Tracking changes in the importance and distribution of diseases under climate change

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Summary

Analyses of the annual incidence and severity of diseases in winter wheat in England show that considerable changes have occurred in their prevalence and importance since 1970. Comparison of these disease measurements with data describing annual changes in weather patterns over the past 15-20 years shows no consistent correlation. Instead, the data are consistent with the fact that disease epidemics are triggered at a finer scale by more specific weather events, and highlight the need for a refined approach to assessing disease risks, particularly in a changing climate. There was also strong evidence of the effectiveness of agronomic practices in ameliorating the impacts of disease epidemics. Under climate change weather patterns will become more unpredictable, so the challenges in assessing disease risks will become both more important and more difficult. Preliminary modelling work using data on mean daily weather to compare historical trends in crop health with predictions for two future climate change scenarios for the years 2081-2090 indicate that brown rust is likely to become more severe whereas severity of *Septoria tritici* will decline due to drier weather during the summer. The effects on disease epidemics predicted due to climate change would appear manageable by continued adaptation and improvement of current agronomic practice, which needs to be supported by robust intelligence/advice and dynamic cultivar resistance breeding programmes.

Introduction

Climate change is now acknowledged to be inevitable and it is clear that the effects are already evident. Recent years have seen weather patterns substantially different than in the preceding decades. For example, monitoring has shown that 11 of the past 12 years (1995-2006) rank amongst the twelve warmest ever recorded and that autumn/winter precipitation has increased significantly in Northern Europe.

Plant diseases are responsive to fluctuations in climate and as a result are potentially sensitive indicators of change. Whereas insect pests respond primarily to changes in temperature, development of disease epidemics depends strongly on temperature, rainfall and humidity. Broadly, these operate upon three critical life cycle processes: the generation of initial inoculum, and subsequent dispersal and crop infection.

In the UK, winter wheat is affected by a number of key diseases which differ in their responses to changes in temperature and precipitation patterns. *Septoria tritici* is currently the most important disease of wheat and becomes severe in crops during warm wet weather, because the spores are more easily dispersed during rainfall and the lesions can develop rapidly under high temperatures. Brown rust tends to cause epidemics during periods of dry hot weather, whereas yellow rust levels decline if temperatures increase above 20°C. Mildew is favoured by warm windy weather, but is checked by temperatures above 25°C, and does not thrive during wet weather. Fusarium head blight is a key indicator disease, as the symptoms are caused by a complex of at least five individual fungal species, which have differing requirements for optimum growth and development. Generally, high levels of fusarium head blight occur if wet weather coincides with anthesis and the spores are splashed onto the ear and infect the developing grain. However, the most dominant species causing symptoms each year depends upon the weather conditions prevailing during the season. Warm summer temperatures favour *Fusarium graminearum*, which poses the greatest threat to crops both in terms of potential yield loss and mycotoxin contamination.

Monitoring of disease intensity and crop management strategies in commercially grown winter wheat crops has been conducted annually in England for more than thirty years. The resulting dataset provides an historical record of the effects of climate on the incidence and severity of diseases and measures the success of strategies utilised by farmers to control epidemics. The long-term datasets on incidence of disease provide not only a long-term historical average of disease incidence and severity, but also a measure of the effects of changes in climate that have occurred over the past ten years. Recent changes, towards warmer winters and hotter, drier summers, are in line with current predictions for future climate change. Analyses of the wheat monitoring data over this period provide a unique opportunity to look at the potential changes in disease pressure which could occur under projected climate change scenarios. These data provide a measure of the success of our current adaptation strategies while trends in the use of cultivars and fungicides provide a basis for examining the potential effectiveness of crop management in the future and in addition may highlight some of the developing challenges.

Materials and methods

Measurement of the incidence and severity of diseases in commercially managed winter wheat crops has been carried out annually since 1970 (except in 1983 and 1984). These surveys are part of a much larger monitoring and advisory initiative conducted within the CropMonitor project currently funded by Defra and HGCA. Samples were taken from up to 300 crops each year in a randomised survey, stratified by wheat-growing area and farm size. Samples comprising 50 tillers were taken at random from each crop at growth stage 73-75 (early-medium milk) and assessed for symptoms of foliar, stem base and ear diseases. In addition, isolation work was carried out on all symptoms of fusarium ear blight to identify the causal pathogens. Data for each individual crop were stored on a relational database, along with specific details of agronomic practice and pesticide use. Summaries and analyses of data are available on the project website at www.cropmonitor.co.uk.

