

A participatory approach to design spatial scenarios of cropping systems and assess their effects on phoma stem canker management at a regional scale

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Souchère

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Corresponding Author: Mrs. Laure Hossard, M.D.

Corresponding Author's Institution: INRA/AgroParisTech

First Author: Laure Hossard, M.D.

Order of Authors: Laure Hossard, M.D.; Marie-Hélène Jeuffroy, PhD; Elise Pelzer, PhD; Xavier Pinochet, PhD; Véronique Souchère, PhD

Abstract: Phoma stem canker is a worldwide disease of oilseed rape, responsible for major economic losses. The main control methods are the use of resistant cultivars, cropping practices and spatial territory organization, involving large-scale spatial processes. A participatory approach can be useful for dealing with this problem, which requires stakeholders' coordination as regards to the timing and spatial layout of cropping practices. The scenario concept is used to plan possible future cropping systems and to reveal their main drivers. In this paper, we test a method to build quantitative land use scenarios and to test them with an existing spatially-explicit model to assess the effects of various scenarios on phoma stem canker management. It was built from previous participatory methods. The method we tested is composed of six steps: stakeholder identification, building with them a common vision of the disease behaviour, collective scenario design, and discussion with stakeholders of modelbased scenario evaluations. We tested this method on a regional case study application in France. This application revealed benefits of the method with respect to the diversity of the designed scenarios (predictive and exploratory scenarios; driven by local or global context change) and the diversity of results on phoma stem canker management. Based on this application, recommendations for participation improvement and model acceptance are made: (1) build a partnership with a key local stakeholder; (2) describe and discuss precisely model functioning with stakeholders (avoid the "black box"); and (3) facilitate interpretation of scenario assessment by adapting model outputs. This method, combining a participatory approach (qualitative and quantitative construction of scenarios and their evaluation with an existing model) highlights the potential benefits of involving stakeholders in attempting to solve a local problem, in this case, phoma stem canker management.



We combined participatory workshops and an available model for a scenario study. Stakeholder trust in the model required a dialogue on disease-practices interactions. Stakeholders designed context-dependent predictive and exploratory scenarios. Model-based scenario evaluation provided information on management options. The tested method could help the use of existing models for local management issues. 1 1. Introduction

> Phoma stem canker (caused by Leptosphaeria maculans) is a worldwide disease of oilseed rape, responsible for major yield and economic losses (Fitt et al., 2006). In a context of an increasing oilseed rape area and production in Europe (Eurostat, 2011), controlling this disease is of prime importance, through (i) a reduction in the pathogen population size and (ii) a limitation of the selection pressure on pathogen populations (Avirulence Management concept. Aubertot *et al.*, 2006). The main field control method is the use of resistant cultivars: partial (quantitative) resistance, reducing the effect of the disease (Delourme et al., 2006) or specific resistance halting the disease if the pathogen and plant harbour a common resistance gene (Flor, 1971). Yet specific resistance can be quickly overcome if the pathogen population adapt when cultivars with this resistance are grown on large areas (Rouxel *et al.*, 2003), leading to risks of large epidemics and subsequent economic losses because of the breakdown of the resistance. Other control methods include cropping practices, e.g. sowing date, fertilization (Aubertot et al., 2004) and tillage practices after winter oilseed rape harvest (Schneider *et al.*, 2006). However, studying phoma stem canker requires scaling up in both time and space. Firstly, considering the landscape scale is necessary to control this disease, as the responsible pathogens are wind-dispersed up to several kilometres (5-8 km; Bokor *et al.*, 1975). Secondly, management strategies have to be planned for the medium term because of the epidemic cycle of the disease, i.e. the disease in a given year affects its severity in the next year, as primary inoculum develops on oilseed rape-infected residues (Hall, 1992). According to Sprague et al. (2006), these "integrated strategies" have to consider cropping practices, cultivar resistance and deployment. While scaling up, control methods may thus involve distributions of cropping practices over time and space (Lô-Pelzer et al., 2010a), including genotype deployment (Delourme et al., 2006), but also the proportion of oilseed rape within the landscape (Fitt *et al.*, 2006). Thus cropping systems enabling sustainable disease control

through an increase in the duration of cultivar resistance efficacy have to be managed on a regional scale to minimize disease incidence, helping to stabilize yields and keep oilseed rape economically competitive. With this aim, a spatially explicit numerical model (SIPPOM-WOSR; Lô-Pelzer *et al.*, 2010a; 2010b) has been developed to support the design and assessment of scenarios of regional cropping system management to allow efficient control of the disease and resistance sustainability.

