Impacts of climate change on phoma stem canker and light leaf spot on UK winter oilseed rape

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Abstract

To illustrate impacts of climate change on plant disease epidemics, an oilseed rape crop growth model, and weather-based disease forecasting models for phoma stem canker (Leptosphaeria maculans) and light leaf spot (Pyrenopeziza brassicae) were combined with projected UK temperature and rainfall under high and low carbon emissions climate change scenarios for the 2020s and 2050s. It was predicted that, if diseases are controlled, oilseed rape yields will increase, especially in Scotland. However, it was also predicted that phoma stem canker epidemics will not only increase in severity but also spread northwards from England to Scotland by the 2020s and that yield losses will increase to 50% in southern England if diseases are not controlled. There is evidence that the major gene for resistance to L. maculans Rlm6 is temperature-sensitive, since it operated at 15°C but not at 25°C. These results provide a stimulus to develop models to predict effects of climate change on other crop diseases. Such predictions can be used to guide policy and practice in adapting to effects of climate change on food security.
Keywords: climate change, crop growth models, food security, global warming, temperature-sensitive host resistance, weather-based disease forecasts

Introduction

Crop diseases threaten global food security because diseases cause crop losses, estimated at 16% globally despite efforts to control them (Oerke, 2006), in a world where more than 1 billion people do not have enough food (Anon., 2009). Thus, food production must be increased by controlling crop diseases more effectively. Food security problems associated with crop diseases are exacerbated by climate change (Garrett et al., 2006). There is a need to evaluate impacts of climate change on disease-induced losses in crop yields to guide government and industry policy and planning for adaptation to climate change. Phoma stem canker (Leptosphaeria maculans) and light leaf spot (Pyrenopeziza brassicae) are the two most serious diseases of winter oilseed rape in the UK, accounting for more than £150M of losses per annum (at a price of £300/t) despite expenditure of more than £12M on fungicides each growing season (http://www.cropmonitor.co.uk/). The distribution of these two diseases is greatly affected by climate, with phoma stem canker most severe in the warmer, drier south of England and light leaf spot most severe in the wetter, cooler west and the north of the UK (especially Scotland). Climate change affects plants in natural and agricultural ecosystems throughout the world but little work has been done on the impacts of climate change on plant disease epidemics. However, it is essential to include methods to control disease problems in strategies for adaptation to impacts of climate change (Evans et al., 2008). This paper reports work to estimate the impact of climate change on oilseed rape yield and losses from phoma stem canker and light leaf spot across the UK.

Materials and Methods

UKCIP02 scenarios predicting UK temperature/rainfall under high- and low-CO_2 emission scenarios for the 2020s and 2050s were combined with a crop simulation model for yield of fungicide-treated winter oilseed rape and weather-based regression models for severity of phoma stem canker (Evans et al., 2008) and light leaf spot (Welham et al., 2004) (http://www.rothamsted.ac.uk/leafspot/) epidemics to investigate crop-disease-climate interactions (Butterworth et al., 2010). The oilseed rape crop growth model (which assumed that diseases were controlled) predicted effects of climate change on yields for 14 UK sites for different climate change scenarios and results were mapped onto oilseed rape growing areas. Multi-site data collected over a 15-year period were used to develop and validate the weather-based models forecasting severity of epidemics of phoma stem canker and light leaf spot on oilseed rape across the UK. Phoma stem canker and light leaf spot yield loss predictions were also mapped onto these areas. Fungicide-treated yield and yield loss data were combined to estimate untreated yields for each region for each scenario.

As part of work to investigate impacts of climate change on crop resistance against pathogens, near-isogenic B. napus lines carrying/lacking resistance gene Rlm6 were used to investigate the effects of temperature and leaf wetness duration on phenotypic expression of Rlm6-mediated resistance against L. maculans (Huang et al., 2006). Leaves were inoculated with ascospores or conidia of L. maculans carrying the effector gene AvrLm6. Incubation period to the onset of lesion development, number of lesions and lesion diameter were assessed. Symptomless growth of L. maculans from leaf lesions to stems was investigated using a green fluorescent protein (GFP) expressing isolate carrying AvrLm6.

Results

Total area of oilseed rape grown in the UK in 2006 was 500,000 ha, with most grown in the east (Table 1). Predictions suggest that climate change will increase yield of winter oilseed rape crops treated with fungicide to control diseases (Butterworth et al., 2010). Baseline fungicide-treated yield was greatest in eastern England/Scotland (3.15 t/ha). The prediction is that in the 2020s and 2050s the greatest yields will be in eastern Scotland and north-east England, with increases in yield greater for the high CO_2 than for low CO_2 emissions scenarios and greater for the 2050s than for the 2020s. The total production was greater in England (1,430,000 t) than Scotland (113,000 t).

However, it was also predicted that phoma stem canker epidemics will increase in severity and spread northwards from England to Scotland by the 2020s and that yield losses (differences between fungicide-treated and untreated yields) will increase to 50% by the 2050s in southern England if diseases are not controlled. Predictions obtained by using the phoma stem canker severity model, a yield loss model and yield predictions from the crop model suggest that climate change will greatly increase yield losses from phoma stem canker, by comparison with the baseline, especially in England. Yield losses from phoma stem canker will be greatest in south-eastern England and total losses for England will be 264,000 t. In contrast with the predicted increase in severity of phoma stem canker epidemics (Evans et al. 2008), the incidence of light leaf spot was predicted to decrease. However, combined yield losses from both diseases are predicted to increase across the UK under climate change scenarios for the 2020s and the 2050s.