Long-term datasets on disease severity and weather and have been examined for evidence of the effects of changing seasonal climate and the potential balancing effects of disease management strategies. The crop disease data used in this paper were all sourced from the CropMonitor databases and indicate the average severity of disease symptoms at the end of the season after the application of fungicides and are not corrected for the effects of changes in agronomic practice such as improved cultivar resistance. Meteorological data were sourced from The Met Office Hadley Centre website at www.metoffice.gov.uk/research/hadleycentre/obsdata. Datasets used were the Central England Temperature dataset (HadCET) (Parker *et al*., 1992) and the UK Precipitation dataset (HadUKP) (Alexander & Jones, 2001). Preliminary analyses have used annual summaries of temperature and precipitation. Further work is ongoing to examine more complex relationships using monthly means.

Additional preliminary modelling work has also been carried out to predict potential levels of disease under climate change for the years 2081-2090. To date, two climate change scenarios described by the UKCIP2002 climate models have been evaluated against baseline data for the period 1971-1980 (Parker, Pers. Comm.). These scenarios are known as B2 (medium low emissions 2081-2090), which is predicted to result in a mean increase in global temperature of 2°C, and A2 (medium high emissions 2081-2090), which is predicted to result in a mean increase of approximately 3°C. The severity of *Septoria tritici*, yellow rust, brown rust and mildew were predicted using two indicator varieties: Consort (susceptible to *S. tritici* and brown rust) and Robigus (less susceptible to *S. tritici*, resistant to brown rust but susceptible to yellow rust).

Results

The HadCET and HadUKP data show that between 1990 and 2007 it has been warmer than average in Central England in 15 of the previous 18 years and wetter than average in ten (Figure 1). Additional monitoring also shows that since 2000 there has been a marked decrease in levels of summer precipitation across England and Wales. These overall trends are consistent with predicted climate change scenarios.

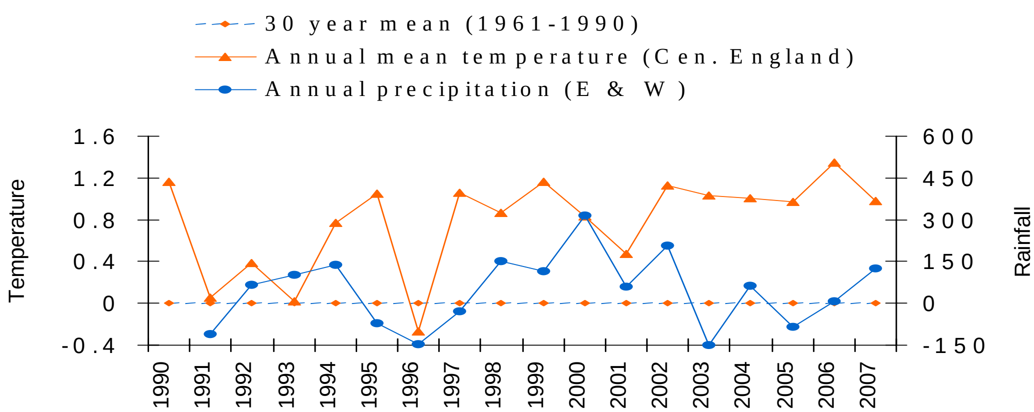

Figure 1. Annual average monthly difference in temperature (Central England) and rainfall (England and Wales) compared to the 30-year mean (1961-1990). Source: Met Office Hadley Centre.

Trends in severity of key diseases of wheat

Summaries of long-term data on the severity of diseases of wheat for the period 1970-2007 show differential trends for the four main foliar diseases. *S. tritici* first became dominant as a disease of wheat in 1985 but the majority of the severe epidemics (>5% area leaf 2 affected) have occurred in the past ten years (Figure 2). Some trends are evident when comparing mean annual weather data with disease monitoring data. The most recent severe epidemic occurred in 2002 when weather conditions were significantly warmer and wetter than average. In contrast, levels were particularly low in 2001 when temperatures and levels of precipitation were considerably lower. However, the data are more consistent with the fact that the frequency and scale of epidemics are related to weather factors at key times of year (e.g. conditions affecting over-wintering success).

