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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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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 cultivars mixtures to allow better control of septoria tritici blotch.

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

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
calculate 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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LITERATURE CITED