The predicted effects of climate change in the 2020s low CO_2 emissions scenario are to decrease untreated yields in all regions of England by 5 to 10%; conversely, the effect of climate change in Scotland will be to increase yield by 3% (Evans et al., 2010). In the 2050s high CO_2 emissions scenario, there is a predicted increase in yield for treated yield for both England (5%) and Scotland (12%) but a predicted decrease in untreated yield for England (11%) by contrast with a predicted increase for Scotland (4%). These predictions suggest that climate change will increase total production of fungicide-treated crops from the baseline of 2.69 Mt to 2.90 Mt in the 2050s high emissions scenario, with the amount produced in Scotland increasing. However, they suggest that total production of untreated winter oilseed rape in England will decrease from 1.17 Mt (baseline) to 1.04 Mt (2050HI).

Table 1 Effects of climate change on the yield of treated oilseed rape (OSR) (Tr) and untreated oilseed rape (Unt) after phoma stem canker losses, calculated by region. The untreated oilseed rape was calculated as the mean of susceptible and resistant cultivars. The area grown per region (2006) and the predicted average regional yield are given for the baseline (1960-1990) scenario. The predicted regional yield as a percentage of the baseline scenario is given for the 2020LO (low CO_2 emission), 2020HI (high CO_2 emission), 2050LO and 2050HI climate scenarios. The figures were calculated after interpolating the results from the treated oilseed rape yield predictions and the stem canker yield loss predictions according to UK government region[c].

Region [a]	Area OSR (ha) [b]	Baseline yield (t/ha)		Yield (% of baseline yield)							
				2020LO		2020HI		2050LO		2050HI	
		Tr	Unt	Tr	Unt	Tr	Unt	Tr	Unt	Tr	Unt
North East	22787	3.16	2.78	93.4	90.1	103.1	98.3	103.9	96.5	105.1	93.3
North West	3601	2.98	2.48	96.5	92.5	88.7	84.2	100.9	92.4	103.4	89.8
Yorks & Humberside	61068	3.12	2.64	95.0	90.7	102.8	97.3	102.4	93.8	103.1	89.3
East Midlands	113479	3.11	2.59	100.7	95.2	100.4	94.0	101.1	91.1	102.7	86.9
West Midlands	34419	3.00	2.37	99.6	94.2	83.4	78.2	103.5	94.0	107.6	91.4
Eastern	103488	3.16	2.58	100.0	94.5	99.7	93.1	103.0	92.8	104.7	88.3
London & South East	79063	3.01	2.34	100.8	95.4	100.9	94.4	103.7	93.0	106.9	89.1
South West	44858	3.05	2.41	100.3	95.1	100.5	94.2	103.1	93.7	106.7	90.7
England total	462764	3.09	2.52	99.3	94.1	99.5	93.4	102.6	92.9	104.8	88.9
Scotland	35780	3.15	3.06	104.8	103.2	107.1	105.0	109.7	96.9	111.5	103.6
UK total	498544	3.12	2.77	101.8	98.7	103.0	99.3	105.9	94.9	107.9	96.4

[a] Government regions can be found at http://www.statistics.gov.uk/geography/downloads/uk_gor_cty.pdf
[b] Area of winter oilseed rape grown in each region in harvest year 2006 (www.defra.gov.uk)
[c] Based on Butterworth et al. (2010), with corrected data for Scotland and UK total

In work to investigate impacts of climate change on crop resistance against pathogens, L. maculans produced large grey lesions on Darmor (lacking Rlm6) at 5–25°C and DarmorMX (carrying Rlm6) at 25°C, but small dark spots and 'green islands' on DarmorMX at 5–20°C. With increasing temperature, numbers of lesions/spots generally increased. GFP-expressing L. maculans grew from leaf lesions down leaf petioles to stems on DarmorMX at 25°C but not at 15°C. This provided evidence that temperature affects phenotypic expression of Rlm6-mediated resistance in leaves and subsequent L. maculans spread down petioles to produce stem cankers. Furthermore, worldwide, the most severe epidemics occur in Australia, with its Mediterranean climate.

Discussion

These results with diseases of UK oilseed rape demonstrate how climate change can increase losses from crop diseases. For UK winter oilseed rape, the increase in losses is associated with the increase in range and severity of phoma stem canker with global warming (Butterworth et al., 2010; Evans et al., 2008; 2010). Predicted losses from canker are substantial even though they may be offset by decreasing losses from light leaf spot. Such predictions illustrate unexpected, contrasting impacts of climate change on complex plant-disease interactions in agricultural and natural ecosystems. This work illustrates how, worldwide, increased disease losses may be associated with increases in severity of existing diseases or spread of diseases to new areas to threaten crop production (Garrett et al., 2006). Thus, there is a risk that the 16% of crop production lost to diseases (Oerke, 2006) may increase, with serious consequences for the 1 billion people who do not have enough to eat (Anon., 2009), unless appropriate strategies for adaptation to this effect of climate change are put in place. For example, there is a need for plant breeders to test new sources of resistance in countries with current temperatures similar to those predicted for the UK, to ensure that future resistance will operate effectively at such temperatures, as part of strategies for adaptation to climate change. To guide government and industry strategies for adaptation to climate change, there is an urgent need for reliable predictions of impacts of climate change on different diseases, obtained by combining impacts on crop growth and on disease epidemics with predicted future weather patterns (Barnes et al., 2010). Since it may take 10-15 years to develop a new fungicide or incorporate resistance to a crop pathogen from a novel source of resistance, it is important to identify future target diseases now.

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