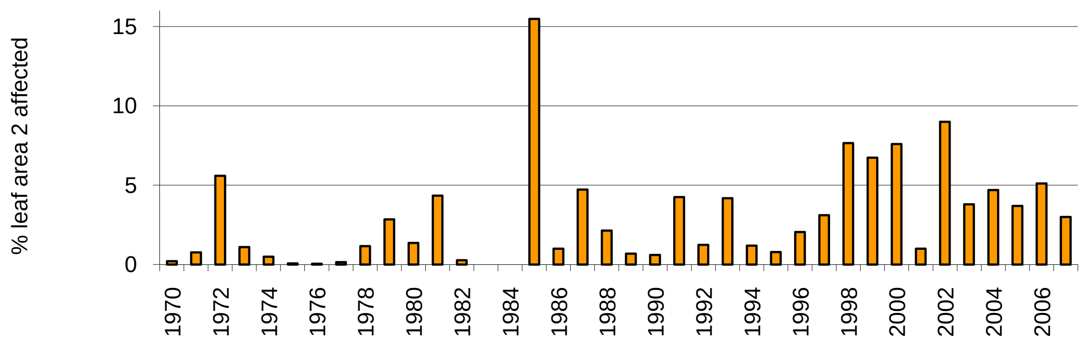

Figure 2. Severity of *Septoria tritici* on winter wheat (1970-2007)

Brown rust tends to occur at low levels in the surveyed crops because fungicide programmes are very effective in controlling the disease when applied optimally. However, changes in severity are still apparent and recent peaks in disease severity occurred in 1998, 1999 and 2005-2007 (Figure 3). Correlations with mean annual weather variables are not apparent, but there is evidence that the disease has been more severe during hot dry summer conditions following mild winters (data not shown).

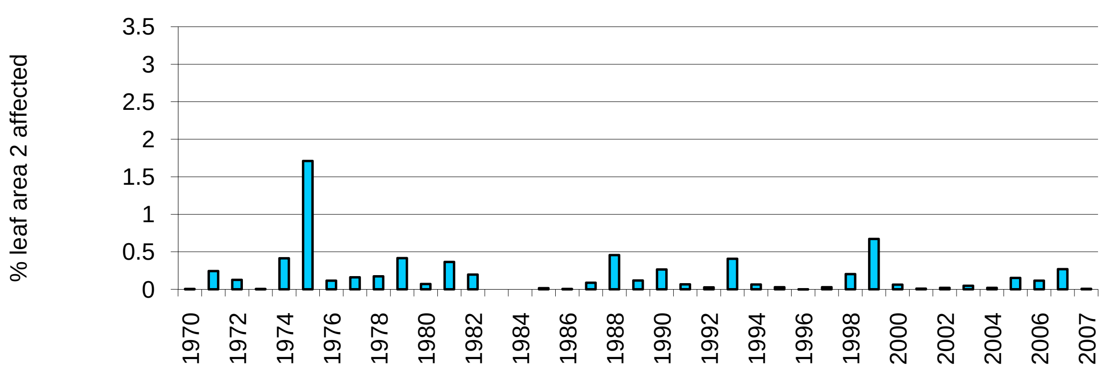

Figure 3. Severity of brown rust on winter wheat (1970-2007)

Severity of yellow rust has been low over the past fifteen years (Figure 4). However, it is a disease which is suppressed during warm dry summer weather, so lower risk has almost certainly prevailed in recent years. The low severity levels are also a function of the efficacy of current fungicides in controlling the disease and a measure of the success of plant breeders in producing cultivars with good resistance.

