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Using 3D virtual plants to evaluate the canopy role in the progression of a splash-dispersed crop disease: a case study based on wheat cultivar mixtures

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Highlights: A model taking into account physical mechanisms involved in splash dispersal of pathogens and host cultivar quantitative resistance has been developed to study the potential of heterogeneous three-dimensional crop canopies such as cultivar mixtures to prevent disease progression. We investigated different spatial organizations, proportions and resistance levels of wheat cultivars mixtures to allow better control of septoria tritici blotch.

Keywords: cultivar mixture, splash dispersal, septoria tritici blotch, wheat, modelling, heterogeneous canopy

INTRODUCTION

Increasing plant diversity within a crop by the use of cultivar mixtures is a strategy, that reduces severity of wind-borne diseases (Wolfe 1985; Finckh and Mundt 1992; Hau and de Vallavieille-Pope 2006). The interest of cultivar mixture practice for the case of rain-borne diseases was controversial. Depending on the study, results are inconsistent, for example previous studies showed rather significantly benefits for reducing splash dispersed diseases (Jeger et al. 1981; Mundt et al. 1995; Mille and Jouan 1997; Mille et al. 2006) or rather non-significant effects (Cowger and Mundt 2002). Septoria tritici blotch (STB), is one of the predominant foliar rain-born diseases on wheat crops caused by the fungus *Mycosphaerella graminicola*, and is regularly responsible for substantial yield losses up to 40% (Oste et al. 2000). Findings of Mille et al. (2006), show the interest of using wheat cultivar mixture to control STB. Recently Gigot et al. (2013) confirmed consistent reduction depending on disease pressure of STB disease severity by the use of cultivar mixture over four years. In this last study, it is also discussed that better control of STB should occur for specific proportions and resistance differences of wheat cultivar mixture of susceptible and resistant components. Newton et al. (1997) also confirmed that for the splash-dispersed *Rhynchosporium secalis* on barley, increasing the number of components brought more benefits on disease control. Therefore, to take full advantage of cultivar mixtures, the design of cultivar mixture needs improvement. Relying only on experimental knowledge can be tedious and time-consuming, for example Mille et al. (2006) had to test experimentally two component mixtures two by two for providing an optimal four components mixture.

We propose here to rely on modelling, to enhance and speeding up the process of designing efficient wheat cultivar mixtures on the control of STB. We investigated different mixture compositions such as spatial organizations, proportions and resistance levels. To do so, such model should at least take into account splash dispersal of spores and the inherently heterogeneous canopy properties of the cultivar mixtures (Calonnec et al. 2013). Because the spores are dispersed at short distances, due to the splashing mechanism from 0 to 20 cm (Fitt et al. 1989; Huber et al. 2006), and plant organs of different resistant types, are spatially heterogeneous, it leads to consider a spatial scale less than 1 cm for modelling dispersal. To reach such requirement, one solution is to describe the physical scene with the help of virtual three dimensional plants (Fournier et al. 2003), as it has been used for light interception computations (e.g. Chelle and Andrieu 1998).

MODEL DESCRIPTION

Here, we propose to focus on physical mechanisms involved in splash dispersal of a non-specialised pathogen within heterogeneous canopies of cultivar mixtures. For this purpose, we developed a framework that takes into account different mechanistic and stochastic models (Saint-Jean et al. 2008; Gigot 2013), including (i) the 3D spatial localization of wheat plant organs of at least two cultivars (periodic boundary conditions have been applied to simulate an infinite canopy); (ii) the calculation of droplet population dispersal based on Monte Carlo integration (Saint-Jean et al. 2004) within a 3D virtual scene; (iii) from this set of trajectories, the potential progression pattern of septoria tritici blotch is assessed on the whole canopy under several assumptions of cultivar resistance levels of the intercepted surfaces; (iv) the polycyclic nature of epidemics, forced by the rainfall occurrences, is modelled by iterating the previous calculations.

RESULTS AND DISCUSSION

Disease progression was computed for different wheat canopies. Highly susceptible pure stand, a moderately resistant pure stand, highly resistant pure stand and an equi-proportion mixture of the previous components have been tested. For those sets of canopies, initial inoculum was set at the fourth leaf (from the top) to 10% of leaf surface diseased. Three cycles of disease progression, *i.e.* pathogen generations or rain events, were computed. Evolution of disease severity (*i.e.* proportion of diseased surface over total leaf surface) was calculated on each leaf depending on their localisation in the canopy, level of resistance and the amount of the disease at the previous cycle. Here, we summed the disease of all the leaf levels of a plant to compute the progression of the disease at the canopy scale (Fig. 1). As it is expected, the more susceptible the cultivar is, the faster the disease progression is (Fig. 1). Comparatively to the mean of the pure stands, the progression of disease potential within the mixture was globally reduced by 35% after three dispersal cycles (Fig. 1). Such order of magnitude of disease reduction has been confirmed in field experiments (Gigot et al. 2013). Increasing both differences between resistance levels and proportion of the more resistant cultivar resulted generally in a higher expected protective effect against the pathogen. Nevertheless, this rule was not observed for very high proportions of a rather resistant cultivar.