To study potential impacts of spatially distributed cropping systems, land use scenarios can be very useful. Van Notten (2005) describes scenarios as "descriptions of possible futures that reflect different perspectives on past, present and future developments", consisting of an initial situation and a description of driving forces inducing a specific future (Alcamo & Henrichs, 2008). Scenarios require identification and consideration of the main drivers of future changes (Dockerty *et al.*, 2006). The causes of change can be physical/ecological (e.g. climate change), social and/or economic (e.g. political, urban). Designing, analysing and assessing future scenarios for phoma stem canker management require consideration of the regional context, together with the spatial extent of the disease and the stakeholders' activities affecting and/or affected by the disease.

For issues involving large-scale spatial processes, designing land use scenarios can benefit from a participatory approach: different studies have shown the value of involving stakeholders concerned with the coordination of actions to promote scenarios that are effective with regard to the issue (e.g. on erosive runoff risks, Souchere et al., 2009). Indeed, local stakeholders take or influence decisions for agricultural production and landscape changes (Primdahl, 1999), so it is appropriate for them to propose ways of solving the problems involved (Voinov & Gaddis, 2008); with solutions probably better adapted to local socio-cultural and environmental contexts (Reed, 2008). Cropping system scenarios aimed at controlling a disease without jeopardizing yields or profits are therefore likely to be better

when designed together with stakeholders, whose actions (e.g. input choice, collected crops, advice) and coordination influence cropping systems.

In participatory studies, scenarios have often been designed by research teams themselves, for the purpose of analysis, evaluation and/or discussion with various stakeholders (e.g. Bacic et al., 2006, Dockerty et al., 2006, Tress & Tress, 2003), sometimes to include stakeholders' preferences (e.g. Tompkins et al., 2008), recommendations (e.g. Lippe et al., 2011) or objectives (e.g. Nidomulu *et al.*, 2007). When scenario design *per se* has been participatory, it has often resulted in qualitative scenarios (e.g. Walz et al., 2007; Kok et al., 2006), i.e. narratives/storylines. Translating these into quantitative scenarios that are required for model simulations can be difficult (Alcamo, 2008). In most studies, this type of conversion has been realized with interactions between stakeholders and modellers occurring prior to modelling, either by co-designing or adapting the modelling framework (e.g. Cornwell, 2004; Therond et al., 2009 respectively). However, few procedures have been described in the literature for a (semi-) quantitative description of key variables by stakeholders. "Fuzzy Cognitive Map" (FCM) is the main semi-quantitative method for participatory scenario development (e.g. Kok, 2009; van Vliet *et al.*, 2010). Although this method can improve the consistency between qualitative scenarios and quantitative models, quantifications by stakeholders are relative and mostly concern the relationships between the key variables instead of the variables themselves. The FCM method thus does not provide direct model parameterization by stakeholders. Two methods for direct estimation of scenario key variables have been proposed recently: Fuzzy Sets (Alcamo, 2008; Dubrovsky et al., 2011) and Bayesian statistical reasoning (Kemp-Benedict, 2010). The Fuzzy Sets approach combines a collective description of qualitative changes by stakeholders with "linguistic variables" (e.g. low/moderate/high change); and individual quantifications of these qualitative changes by stakeholders. These individual opinions, resulting in a distribution of values, are then

combined by the research team to be translated into a single variable value (Dubrovsky *et al.*, 2011). This last step can hinder the reliability of this value, as extreme opinions can potentially strongly influence it. This problem is partially solved by the Bayesian statistical reasoning, which provides a probability distribution of variable values (Kemp-Benedict, 2010), based on the qualitative description of how a variable differs from its reference value. Thus detailed and accurate reference distributions are crucial. Kemp-Benedict (2010) proposed to use historical data to do so, but the availability of such data clearly depends on the considered issue and its working scale. For local issues (e.g. phoma management), the required level of detail on numerous variables could make this method hardly feasible.

In this paper, we aimed at designing, directly with stakeholders, diverse scenarios of cropping systems, numerically-described and linked to possible future contexts and their uncertainty. The objectives of this work were twofold. The first objective was to test on a case study a method for the participatory design of quantitative scenarios of local cropping systems and their assessment with an available model. The second objective was to evaluate this method in order to provide recommendations and guidelines for its improvement. The case study concerned the regional management of phoma stem canker and of the sustainability of a new resistant gene. The Rlm7-gene was used as an example; this gene was introduced in some cultivars in 2004 and is still efficient.