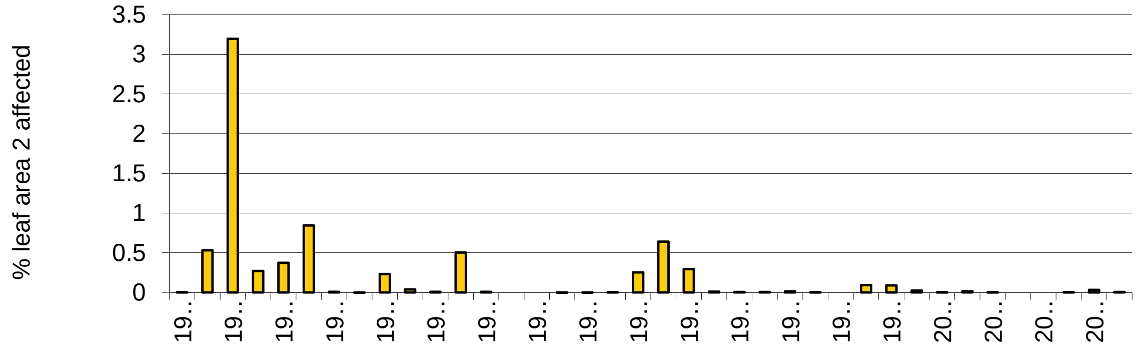

Figure 4. Severity of yellow rust on winter wheat (1970-2007)

Severity of mildew has shown the most significant decline of all (Figure 5) and has not been recorded at significant levels since the early 1980s. Again, effective crop management practices are likely to be a reason.

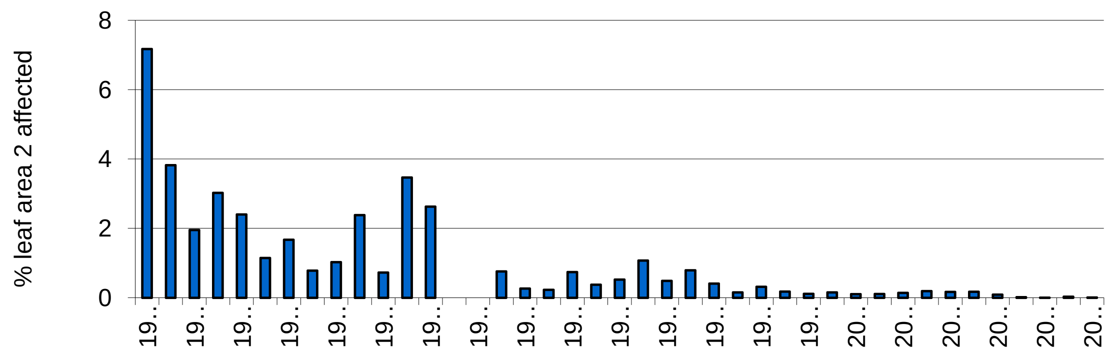

Figure 5. Severity of mildew on winter wheat (1970-2007)

The predominance of fusarium head blight pathogens changes year to year depending on weather conditions. Monitoring data show an increasing prevalence of *Fusarium graminearum* (Figure 6) during the period when annual temperatures have increased. This pathogen has not only increased in incidence but has expanded its geographical range from predominance primarily in the south-west, to be more widespread across England. However, *Microdochium* species have dominated in some years (e.g. 1998) when conditions over the autumn and spring have favoured build-up of these species.

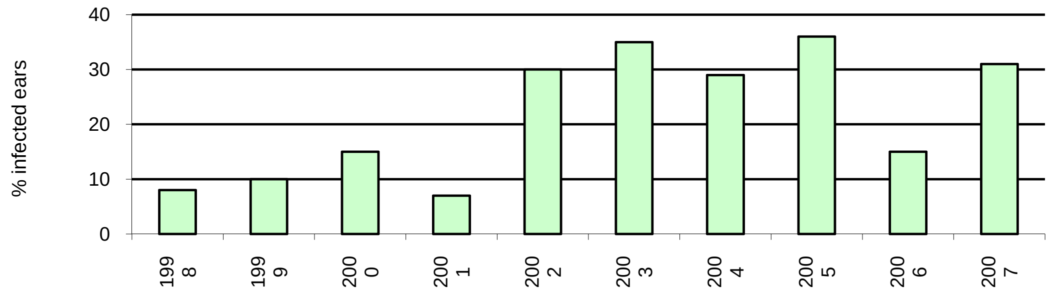

Figure 6. Changes in prevalence of *Fusarium graminearum*

New or emerging disease threats under climate change

Historically, tan spot (*Pyrenophora tritici-repentis*) has been regarded as a minor disease of wheat, but in recent years the incidence (% crops affected) of this disease has increased (Figure 7). Although severity levels (% leaf area affected) were very low, disease incidence reached a peak of 20% in 2006. The pathogen over-winters on stubble and is likely to occur during wet growing seasons. Examination of the mean climatic data does not provide any obvious explanation for this recent increase in prevalence, but warmer summers are expected to favour epidemic development.

