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Meta-modelling of the impacts of regional cropping system scenarios for phoma stem canker control

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ABSTRACT

In agricultural landscapes, pest and disease control mainly rely on cropping system characteristics and location. We have combined a participatory approach and a spatially-explicit model, to design and assess cropping system scenarios for future contextual changes in the small region of Picardie, France. Phoma stem canker of winter oilseed rape (WOSR), a widespread disease responsible for major economic losses, was used as a case study to investigate the effects of modifying cropping systems, at a regional scale, on disease controlling and on the sustainability of a newly introduced specific resistance gene (RlmX). Meta-models were fitted to assess the effects of cropping practices and weather conditions included in scenarios on three complementary model outputs: size of the pathogen population, yield loss, and fraction of the virulent population on RlmX-cultivars. We ran three replicates of each cropping practice scenario, varying the location of WOSR and associated cropping characteristics within the region. Outputs differed slightly between replicates, but there were no significant differences between replicates (alpha = 0.001) for each output. The size of the pathogen population was well explained by winter oilseed rape acreages, cultivar landscape composition and tillage, and the yield loss was explained by weather conditions and cultivars. The fraction of the virulent population on RlmX-cultivars was explained primarily by cultivar landscape composition. These differences in explanatory variables for the different outputs highlighted their complementarity. Cropping practices and weather impacts on the three variables remained consistent among the explored possible future contexts. Highlighting the most efficient cropping practices to be applied in the event of different future changes could help local decision-makers to design cropping practices in the face of contextual change.

1. Introduction

In agricultural landscapes, pest and disease control depends on cropping system characteristics. Disease severity is influenced by crop management practices modifying the host (i.e., the crop), the pathogen, or the environment (Krupinsky et al., 2002). Phoma stem canker (causal agent *Leptosphaeria maculans*) of winter oilseed rape (WOSR; *Brassica napus*) is an internationally important disease responsible for large economic losses (Fitt et al., 2006). Its control currently relies mainly on the use of resistant cultivars, which have quantitative partial resistance, limiting crop damage, and/or qualitative specific resistance, limiting pest attacks. The specific resistance, based on gene-for-gene interaction (Flor, 1971), stops disease development when the crop carries a resistance gene and the pathogen carries the corresponding a virulence gene (Delourme et al., 2006). However, due to widespread use of the same resistance gene, qualitative resistance can be overcome in a few years (Rouxel et al., 2003), and requires management to increase the duration of effectiveness. Aubertot et al. (2006) showed that preservation of resistance and disease control can be improved by (i) managing pathogen population size (quantitative feature), and (ii) limiting the selection pressure on pathogen populations (qualitative feature). These epidemiological components may be influenced by landscape composition in terms of proportion of host crop (Fitt et al., 2006; Skelsey et al., 2010), of cultivars (e.g., on wheat leaf rust epidemics, Papaïx et al., 2011; on virus in Fabre et al., 2012), including resistance gene deployment (Pink and Puddephat, 1999),

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and cropping practices (e.g., on phoma stem canker of oilseed rape, Lo-Pelzer et al., 2010). Spatial organization of WOSR fields during successive years also influences resistance sustainability (e.g., Lo-Pelzer et al., 2010). For phoma stem canker management, the design of control strategies requires scaling up from annual/field to multi-year/regional (Lo-Pelzer et al., 2010). Combining both resistance deployment and cropping practices in space and time may help disease control (Aubertot et al., 2006), since the epidemic cycles of this disease are characterized by year-to-year recurrence processes (Hall, 1992; Lo-Pelzer et al., 2009) and long-distance dispersal (5–8 km, Bokor et al., 1975).

For phoma stem canker of winter oilseed rape, the main cropping characteristics influencing the disease are cultivar choice (i.e., resistance characteristics; Lo-Pelzer et al., 2009), tillage practices after WOSR harvest (Schneider et al., 2006), fertilization during autumn and sowing dates (Aubertot et al., 2004). Designing sustainable strategies for phoma stem canker control requires these practices to be combined at large spatial and temporal scales (Lo-Pelzer et al., 2010). To assess the effects of combinations of practices, the use of a modelling approach integrates all the necessary variables (including cropping system characteristics) at the relevant spatial and temporal scales. It allows virtual experiments to be carried out that would have been impossible in the real world (Legg, 2004). Such experiments evaluate differences in cropping system characteristics, as well as their temporal and spatial locations, for disease control and resistance sustainability. For a complete assessment, all disease characteristics should be evaluated. Disease control and resistance sustainability include different parameters, which may differ between studies (e.g., in Brun et al., 2010; in Fabre et al., 2012). For phoma stem canker, disease development depends on the size of the pathogen population, its genetic structure, and severity (Lo-Pelzer et al., 2009, 2010).