2. Materials and methods

2.1. Study area

The study area was the "Centre region" of France (46°N, 2°E, Figure 1), which is France's
main producer of Winter OilSeed Rape (WOSR), providing 20% of the total French
production in 2010 on about 15% of the region's arable land (Agreste, 2011). A threefold

99 increase in the area cropped with WOSR has occurred in the "Centre region" since the early
90s, from 92300 ha in 1990 to 305300 ha in 2010 (Agreste, 2011).

This region has experienced numerous phoma stem canker epidemics, which were particularly severe in the late 90s. These large epidemics were due to the rapid loss of a specific resistance efficacy (Rlm1), which has been intensively used in the "Centre region": registered in 1992 and widely introduced in 1995, cultivars with this gene represented more than half of the total acreage of WOSR grown in 1998-1999 (Rouxel *et al.*, 2003).



Figure 1. Location of (A) study site (white rectangle) and (B) landscape modelling support (white: cropped lands; black: uncropped lands, i.e. farmhouses; forests; fallow lands)

The precise area used for simulations (step 5 of the method, Figure 2) is located in the "Centre region", around Civray (Figure 1). An area of 121 fields was chosen (Lô-Pelzer *et al.*, 2010a), whose landscape characteristics and cropping practices are representative of the region according to local experts (Regional Cetiom: the French technical centre for research and development of oilseed production, hereafter referred as the Specialist Technical Organization). Present-day cropping systems, based on local farmers' interviews and described in previous studies (Lô-Pelzer et al., 2010) are composed of about 31% of oilseed rape per year throughout the considered area (Table 1) and mean field size is 14 ha. These data are in accordance with statistical data (analyses performed by the authors on the database Agreste – Enquêtes sur les pratiques culturales, 2006) and expert knowledge (interviews of

the main stakeholders, see description in 2.2.2 and Table 1). This area can thus be considered as representative of the region, with respect to cropping systems and landscape characteristics. This 17 km² zone extends from 46°56'07.05'' to 46°59'42.4''N and from 02°07'10.3'' to 02°11'26.9''E (Figure 1). It is composed of 21 ha of forests (3 plots), 12.4 ha of farmhouses (2 plots), 9.2 ha of fallows (4 plots) and 1656.8 ha of cropland (112 plots). Five main soil types have been identified in the studied area by field regional monitoring (189 fields). At each field was attributed one of the five soil types, according to their regional importance (Lô-Pelzer *et al.*, 2010a).

Weather data for this zone provided by Meteo France were used (weather station located at
46°59'30" N 02°10'54" E). This zone often experiences mild wet autumns, which can favour
phoma stem canker development on WOSR leaves (e.g. in controlled environment
experiments; Huang *et al.*, 2006).

Variable	Value
WOSR frequency	31%
Sowing dates	from 22/08 to 09/09; about 86% of WOSR areas sown between 25/08 and 04/09
Mean sowing densities	44 seeds.m ⁻² for hybrids and 62 seeds.m ⁻² for lines
Nitrogen fertilisation	13% of WOSR areas with organic nitrogen fertilisation at sowing
Cultivars	19% of WOSR areas sown with Rlm7-cultivars; 75% of WOSR areas sown with high level of quantitative resistance cultivars; 5% with cultivars with a low level of quantitative resistance; 1% of WOSR areas sown with susceptible cultivars
Tillage after WOSR harvest	28% of WOSR mouldboard ploughed after harvest; 21% with one stubble breaking operation, followed by one harrow operation and one chisel operation; 21% with one stubble breaking operation only; 12% with one harrow operation only; 18% with one stubble breaking operation followed by one chisel operation (7%), one harrow operation (7%) or one stubble breaking operation (4%)
Autumn application of Fungicide/growth regulator	On 63% of WOSR areas

 Table 1. Main characteristics of reference situation of the study area in "Centre region"
(France), based on farmers' interviews about their cropping practices during the period 20042008

- 145 2.2. Methodological approach
- 146 2.2.1. General framework of the method

147 The method developed combines participatory scenario construction, numerical modelling

148 and participatory scenario evaluation; all the main stages involving stakeholder participation

(Figure 2). This method, mainly based on previous participatory methods, is composed of six

steps, which are detailed below.



Figure 2. Schematic representation of the methodological approach developed in this study.
 Circular arrows represent feedback loops.