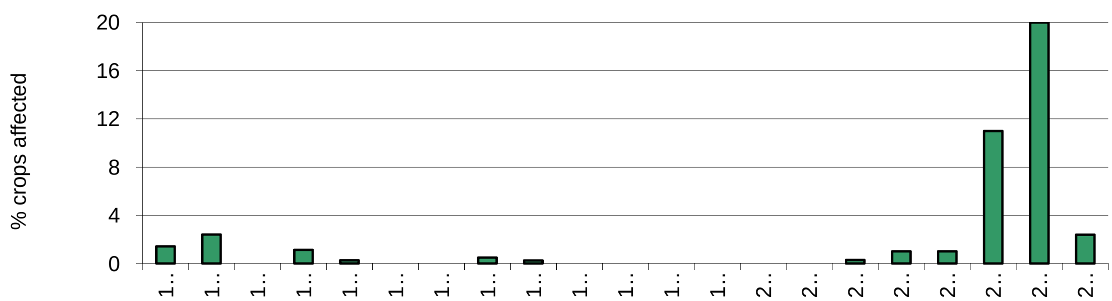

Figure 7. Incidence of tan spot on winter wheat (1987-2007)

Influences on crop development and agronomic practice

Climate change will have additional indirect effects on crop disease prevalence through influence on key agronomic practices such as date of sowing and scheduling of fungicide sprays to target key growth stages. Monitoring data show that there has been a very clear move towards earlier sowing dates (September) over the past thirty years and a more recent trend towards sowings before the 20th September (Figure 8).

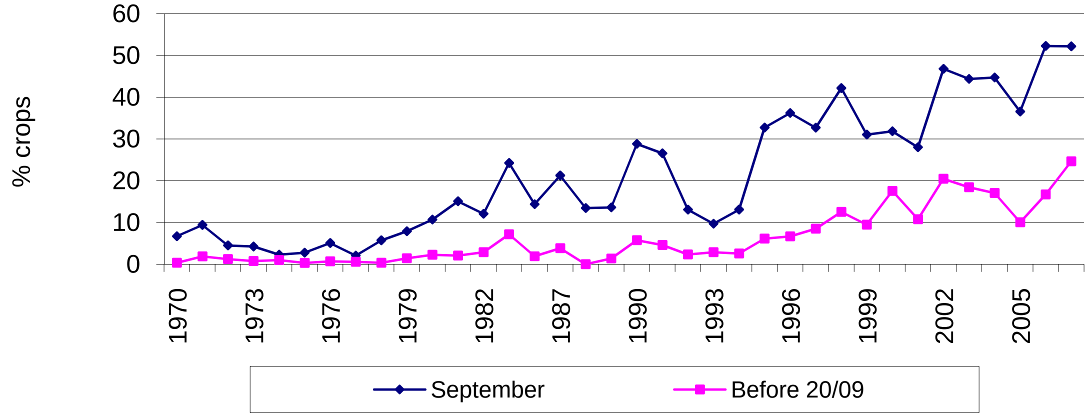

Figure 8. Sowing dates of winter wheat crops (1970 –2006)

Earlier sowing can have significant effects on the establishment and development of diseases in the early part of the growing season. Analyses show that this is a significant factor in the development of *S. tritici* and that the earlier the crop is sown the higher the risk of development of disease (Turner, unpublished). Generally, earlier sowing provides a longer period for diseases to establish before the onset of unfavourable weather, while under milder winter conditions with fewer frost days, more inoculum can survive and symptoms may be visible in crops earlier in the spring.

