Contents lists available at ScienceDirect



Agriculture, Ecosystems and Environment

journal homepage: www.elsevier.com/locate/agee

Research Paper

Effectiveness of field isolation distance, tillage practice, cultivar type and crop rotations in controlling phoma stem canker on oilseed rape



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ARTICLE INFO

Keywords: Yield loss Cultivar resistance Pathogen population Strategy ranking Spatially-explicit model Mosaic design

ABSTRACT

Modern agriculture has led to simpler agricultural landscapes that favour the spread of pathogens and increase pressure from pests and diseases. Landscape-dependent interactions between crops and pathogens, including disease related dispersal patterns, and the benefits of reducing pathogen significance call for the design of disease-suppressive landscapes. Model-based assessment is the most efficient method of choosing among management strategies. Based on a case study in France, we ranked the effectiveness of different crop mosaics for control of phoma stem canker on winter oilseed rape (WOSR). Assessed crop mosaics were developed from strategies defined by local stakeholders: (1) isolating target from source fields (all WOSR or only WOSR harbouring RlmX specific resistance), and (2) specifying tillage on WOSR stubble according to cultivar type (with or without RlmX). Model simulations highlighted the effectiveness of WOSR-isolation as compared to RlmX-isolation. Our analyses suggest that tillage (mouldboard ploughing) was the most important factor in explaining the size and genetic structure of the pathogen population (determinant in explaining the breakdown of resistance), and yield loss. While the pathogen population and yield loss decreased with intensive management of non-RlmXcultivars (85% of WOSR), the same management with RlmX-cultivars modified the genetic structure of the pathogen population. Increasing isolation distances led to reductions in pathogen population and yield loss only in the strategy of WOSR-isolation. Isolating source and target RlmX-cultivar had no effect on the evolution of the population's genetic structure. Although effective in phoma stem canker control, changing tillage can require significant changes for farms. Isolation distance would require extensive information on the landscape, and imply an aggregation of crops that might or might not be possible depending on a farm's spatial organization. This study could lead to the design of a Decision Support System targeting high risk (diseased) WOSR fields to be ploughed or isolated from the following year's cultivation.

1. Introduction

In recent decades, modern agriculture has led to the simplification of agricultural landscapes, both in terms of structure and crop composition (Stoate et al., 2001; Baessler and Klotz, 2006). This intensification process, linked with a simplification of cropping systems (Stoate et al., 2001), has strongly reduced crop genetic diversity in the field, thus favouring pathogen spread (Stuckenbrock and McDonald, 2008), and driving agrosystems towards increased vulnerability to pests and diseases (Meehan et al., 2011). With significant yield losses from pests and diseases (Oerke and Dehne, 2004; Oerke, 2006), crop arrangements in time and space (i.e., crop mosaics) represent a critical parameter to mitigate susceptibility to these losses. For instance, landscape composition and complexity have been identified as driving parameters of the rate of pollen beetle parasitism (Rusch et al., 2011), aphids and wheat diseases (Gosme et al., 2012), and the pathogen population structure responsible for wheat leaf rust (Papaix et al., 2011). These types of landscape-dependent crop-pathogen interactions and the desire to reduce pathogen significance call for the design of disease-buffering or disease-suppressive landscapes (Skelsey et al., 2010).

For pathogens exhibiting a dispersal process (either active, e.g., insects, or passive, e.g., wind- or water-dispersed), pest-suppressive landscapes have to be designed both in terms of composition (e.g., proportion of the different crops/cultivars; Papaix et al., 2011), and configuration, including the exact and relative locations of crops and associated cropping systems (Leenhardt et al., 2010). In addition, landscape temporal evolution has to be characterized as crop-pathogen interaction exhibiting a year-to-year relationship (e.g., for pollen beetle

http://dx.doi.org/10.1016/j.agee.2017.10.001 Received 19 May 2017; Received in revised form 3 October 2017; Accepted 5 October 2017

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in Rusch et al., 2011; for phoma stem canker in Bousset et al., 2015). The consideration of spatial and temporal scales depends on processes and knowledge about the specific topic to address (e.g., crop-pathogen interactions), leading to rules defined in time (crop rotations and crop return time; Castellazzi et al., 2010), and/or in space (isolation distance or buffering zones) (e.g., Skelsey et al., 2010 on potato late blight; Colbach et al., 2009 on maize gene flow).

Although disease-suppressive landscapes can theoretically be identified, their design and assessment remain challenging. Their design should begin by the identification of potentially efficient control methods (cultural, physical, biological or chemical), and their effect on pathogen populations, which have to be defined both in time and in space (Aubertot et al., 2006). Once identified, strategies that organize and coordinate these control methods on a landscape scale have to be built. Involving stakeholders in this step can help to develop and explore more suitable proposals (Brandenbourg et al., 1995), especially for agricultural landscapes where the choice and location of cropping systems are decided by local farmers (Primdahl, 1999), and influenced by local stakeholders (e.g., input providers, crop collector). Such involvement helps the integration of local specificities, providing more complete information on characteristics such as soil, climate, and markets (Reed, 2008; Voinov and Bousquet, 2010). Experimentation to assess the designed landscapes can be problematic, especially when exploring the effectiveness of several possible pre-identified alternatives, i.e. various arrangements of crops and control methods (Skelsey et al., 2010). Explorative modelling of the landscape system appears to be a suitable, and even necessary option. This method uses dynamic and spatially explicit models representing the necessary processes at field and landscape scales (e.g., Veldkamp et al., 2001; Lô-Pelzer et al., 2010b).