Box lines reflect the involvement of stakeholders in the different steps: boxes bordered by dotted lines indicate no interaction with stakeholders; boxes bordered by solid lines represent involvement of some stakeholders, with information derived from other sources (e.g. literature, national statistics); boxes bordered by dashed+dotted lines represent participatory workshops.

171 2.2.2. Identification of relevant stakeholders

The first step to implement a local participatory scenario design is the identification and selection of all stakeholders whose activities could be substantial for local management of the concerned issue. The research team first determined the stakeholders to be involved, based on their impacts on the possible technical levers for the disease control.

176 2.2.3. Interview of stakeholders

After identification of the main stakeholders to be engaged in the study, gaining knowledge on local practices and local stakeholders is necessary, in order not to omit stakeholders who could be relevant and not pre-identified by research team (Reed, 2008). Thus, we interviewed the local stakeholders who have an in-depth knowledge of WOSR growing in the region: the local Specialist Technical Organization, the main technical advisors (the local Chamber of Agriculture) and the main crop collector. They were interviewed on two items: (1) local cropping systems and (2) identification of the different stakeholders to be involved in the study, with information on their concerns and courses of action (e.g. van den Belt *et al.*, 2010) over phoma stem canker.

2.2.4. Building a common scheme of phoma behaviour and of stakeholders' effects on phoma management

Once all stakeholders were identified and the research team gained insight into regional cropping and organisational characteristics through interviews, the challenge was how to involve stakeholders and build a common background on the disease functioning. Since no serious phoma epidemic has occurred in the region since 2002, the control of phoma stem canker by lengthening the duration of effective resistance is now an academic topic. Thus, in order to involve stakeholders in this issue, and make them aware of the possible consequences of a return of phoma stem canker on WOSR, we decided to build with them a scheme of their shared vision of phoma stem canker, taking inspiration from the ARDI (Actors, Resources,
Dynamics and Interactions) method (Etienne *et al.*, 2011). The objectives of this scheme were
fourfold: (i) for the stakeholders to identify the cultivation techniques (under their control)
which might affect the disease; (ii) to give stakeholders confidence in the modelling
framework supporting simulations and its underlying hypotheses, through a comparison of the
scheme on resources and dynamics they created and the SIPPOM-WOSR functioning scheme;
(iii) to ensure stakeholder representativeness and (iv) to involve stakeholders in a learning
process regarding the processes involved in stem canker management. During a four-hour
collective working session, participants were invited to present their visions of the behaviour
of the disease and potential technical levers, and of the stakeholders whose actions may
impact phoma control methods (e.g. cultivar choice, residue management), i.e. to represent
their mental model on disease functioning and acting stakeholders.

2.2.5. Scenario design of winter oilseed rape evolution

After a consensus has been reached among participants on the important levers for phoma stem canker management, a second four-hour working session was devoted to the scenario design of future WOSR cropping conditions. A scenario is composed of necessary detailed inputs for SIPPOM-WOSR simulations, i.e. specification (value) for the seven variables, defined yearly at field and/or at regional scale: WOSR acreages, sowing dates, sowing densities, cultivars (with or without the RlmX-gene), nitrogen fertilization at sowing (product type and fertilization rate), autumn fungicide application (date) and tillage after WOSR harvest.

At the beginning of the session, a short presentation was made to:

- Describe model behaviour, required inputs and possible outputs, and identify precisely the variables on which the scenarios could differ (i.e. variables described in Table 1)

- Present characteristics of the simulation support landscape

- Present a reference situation representing recent local practices (Table 1): cropping systems and WOSR cultivation techniques, as well as cultivars (based on earlier interviews with farmers whose cropped fields in 2004-2008 were considered in the simulation support landscape) and numerical simulation results of this scenario.

Then, stakeholders were asked to imagine futures/trends for WOSR in their region and to describe what contextual changes, either local or global (e.g. political, economic, epidemiological, etc.), would be necessary for such futures to materialize. To illustrate French national tendencies, national acreages of WOSR since 1989 (data Agreste) were presented. Finally, stakeholders were asked in an open discussion to illustrate the identified futures with detailed WOSR acreages (linked with crop sequences) and cultivation techniques, that could affect phoma stem canker control, i.e. cropping characteristics corresponding to model inputs (variables of Table 1), including their quantitative assessments. As phoma stem canker control can depend on interactions between techniques (e.g. cultivar and sowing date, Aubertot *et al.*, 2004), stakeholders were asked about combinations of cultural practices, as well as about the factors governing the location of cropping systems and crop management (e.g. relationships between soil types and cultivation techniques).