Under climate change the occurrence of sporadic adverse weather conditions will affect spray schedules and potentially cause key timings to be missed. Early appearance of disease often leads to an earlier start of spray programme or additional sprays. In recent years, monitoring has recorded a marked increase in the use of T0 sprays, particularly when brown rust has appeared early in the crop, and the mean number of sprays applied to wheat over the last three years is the highest ever recorded. In 2005 and 2007, additional sprays were used to try to control the developing brown rust epidemics. However, this is an unsustainable approach both in terms of disease control, due to increasing problems with development of resistance to fungicides in key pathogens, and in minimisation of the environmental impacts of farming.

Future scenarios

Estimates of disease severity under climate change scenarios for 2081-2090, within each climate change scenario and the baseline data, show a high degree of year-to-year variability. This suggests that significant seasonal and regional differences in disease pressure are likely to continue to occur under climate change. Overall predictions of the severity of the main four foliar diseases in untreated crops indicated that *S. tritici* and mildew would decline under the climate scenarios tested; yellow rust levels were relatively unchanged, whilst brown rust would increase considerably. The degree of increase or decrease in predicted disease level was much greater on the susceptible cultivar. For example, *S. tritici* severity on the susceptible cultivar was seen to decline by 7% on leaf 1 and 5% on leaf 2 under the medium high emissions scenario compared to the baseline, whereas disease severity on the resistant cultivar was unchanged. Provisional conclusions from the analyses suggest that appropriate fungicide inputs to control the disease levels predicted would be unchanged at T1 and lower at T2 (mainly due to the decline in *S.tritici*). Modelling these climate scenarios also highlights that crop development might also be significantly affected. For example, under these models the date of GS 32 occurred almost two weeks earlier under the medium high emissions scenario compared to baseline conditions.

Adaptation strategies

Data indicate that management strategies can be very effective in ameliorating major disease epidemics. If disease pressures increase due to earliness of sowing it may be prudent in future to alter the strategies to later sowing or the growing of spring-sown crops. The use of resistant cultivars is key to the management of future disease epidemics. Trends in current levels of resistance to disease in wheat cultivars provide an indicator of potential strengths and weaknesses over the next few years. Figure 9 shows the proportion of crops grown in England over the past twenty years which had low resistance (rating <=4) to the four main diseases. Overall levels of susceptibility to diseases have decreased significantly over the past ten years and show a positive trend for the use of cultivar resistance as a cornerstone of disease management strategy. However, the decrease in susceptibility to *S. tritici* has been matched by an increase in the susceptibility to yellow rust (due to popularity of a specific cultivar). This is a major risk, as cultivars which are highly resistant to one disease are often susceptible to another. A major challenge for the breeders will be to ensure that sufficient availability and breadth of resistance is available within crop cultivars, so that rapid responses can be made to changes in the dominance of the diseases posing threats to crops as a result of climate change.

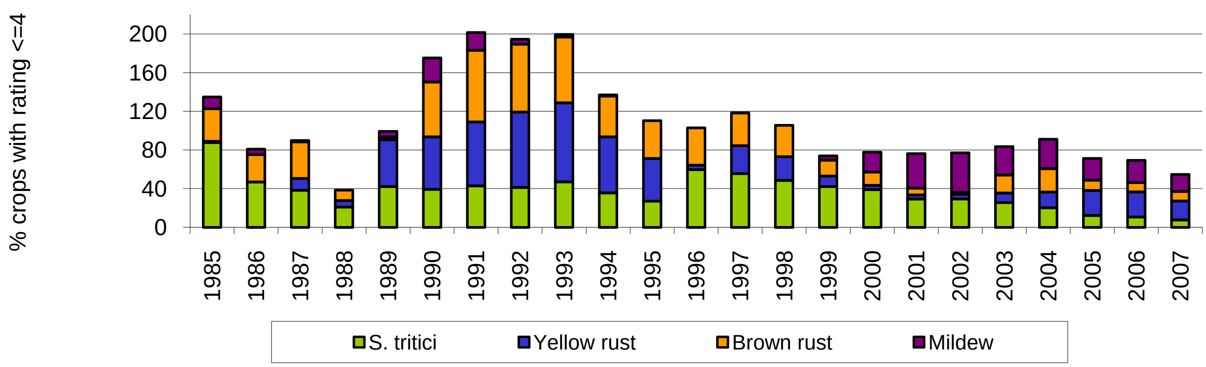

Figure 9. Percentage crops in national surveys with low levels of resistance to disease

