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SIPPOM-WOSR: A Simulator for Integrated Pathogen POpulation Management of phoma stem canker on Winter OilSeed Rape
II. Sensitivity analysis

E. Lô-Pelzer[a,*], J.N. Aubertot[b], L. Bousset[c], M.U. Salam[d], M.H. Jeuffroy[a]

[a] UMR 211 Agronomie, INRA, AgroParisTech, BP 01, F-78850 Thiverval-Grignon, France
[b] UMR 1248 AGIR, INRA, ENSAT, BP 52627 Auzeville, F-31326 Castanet-Tolosan, France
[c] UMR 1099 BiO3P (Biology of Organisms and Populations applied to Plant Protection), INRA, Agrocampus Rennes, F-35653 Le Rheu, France
[d] Centre for Cropping Systems, Department of Agriculture and Food, Western Australia, PO Box 483, Northam, WA 6401, Australia

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ABSTRACT

SIPPOM, a simulator for integrated pathogen population management, has been developed to assess and rank Integrated crop management (ICM) strategies, at the regional scale. The input variables are weather data, soil characteristics, the description of cropping systems (crop sequence and winter oilseed rape crop management) and their spatial distribution, plus the initial size and genetic structure of pathogen populations. Here, we use SIPPOM to simulate phoma stem canker severity, the genetic structure of the pathogen populations, and the yield loss caused by the disease. Sensitivity analysis is conducted to quantify how strongly state variables (sub-model output variables) respond to variations in parameters. The results indicate which parameters need to be more accurately estimated, and it elucidates the steadiness of the rankings of contrasting control strategies under various weather conditions when parameters were varied. Due to the complexity of SIPPOM, the scope of this work was limited to a sensitivity analysis of each sub-model independently. Three values of each parameter were tested under various environmental conditions and crop management according to their expected or known effects on disease and yield. Qualitatively speaking, variations in input variables and parameters provided sub-model output variables that behaved as expected by experts. Parameters with the greatest effect on state variables and that need to be estimated more accurately are for instance those related to pseudothecia maturation and disease severity index estimates. Improvements are foreseen (*e.g.*, the calculation of both the number of phoma leaf spots and the severity disease index). Because the ranking of the simulated control strategies remained steady, despite large variations in the simulated variables linked with variations in parameters, the sensitivity analysis shows that the model, as it stands, can be used to compare and rank ICM strategies with respect to their effectiveness. Possibilities of a sensitivity analysis of the overall model are discussed.

1. Introduction

Agricultural research is currently investigating alternative cropping systems for pest management to limit the use of pesticides in the field and preserve the efficiency of control methods over time (Tilman et al., 2002; Aubertot et al., 2005). Integrated Pest Management (IPM) combines different control methods (chemical, genetic, cultural, biological, and physical) to meet economical, ecological, and toxicological requirements (IOBC-SROP, 1973). In the case of disease management, genetic resistance, the main control method, is known to lose its efficiency over time because pathogen populations quickly adapt to specific resistance genes under selection pressure, sometimes leading to a complete loss of efficacy within just a few years (*e.g.*, Rouxel et al., 2003). To prolong resistance, it is necessary to reduce the selection pressure exerted on pathogen populations by applying a suitable strategy for the spatial and temporal use of cultivars (McDonald and Linde, 2002), while, at the same time, it is necessary to reduce the size of pathogen populations by combining cultural and chemical control methods (coined 'Integrated Avirulence Management' by Aubertot et al., 2006a).

In the case of airborne diseases, the dispersal of inoculum often exceeds field boundaries. In addition, many diseases are polyetic. Rather than approaching the issue from the often used field and crop cycle scales, designing control strategies at a regional and

* Corresponding author at: INRA-Centre de Recherches de Versailles Grignon, UMR 211 Agronomie, Bâtiment EGER, BP 01, 78850 Thiverval-Grignon, France. Tel.: +33 1 30 81 45 84; fax: +33 1 30 81 54 25.
E-mail address: Elise.Pelzer@grignon.inra.fr (E. Lô-Pelzer).

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multi-year scale should be further investigated (Aubertot et al., 2006a). SIPPOM-WOSR, a simulator for integrated pathogen population management for winter oil seed rape (Lô-Pelzer et al., 2010), has been developed to assess and rank Integrated crop management (ICM) strategies, at these scales, accounting for cultural practices, cultivar choice, and chemical control according to their ability to bring phoma stem canker under control while preserving the efficiency of specific resistances. The model simulates the disease severity and the genetic structure of this pathogen population (in terms of pathotype frequencies) in each field of a given region, as well as yield, gross margin, and environmental cost of cultural practices applied to manage the crop and to control the disease.

Sensitivity analysis of a model aims at determining how sensitive the outputs are to variability in any one of several elements, such as the values of the parameters or the input variables (Monod et al., 2006). In order to improve the predictive quality of a model, Ruget et al. (2002) and Makowski et al. (2006) emphasized the importance of pinpointing the parameters that need to be estimated with a higher precision. In the case of complex models such as SIPPOM, which has 316 parameters (Lô-Pelzer et al., 2010), a sensitivity analysis to variations in parameters is particularly useful as the estimation of some parameters can require specific experiments that are time-consuming and often difficult to set up (Makowski et al., 2006). Moreover, the aim of SIPPOM is to rank strategies that would control phoma stem canker. Despite any uncertainty in the estimations of parameters, the ranking of strategies has to be stable when parameters are varied if the model is to be used to this end. A sensitivity analysis to input variables in order to identify which crop practices impact more outputs and to select for ICM strategies (*e.g.*, Breukers et al., 2007) is not to be neglected; however, given the complexity of SIPPOM, the sensitivity to parameters is an issue in and of itself.