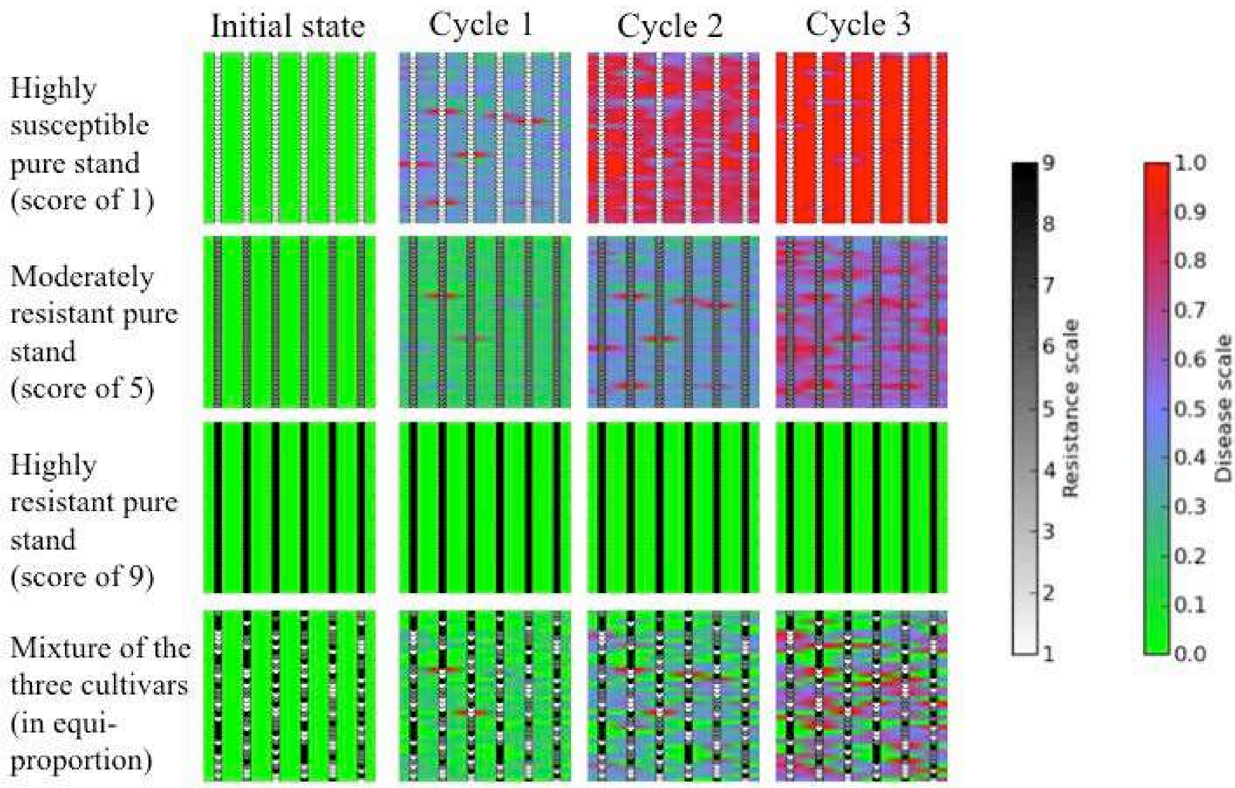

Fig. 1. Disease progression within a wheat cultivar mixture for 4 wheat canopy types (from top to bottom, highly susceptible pure cultivar; moderately resistant pure cultivar; highly resistant pure cultivar and three cultivar mixture in equi-proportion of the previous cultivars). Grey scale represents from light to darker the resistance scale. Colour scale (from green to red) represents the increasing potential of disease severity.

Our results illustrate that (i) mixture efficiency against a splash dispersed fungus may evolve differently across the successive pathogen generations, and (ii) optimal cultivar proportions can be established depending on resistance levels. Mixture component characteristics have to be precisely considered to find a compromise in terms of diversity within the field. Therefore such modelling approaches could be used for the design of cultivar mixture in order to find optimal and complementary properties of the mixture in order to integrate protective effects against splash-dispersed diseases among other beneficial properties of cultivar mixtures.

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