236 2.2.6. Scenario simulation with SIPPOM-WOSR

In order to assess consequences of management scenarios designed by stakeholders,
numerical simulations of these scenarios were realized using the numerical modelling
framework SIPPOM-WOSR; a Simulator for Integrated Pathogen Population Management
(Lô-Pelzer *et al.*, 2010a; Figure 2). It is a spatially explicit model simulating the dynamics of
pathogen population evolution (size and genetic structure) and consequent effects of phoma
stem canker on yield resulting from spatially-distributed cropping systems. This model

highlighted stable ranking of a wide range of oilseed rape management strategies, ranking
being consistent with experts' opinions (Lô-Pelzer *et al.*, 2010b). It integrates five submodels: (i) production of the primary inoculum, (ii) dispersal of the pathogens, (iii) genetics
of the pathogen population, (iv) crop growth, and (v) plant infection and calculation of the
subsequent yield losses.

Model inputs are a map of detailed cropping systems for each field (which is the simulation unit), weather data, and the initial size and genetic structure of pathogen populations. Outputs, for each simulation year at field scale, are disease severity, yield losses due to phoma stem canker, and the genetic structure of the pathogen population (i.e. frequencies of virulent and avirulent pathogen for a major resistance gene that are able and unable respectively to infect WOSR varieties with this resistance gene). Initial frequency of virulent pathotypes on RlmX-gene cultivars has been fixed to 10⁻⁷ of total pathogen population size.

Scenarios defined by stakeholders were run with the model for simulations of five years (one year for model initialization and four years of simulations). When no specific rule was available for crop or crop management allocation, these were allocated at random to fields using R software V2.10.0 (R Development Core Team, 2009) to obtain a mixed landscape, changing every year according to crop rotations, for both WOSR cropped area and WOSR management techniques. There were three replicates for these allocations.

261 2.2.7. Discussion on scenario evaluations

Finally, the last step of the method was comprised of a third four-hour workshop. It presented and discussed the numerical evaluation of scenarios. After a brief presentation of model characteristics and of the previously designed scenarios, scenario simulation results for the last simulation year and the whole landscape were presented. This included graphical representations of all scenarios for the output variables Yield losses, Size of pathogen

population and Frequency of virulent pathogen; and a summary of the more important input variables (i.e. cropping characteristic) that impacted these outputs).

After the presentation, stakeholders were asked to share their analysis on the scenario simulations and other scenarios they could imagine, to initiate an iterative process between scenario design and discussions.

Results 3.

3.1. Characteristics of the stakeholders, derived from interviews

Three types of stakeholders were interviewed: the main crop collector (representing 65% of oilseed rape collection in the area), the local Specialist Technical Organization (two persons: the regional advisor and the manager of local crop experiments) and the main extension and advisory service, i.e. the local Chamber of Agriculture (Table 2).

Their visions of current agricultural systems and crop management strategies for WOSR were largely in agreement with each other and with detailed data collected on the simulation area (Table 1). The general vision of stakeholders' organization for WOSR production/collection and involvement in phoma stem canker management were also consistent: the interviewed stakeholders considered that (i) policy makers have moderate courses of action and are not concerned by phoma management; (ii) extension and advisory services are highly concerned but have limited courses of action; (iii) crop collectors (cooperatives and retailers) are highly concerned and have several courses of action; and (iv) breeders have the most concern about phoma management and the most courses of action. According to the interviewed stakeholders, farmers' behaviour is more contrasting. Farmers' concern on phoma may depend on their experience, i.e. if their crop already suffered from phoma stem canker. Interviewed stakeholders had different opinions on the Specialist Technical Organization

(Cetiom) behaviour: its courses of action were considered to be few by the main cropcollector and many by the Chamber of Agriculture.

According to the different interviews, the identified stakeholders affect WOSR management in different ways. Breeders influence cultivar characteristics (e.g. sensitivity to disease) and their potential availability for cooperatives/retailers. Crop collectors affect crop management by restricting farmer choice through the inputs they sell (e.g. fungicides and cultivars) and by their advice on cultivar choice. Farmers are the final decision makers for oilseed rape cultivar choice and practices. Their practices can be constrained by policy, e.g. on dates for tillage practices. They are advised by the extension and advisory services, who communicate experiments results on WOSR cultivar and crop management strategies. These experiments are mainly conducted by the local Specialist Technical Organization (Cetiom) and influence breeder strategies.