The two objectives of the sensitivity analysis to variations in parameters that is presented here were (i) to pinpoint the parameters that need to be estimated with a higher precision and (ii) to test the steadiness of the rankings of contrasting control strategies under various weather conditions when parameters were varied. In the first part of this paper, the structure of SIPPOM-WOSR is briefly described and the method used to conduct an independent sensitivity analysis of each sub-model is detailed. This entails the parameter values, the management strategies and weather conditions in addition to the output variables. Parameters that need to be estimated with a higher precision are identified and discussed, as well as the behaviour of each sub-models depending on contrasting input variable values. Finally, the next step, a sensitivity analysis of the overall model to input variables, is evoked.

2. Materials and methods

2.1. Description of the SIPPOM-WOSR model

The SIPPOM-WOSR model has been described in detail by Lô-Pelzer et al. (2010). It is composed of five sub-models (Fig. 1).

The primary inoculum production sub-model simulates the primary inoculum production of *Leptosphaeria maculans*, the causal agent of phoma stem canker. Pseudothecia mature on stubble left on the soil surface after harvest and produce ascospores, the primary inoculum (Hall, 1992). This sub-model calculates, between the harvest of the crop in the previous season and the beginning of winter in the given season, (i) the impact of tillage on vertical dis-

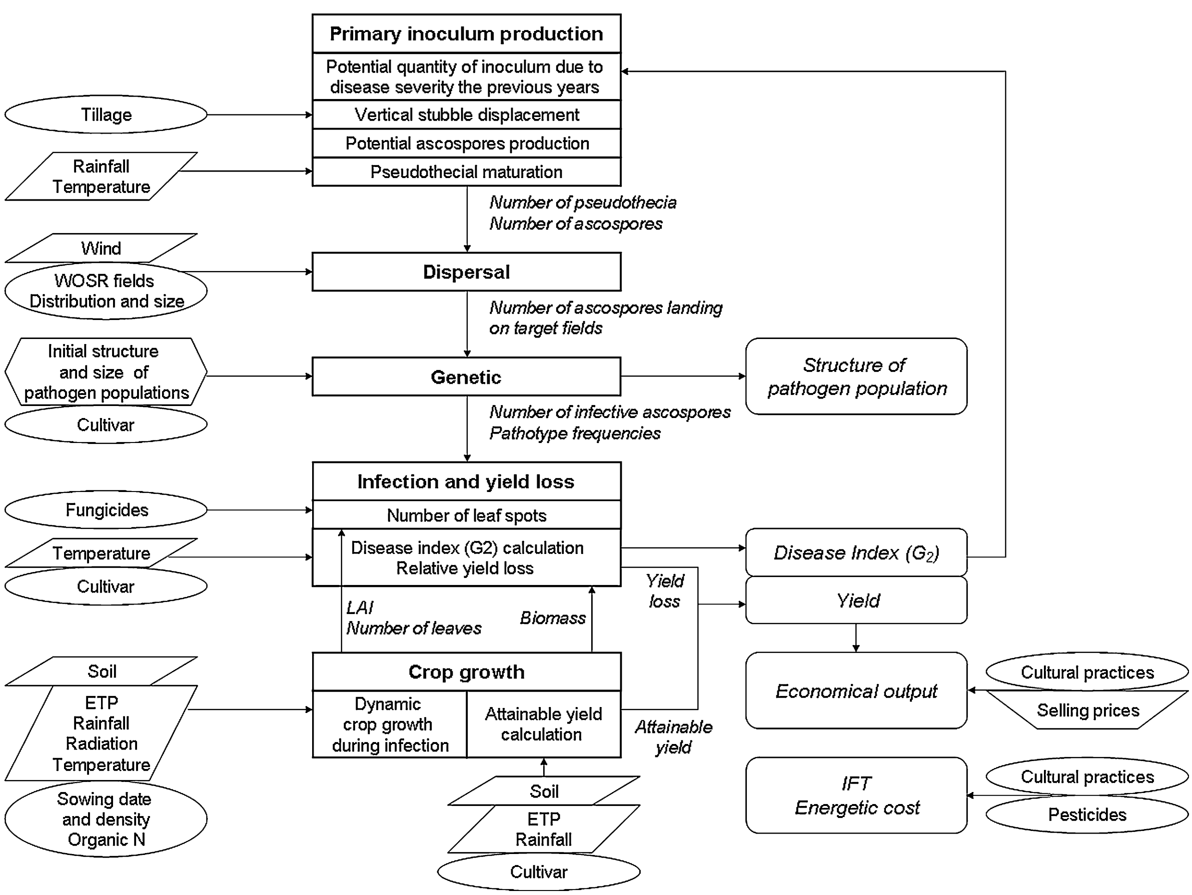

Fig. 1. Flow chart of SIPPOM-WOSR. Sub-models, as well as parts of sub-models for the sensitivity analysis, are represented by squares, weather and soil input data by diamonds, technical input data by ovals, and output data by rounded squares. Output variables of each sub-model (state variables of SIPPOM) are shown in italics. The structure of pathogen populations is an input variable (initial structure), as well as an output variable.