Phoma stem canker of oilseed rape (causal agent Leptosphaeria maculans fungus) is responsible for major yield and economic loss worldwide (Fitt et al., 2006) and is characterized by crop-pathogen interactions, and potential control methods, which are defined in time and space (Aubertot et al., 2006; Lô-Pelzer et al., 2010b). Its epidemic cycle exhibits a year-to-year recurrence, and the primary inoculum (spores) is produced on winter oilseed rape (WOSR) stubble. These spores are wind-dispersed up to 5-8 km (Bokor et al., 1975), and can subsequently fall and infect young oilseed rape (Hall, 1992). A distance of 500 m between fields has been highlighted as theoretically efficient to avoid epidemics (Marcroft et al., 2004). At field level, the main control method is the use of resistant cultivars. Two types of resistance can be used: quantitative (partial) resistance, controlling the extent of the disease (Delourme et al., 2006), or qualitative (specific) resistance (RlmX-gene), which prevents the disease if a common resistance gene is harboured by both the landing pathogen and the cropped WOSR cultivar (Plissonneau et al., 2016). However, large-scale cultivation with a qualitatively-resistant cultivar can quickly lead to the breakdown of its specific resistance (Rouxel et al., 2003), and require other associated control methods. Field control methods include WOSR sowing date, fertilization (Aubertot et al., 2004), tillage for WOSR stubble management (Schneider et al., 2006), and fungicide applications that are only effective during a limited time span (Gladders et al., 2006). These methods can help control the disease by two means: reducing the size of the pathogen population, and limiting the selection pressure on pathogen populations (Aubertot et al., 2006). To be efficient, these control methods have to be combined and organized in space and time through 'integrated' strategies that combine agronomic practices and/or the deployment of cultivar genotypes (e.g., minimum between-field distance) (Gladders et al., 2006; Sprague et al., 2006).

Integrating results (i.e., processes, scales) of empirical studies in a modelling framework can help to understand and tackle the many interactions between crop and pathogen and their spatio-temporal dynamics (e.g., on potato late blight in Skelsey et al., 2009, 2010). Indeed, such strategies cannot be tested in the real world because of their necessarily large spatio-temporal scales (Legg, 2004). Spatially explicit modelling is thus seen as very useful to assess performances of

strategies designed at large spatial and temporal scales (Hijmans and van Ittersum, 1996; Vinatier et al., 2016). Such models can then be used as virtual laboratories (Charnell, 2008) to conduct *ex ante* simulation experiments (i.e. strategy testing) at large scales. Using this type of models in combination with expert knowledge can improve the realism of such simulation experiments (e.g., Sadok et al., 2009).

For phoma stem canker of oilseed rape, SIPPOM-WOSR is, up to our knowledge, the only spatially explicit model taking into account the effects on disease development, in time and space, of the whole set of cropping practices impacting disease control, i.e., proportion and location of oilseed rape, cultivar type, sowing date and rate, fertilization and tillage practices, and fungicide application (Lô-Pelzer et al., 2010a,b). This model was applied on "extreme situations", by testing the effect on pathogen population size of two contrasted crop management plans (limited vs. good disease control) and two virtual landscapes (random location of spores' sources/targets vs. maximizing the distance between sources and targets) (Lô-Pelzer et al., 2010b). These simulations confirmed the general effect of crop management (tillage practices, sowing date and density) and source/field distances on Leptosphaeria maculans pathogen population (Lô-Pelzer et al., 2010b). As the implementation of integrated pest control strategies requires the participation of stakeholders (Rusch et al., 2010), SIPPOM-WOSR was then used in a participatory scenario approach, where local stakeholders numerically designed future cropping systems that could happen in case of contextual changes (Hossard et al., 2013). These cropping systems were simulated with SIPPOM-WOSR to assess their effect on phoma stem canker control, with regards to indicators describing the pathogen population (size, genetic structure) and subsequent yield loss. Simulations were analysed in order to (1) identify efficient scenarios (Hossard et al., 2015b), (2) highlight, rank and quantify the effect of the most impacting cropping practices (Hossard et al., 2013, 2015a,b), and (3) identify the spatial scale at which cropping practices influence the pathogen genetic structure (Hossard et al., 2015a). However, the simulations performed in these studies mostly corresponded to model 'testing' by the stakeholders, and led to a kind of "sensitivity analysis" on cropping practices, more than to the design coherent strategies. Indeed, the designed scenarios included extreme values for key variables (e.g., crop rotation, cultivar characteristics, random crop allocation) leading to a low chance that such scenarios would happen in reality (Hossard et al., 2013, 2015b), and thus provided a limited support for local stakeholders. Nevertheless, such models are of interest for local stakeholders as they can assess the effects of coordinated actions aiming at solving a local issue (Souchere et al., 2010). Following the previous studies on the most sensitive model variables, parameters and inputs (Lô-Pelzer et al., 2010a; Hossard et al., 2015a,b), SIPPOM-WOSR could then help local stakeholders to foresee the consequences on phoma control of different coherent strategies of cropping systems and their spatial distribution, contributing to support their strategic thinking by an *ex ante* assessment of multi-plot and multi-years strategies.

Based on a real-world case study located in France, this paper is aimed at characterizing, comparing, and ranking the effectiveness of different types of crop mosaics for phoma stem canker control. The designed crop mosaics were built from different cropping strategies, defined by local stakeholders: (1) isolating target fields from source fields in time and/or space, and (2) specifying tillage practices according to their cultivar type. These mosaics, describing both annual cropping plans and cropping systems, were assessed with SIPPOM-WOSR (Lô-Pelzer et al., 2010a,b).

2. Material and methods

2.1. Method overview

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