23 % loss per percent DI, respectively). Consequently the threshold DI for economic loss changed from 12 to 27 % (Dunker et al., 2005). Thirdly, we recently observed a new disease caused by sclerotinia, namely root infection. This is a common symptom in sunflower but not in oilseed rape. It is suggested that root infection is induced by myceliogenic germination of sclerotia in the soil and direct hyphal infection of the roots. Work is now starting to test whether occurrence of this root infection is related to climatic or other factors.

Phoma stem canker is the most severe disease of oilseed rape in many parts of the world, causing significant economic losses (Fitt et al., 2008). A survey of the UK by the Department for the Environment Food & Rural Affairs showed that canker incidence was greatest in the south-east region of the main oilseed rape growing area of England (www.cropmonitor.co.uk/). Disease prediction models have been updated with meteorological data from many sites across the UK, in order to make predictions in autumn of the date of increase in incidence of phoma leaf spotting (www.rothamsted.bbsrc.ac.uk/ppi/phoma/). These predictions of the date of increase in phoma leaf spotting can then be used to predict the date of canker onset in spring, canker severity at harvest (Evans et al., 2008) and potential yield loss. Growers can use this information to make spray application decisions in the autumn at the best time to control the initial leaf spotting and prevent stem canker development.

A weather-based prediction model for phoma stem canker was run with data sets from climate change models for different years and CO_2 emission scenarios in the UK. For example, a climate model based simulation was done for the high CO_2 emission scenario and the 2020s compared to present times. If 1200 degree-days after sowing is used as the threshold for canker onset in spring, the prediction is that start of disease will be a significantly earlier (by about 40 days). Thresholds from disease forecasting models can also be connected with geographic climate scenarios, under the predicted weather for future periods (2020s, 2050s) under low or high CO_2 emission scenarios. These predictions suggest that the range of the disease will extend northwards, so that farmers in Scotland, who currently have phoma leaf spotting may start to have problems with stem canker.

Soil-borne diseases

Soil-borne diseases will be affected by altered mean temperatures in the soil. Crucial stages in the life cycle of pathogens such as *Plasmodiophora brassicae* and *Verticillium longisporum* are infection of roots and survival of resting spores or microsclerotia. Currently, it is not known what impact temperature increases will have on this type of pathogen but recent observations indicate that there may be serious effects.

Verticillium is a disease which has recently increased in importance, particularly in the cooler oilseed rape growing regions in Europe. *V. longisporum* accumulates microslerotia in the soil; mycelium originating from these microsclerotia then infects the crop roots. Although *V. longisporum* is a xylem-invading fungus, there is some evidence that it is very weather-dependent. In Northern Germany, yield losses on single plants were up to 70%. Although these losses were partly compensated by increases in plant biomass per m^2, yield losses of 10 to 30% can be expected where there is a high incidence of the disease on susceptible cultivars (Dunker et al., 2008). Given a temperature threshold for infection of 15°C and a 2°C increase in mean soil temperature, the critical period when the crop is susceptible to infection would extend by about 4 weeks in autumn and 2 weeks in spring, based on the 2006/2007 weather data from Rosemaund, UK. This may significantly aggravate the impact of this disease in the future.

Another emerging threat is clubroot, which has recently increased in importance as a disease of oilseed rape in Germany, particularly but not only in the traditional oilseed rape growing regions. Taking the Rosemaund data for 2006/07 and a threshold temperature for root infection of 16°C, this implies an increase in the length of the infection period in autumn by about 6 weeks and may have a considerable impact on the incidence of disease and the resulting economic losses. Overall, the impact of changed soil conditions on soil-borne diseases is not yet understood and requires particular research efforts in the future.

Conclusions

In conclusion, climate prediction models are likely to remain imprecise and thus make it difficult to predict changes in severity of diseases and pests or to make risk assessments for crop protection. The best course of action is surveillance and adaptation. There is a great need for detailed disease surveys which will allow us to detect changes and adaptation in pathogen life cycles sufficiently early to develop appropriate crop protection measures. This will in part be the task of farmers and advisers in their continuing efforts to improve crop protection systems but needs substantial support from crop protection research to identify the underlying biological principles.

Acknowledgements

We thank the UK Biotechnology and Biological Sciences Research Council (BBSRC) and Department for Environment, Food and Rural Affairs (Defra, OREGIN) and Sustainable Arable LINK programme (PASSWORD, CLIMDIS) for funding this research.

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