Degree of stakeholder involvement in/concern about WOSR crop management for phoma stem canker depends on the possible consequences of the disease's return: Yield loss for farmers (and indirectly for advisory services), crop collectors and Cetiom; need for innovation for crop breeders in case of resistance failure.

Stakeholders' courses of action will impact phoma stem canker management either directly (e.g. farmers' choices of cultivation practice) or indirectly (e.g. communication). Although these courses of action cannot be directly taken into account in the model SIPPOM-WOSR, they are translated into actions on cropping systems, which are the main inputs of the model (cf. Part 3.4). Stakeholder concerns will impact the model output to be studied by the research team.

Type of stakeholder	Step 2. Interviews	Step 3. Scheme building	Step 4. Scenario design	Step 6. Scenario result discussion
Decision makers				

Farmers	-	1	1	1
Crop collectors	1	1	2	2(1)
Crop breeder	-	2	0	0
Specialist				
Technical	2	2	0	1
Organization				
Extension and	1	Δ	2	1
advisory services	1	-	2	1
Policy makers	-	1	1	0
Other stakeholders				
Researchers	-	5	3	3
Total	4	15	8	7

Table 2. Type and number of stakeholders attending to the four steps of the method stakeholders were involved in (c.f. Figure 2 and paragraph 3.1. for details on the types of stakeholders). Italics underline the participation of a new stakeholder from an organization that had already attended to a previous workshop.

Study participant vision of phoma behaviour and stakeholders' management options 3.2. This step resulted into two schemes presenting (a) resource dynamics (resources: cultivation techniques, stubbles, etc.) affecting phoma stem canker and the type of relationships between the resources; and (b) stakeholders' impacts on cultivation practices (e.g. testing, regulation) and type of relationships between stakeholders (e.g. communication). These schemes, collectively constructed during the first workshop, showed that the main relevant stakeholders were involved in the study, i.e. every stakeholder included in the stakeholders' scheme (b) was identified in steps 1 and 2 (Figure 2) and invited to workshops. Direct comparison between the resource dynamics scheme of the model (based on Lô-Pelzer *et al.*, 2010a; 2010b) and the one designed by stakeholders (scheme a) highlighted that the model structure was in accordance with stakeholders' vision of the disease (although some factors are absent from the model, e.g. working time, machine availability). Attendance at this workshop was high (15 people), with representativeness of all stakeholder type and some diversity within type (e.g. two crop breeders, four for extension and advisory services) (Table 2).

Participatory scenario design 3.3.

A summary of the future trends imagined by the stakeholders was made in order to get structured scenarios with all the details required for model inputs. Quantifications of model inputs were designed as implicit comparisons (i.e. "increase" or "decrease") with the reference situation (Table 1), as expressed by stakeholders during the workshop (Table 2). Three main trends were identified (Table 3), corresponding to different contextual changes (political, epidemiological, economic or regulatory contexts). Trend A assumes an increase in WOSR area (in comparison with the reference situation), which seems the most plausible to the different stakeholders, in accordance with the national trend and the development of biofuels. This global trend results in shorter crop rotations (e.g. WOSR-Winter Wheat-Barley becomes WOSR-Winter Wheat), which are associated with varieties containing quantitative and/or qualitative resistance, different areas with mouldboard ploughing, and an increase in autumn nitrogen applications. Trend B assumes a decrease in WOSR area, which might occur if WOSR became less profitable or if policies were to change, e.g. if nitrate regulations were to increasingly restrict the time window for tillage practices, work organization could need to diversify crops to decrease working pressure at a certain time. This trend was associated with longer crop sequences, current varieties and cultivation practices; except for autumnal nitrogen applications. Trend C assumes a significant increase in areas with mouldboard ploughing after WOSR harvest, which would occur either if the current qualitative resistance would quickly be overcome and thus become inefficient, or if the herbicide glyphosate would be banned, in conformity with current policies to reduce pesticides. This trend is associated with cultivars with quantitative resistance and an increase in autumnal nitrogen applications (Table 4).

Workshop participants (Table 2) associated the three trends with two climatic datasets: (1) current data (2003-2008); and (2) weather data favouring development of phoma stem canker

epidemics (i.e. with wet mild autumns). Participants associated fungicide applications on
WOSR with the second weather dataset. They asked the research team to define this weather
dataset as the repetition of the year presenting the highest temperatures and rainfalls in
September and October in the last ten years.