Different methods can be used to design strategies at the landscape scale. In the case of agricultural landscapes, decisions about landscape changes and agricultural production are mainly taken by local farmers (Primdahl, 1999) and influenced by stakeholders acting at local and wider scales (e.g., crop collectors, markets). Based on their expertise on local agricultural conditions, stakeholders can envision possible technical changes (Carr and Halvorsen, 2001) in the face of modifications to the local and global context. These locally-decided proposals may be more suitable than generic ones (Brandenburg et al., 1995), as they take into account more complete information (Reed, 2008) on technically-feasible options, constraints, flexibility (Joannon et al., 2006) and cost-effectiveness (Voinov and Bousquet, 2010). To provide useful elements for decision-making on a large spatial scale, a participatory approach can be beneficial, especially when the effective strategies involve the coordination of several stakeholders, including farmers (e.g., on risks from runoff erosion, Souchere et al., 2010). These scenarios may differ among various contexts (Hossard et al., 2013), such as economics (market prices of crops, etc.), which may promote or influence specific crop choices. Designing and assessing strategies of cropping systems with stakeholders may then help to identify reliable and suitable cropping system options that could be used to cope with future contextual changes. The objectives of this paper were to (1) identify scenarios allowing efficient disease control, and (2) assess and rank ex ante the impacts of different cropping system scenarios on the control of phoma stem canker on a regional scale.

2. Materials and methods

2.1. Method overview

The cropping system scenarios presented in this study are sets of options that could be implemented in the event of future contextual changes, and the scenario ranking was done using regressions to build meta-models. The identification, assessment and ranking of efficient scenarios and cropping practices for phoma control was separated into several steps (Fig. 1):

(A) Based on the method proposed by Hossard et al. (2013), the first step was to design the future contexts and cropping systems that might apply if such changes were to occur. These scenarios were designed with local stakeholders, and defined by a combination of weather patterns and cropping practices. Each cropping practice was described at the regional scale by both the choice of a specific practice (e.g., type of tillage) and its level of adoption (i.e., the extent of this practice in the region).

(B) In the second step, we ran the collectively-designed scenarios with the spatially explicit numerical model SIPPOM-WOSR (Lo-Pelzer et al., 2010) to assess the effects of the new cropping systems on phoma stem canker control and resistance durability.

(C) The third step aimed to identify and characterize, for each future context, the cropping system scenarios that enable efficient control of phoma stem canker and/or resistance durability. Scenario outputs were compared to identify those minimizing one evaluation criterion.

(D) The last step was to identify and rank, for each future context, the cropping characteristics most determinant for phoma control, using linear meta-models.

2.2. Study area

The Picardie region of northern France was chosen for a case study. A field map was used to support simulations, corresponding to the Beauvais area (Fig. 2; 158 arable fields, 16.7 km^2, from 49°25′54.8″ to 49°28′51.2″N and from 02°09′13.0″ to 02°15′13.8″E). Weather data were provided by Meteo France from a weather station located at 49°26′42″N 02°07′36″E.

2.3. Scenario characteristics

In this study, a scenario is composed of detailed cropping practices linked to a contextual change. Scenarios generally include

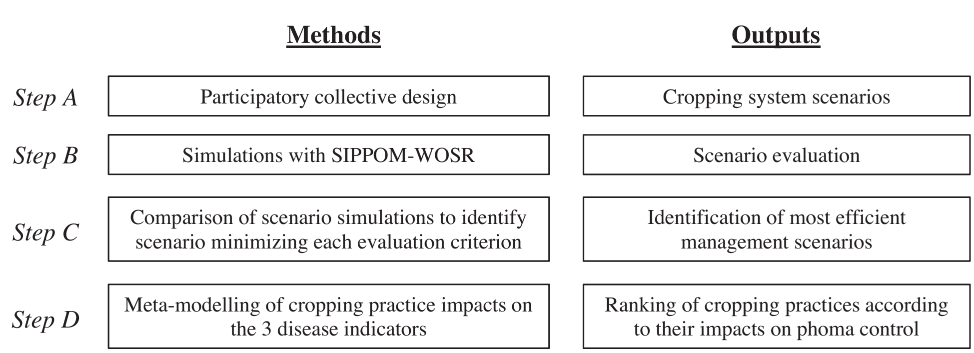

Fig. 1. Organization of the regional analysis of future scenarios: methods and expected results.