Further adaptation is possible through increased risk analysis, awareness of likely disease problems and availability of reliable strategies to control major epidemics. The industry faced significant challenges in 2007 due to unusual weather conditions accelerating crop development in the early part of the season (crops were up to two weeks advanced in some regions) and a very significant epidemic of brown rust (analyses above indicate that these scenarios are likely to be more common under climate change). Monitoring activities made a major difference by alerting growers to the issues at a regional/local level and providing up to date in-season data on leaf emergence and disease development via a range of information services and media outlets. For example, leaf emergence data were available via Farming Online and CropMonitor websites and alerts on the developing brown rust epidemic were issued early in the season by CropMonitor and widely reported in the press. In the future, use of these and other information resources could play a major role in assisting growers to respond at a regional/local level to the challenges of managing disease epidemics driven by climate change.

Conclusions

Data from long-term monitoring of diseases in wheat crops in England shows that significant changes in the prevalence and importance of individual diseases have already occurred over the past 10-20 years. The frequency of damaging epidemics of *S.tritici*, brown rust and fusarium head blight has increased whereas epidemics of mildew and yellow rust have become less common. Significant fluctuations in disease levels occur from year to year but changes in disease prevalence do not specifically follow average trends in weather variables. Instead, data support the fact that disease epidemics are triggered at a much finer scale by more specific weather events. This indicates that the response to these seasonal differences will need a refined approach if risks are to be assessed accurately. Therefore, in assessing the likely impacts of climate change on diseases it will be important to examine the impacts of changes in weather patterns in detail, rather than at a gross scale. Data also highlight the importance and success of current management strategies in curbing the development of major epidemics and dealing with the changes in pathogen dominance.

Seasonal fluctuations in the severity of diseases will continue under climate change scenarios. However, because the different diseases on wheat are sensitive to different weather variables, it is likely that increases in one disease may coincide with decreases in one or others. In addition, sporadic problems with currently minor diseases such as tan spot may also occur. It is also likely that regional differences in disease risk will continue to be significant across the major wheat growing areas of the country. Predictions of future disease levels under climate change indicate that brown rust will become the primary target for disease control strategies, as this pathogen will be favoured by the warmer drier summers. Conversely, average levels of *S. tritici* are predicted to decline due to the reduction in rain events favouring disease dispersal. However, there will still be potential for high and low years for all diseases due to sporadic weather. A key output of the analyses was the significant influence of cultivar resistance on disease levels with the greatest differences and fluctuations in future disease levels occurring on susceptible cultivars.

Changes in climate will not only affect development of pathogen epidemics but also will affect development of the crop. Drought or water-logging will affect crop growth and yield and heavy precipitation may physically damage crops and prevent sprays being applied. Both crop, <u>and</u> disease, development are driven by accumulated temperature. However the degree of response is different, so changes in temperature may result in changes in the degree of synchronicity between the susceptibility of the crop and the peak dispersal and infection phases of the pathogen. These indirect effects of climate change on diseases will make risk prediction even more challenging; for example, a crop may grow away from a disease threat, or alternatively become susceptible at a far more critical time, or for a longer duration.

Under climate change the more unpredictable nature of the weather will create greater challenges in trying to respond to potential disease risks without resorting to the use of ever increasing amounts of fungicides. In-season responses to changes in disease risk will become more important as the weather patterns become more chaotic and outcomes of prevailing conditions become less easy to predict. Under such unpredictable weather, pre-planning programmes of disease control will become more difficult. This may lead to increases in inputs, making them less sustainable from economic, fungicide stewardship and environmental perspectives. As a consequence, in-season monitoring of epidemic development by growers, agronomists and expert systems such as CropMonitor will become increasingly important in measuring the influence of climate on disease pressure, crop growth and agronomic practice, particularly at the regional and local level. This, coupled with the use of resistant cultivars, w ill remain an essential core element of disease management strategy for the future, but will have to be approached at a more expert level. However, analyses suggest that with the use of robust agronomic practices and well-judged use of fungicides, these challenges can be managed, especially since current predictions are that overall yields in Northern Europe are likely to increase under climate change. Current breeding programmes will hopefully further strengthen this element to support adaptation of agriculture to meet the challenges of continued food security under climate change.

Acknowledgements

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