A. Ir comp situa	ncrease of WOSR areas (in		e e	Other changed variables	
	parison with the reference ation)	Present economic trend; biofuel production increase	Crop sequences	Cultivars, tillage, sowing dates nitrogen fertilisation frequency fungicide frequency, climate	
		WOSR net return decrease			
B. Decrease of WOSR areas (in	Nitrate regulation change, restricting time-windows for tillage	C	Nitrogen fertilisation frequence		
situa	comparison with the reference situation)	Policy change to promote longer crop rotations	Crop sequences	fungicide frequency, climate	
C. In mou	C. Increase of areas with mouldboard ploughing after	Overcome of currently used qualitative resistance (RlmX)	Tillage frequency after	WOSR frequency, nitrogen fertilization, fungicide frequent	
WOS	SR harvest	Banning of glyphosate	wost harvest	climate	

For the three trends, stakeholders identified soil type as the location factor for crop rotation, tillage practices, nitrogen fertilization and fungicide applications. No association between cropping practices was suggested at this stage, except for the sowing densities, which were determined by cultivars.

For the three trends, stakeholders suggested extreme values for the different variables. For instance, for trend A, stakeholders proposed an increase from 33% to 50% of the whole cropped area sown with WOSR. A 50% WOSR frequency corresponds to a two-year crop rotation (WOSR – Winter Wheat) on the whole area, already occurring locally in some farms. As some stakeholders questioned the sustainability of such a crop rotation, stakeholders also decided on a three-year crop rotation (WOSR - Winter Wheat - Barley) with up to 33% of the local area cropped with WOSR. In order to compromise between the two WOSR acreages, the research team suggested scenarios with intermediate variable values (e.g. 42%), to try considering more plausible regional configurations and explore the consequences of making smaller changes.

Once workshop participants had defined the main variable specification for a trend (i.e.
WOSR crop areas for trends A and B vs. mouldboard-tilled areas for trend C; Tables 2 and 3),
ranges for other variables were defined. Participants decided to define these ranges
independently for each variable. All combinations were thus simulated.

For instance, for trend A, stakeholders defined (Table 4): (i) three specifications for sown
cultivars; (ii) one specification of WOSR sowing date; (iii) one specification for sowing
density; (iv) three specifications for organic nitrogen fertilization at sowing; (v) two
specifications for fungicide treatment depending on weather conditions; and (vi) three
specifications for mouldboard tillage practices after WOSR harvest. As stakeholders did not
mention links between variable values, all combinations of variable specifications lead to 162

scenarios for trend A. Following the same methodology for trends B and C, the total number

of scenarios was 234 for the three trends (Table 4).

Variable	Trend A: Increase of WOSR acreages	Trend B: Decrease of WOSR acreages	Trend C: Increase of mouldboard ploughing after WOSR cultivation
WOSR frequency -% of total area-	33; 42; 50%	26.7; 28.9; 30%	30; 33; 42%
Sowing dates	From 15/08 to 05/09 (peak between 20 and 30/08)	Reference values	Reference values
Mean sowing densities	45 s.m ⁻² for line cultivars; 35 s.m ⁻² for hybrid cultivars	45 s.m ⁻² for line cultivars; 35 s.m ⁻² for hybrid cultivars	45 s.m ⁻² for line cultivars; 35 s.m ⁻² for hybrid cultivars
Nitrogen fertilisation - % of total area- (on shallow; deep soils)	10% (20; 0); 22.5% (35; 10); 35% (50; 20)	10% (20; 0); 22.5% (35; 10); 35% (50; 20)	10% (20; 0); 22.5% (35; 10); 35% (50; 20)
Cultivars	100% RlmX-cultivars; 100% with high partial resistant cultivars; 50% RlmX and 50% of high partial resistant cultivars	Reference proportions for RlmX and non-RlmX cultivars	100% of high partial-resistant cultivars
Tillage	0; 10; 20% of WOSR acreages	Reference values	30; 40; 50% of WOSR acreag
Fungicide	On 10% of WOSR acreages if wet and warm climate option; 0 otherwise	On 10% of WOSR acreages if wet and warm climate option; 0 otherwise	On 10% of WOSR acreages if wet and warm climate option; otherwise
Weather	Current; warm and wet	Current; warm and wet	Current; warm and wet
	162	18	54

387 3.4. Model-based scenario simulation

Simulations of the 234 scenarios had to be performed with the modelling framework
SIPPOM-WOSR. As stakeholders did not define specific localization factors for WOSR
and/or practices during the scenario construction workshop (except for tillage and nitrogen
fertilization, linked with soil type), three replicates for the random spatial distribution of crop
and practices were used, leading to 702 scenarios (234 scenarios x 3 replicates) (Figure 3).



Figure 3. Example of one year-random cultivar allocation (3 replicates of the same scenario). Cv : cultivar ; WOSR: Winter OilSeed Rape

3.5. Scenario evaluation and discussion with stakeholders

3.5.1. Model-based scenario evaluation

Model-based simulation of co-designed scenarios resulted in very diverse results for the three main output variables, i.e. frequency of virulent pathotypes on RlmX-cultivars, yield losses and size of the total pathogen population, i.e. including all pathotypes (Figures 4 and 5, -only one replicate presented for trends A and C for brevity-). Trends B and C (decrease in WOSR acreages and increase in mouldboard ploughed areas respectively) showed lower yield losses and sizes of total pathogen population than trend A (increase in WOSR acreages) (Figures 4 and 5). Trend C showed lower frequency of virulent pathotypes on RlmX-cultivars than trend B. Trend B mean frequency of virulent pathotypes on RlmX-cultivars was lower than for trend A. Trend A displayed very variable results for frequency of virulent pathotypes on

RlmX-gene, from 0 to 100% of virulent pathogen (Figure 4). This is due to the large extent
explored for the model input frequency of RlmX-cultivars in the area in this trend (Table 4,
Figure 4). For trend A, only scenarios with no RlmX-cultivars had lower frequency of virulent
pathotypes on RlmX-gene than the reference situation (Figure 4).

Trends B and C had lower yield losses and sizes of the total pathogen population than the
reference situation (Figures 4 and 5). Trend C had mostly lower frequency of virulent
pathotypes on RlmX-gene than the reference, due to the absence of RlmX-cultivars in this
trend, consistent with trend A results with the same cultivar configuration. Trend B displayed
different frequencies (but rather high) of virulent pathotypes on RlmX-cultivars, which
highlighted the importance of rules for locating and combining crops and practices (Figure 5).
Main explanatory variables differed between model outputs (Figure 4) but were consistent
between trends (data not shown).





Trend A (162 scenarios): fig. a and c; Trend C (54 scenarios): fig. c and d. Round symbols
represent scenarios of trends A and C; square symbols are for the reference situation (see
Tables 1 and 4 for description). Main cropping variables (i.e. explanatory variables) impacting
outputs are summarized in the black boxes.



Figure 5. Scenarios simulation results (three replicates): Yield losses depending on Frequency of virulent pathotypes on RlmX-cultivar (figures a,
b, c) and Size of total pathogen population (figures d, e, f) for trend B. Trend B (18 scenarios): Decrease of WOSR areas in link with
economical/political changes. Round symbols hold for scenarios of trend B; squared symbol holds for reference situation.

474 3.5.2. Scenario collective discussion

During the workshop, study participants (Table 2) expressed to the research team that scenarios evaluations highlighted relevant features to them. For instance, they highlighted that the information on cropping practices' ranking for phoma stem canker management could help them to adapt their technical advices (see Figure 4). They recognized the temporal and spatial scales of the model as valuable to see consequences of individual choices on phoma stem canker management. Indeed, although they acknowledged that field scale is their main working scale; past phoma epidemics showed them the necessity of considering the interannual and inter-fields processes, for which the modelling approach is very informative. Moreover, discussions also highlighted some elements stakeholders found missing in the model (e.g. intercropping practices, crop mixtures, partial resistance behaviour over time) that could affect phoma management.

During the discussion of the simulation results the reference situation was challenged. Although it had been presented to stakeholders during the second workshop, prior to the participatory scenario design, stakeholders asked for its reappraisal, concerning cultivars, as well as types and dates of tillage operations. This reference situation was considered too local, i.e. taking into account very local contextual issues as for instance the nearby presence of pig farms affecting the type, level and frequency of organic nitrogen fertilization. Thus, study participants were willing to explore a new reference situation, that differed for some cropping practices (e.g. nitrogen fertilization, soil tillage timing).

494 At the end of the workshop, stakeholders discussed the driving forces necessary for cropping 495 practice changes and the impacts of such changes. For example, increasing WOSR frequency 496 in the crop rotation would involve a reduction in deep soil tillage (more direct sowing) due to 497 lower working-time availability. For instance, one participant insisted on the "attractiveness

of increasing crop rotation duration" with regard to phoma stem canker management but put it into perspective with economic and agronomic contexts: "such an option would face profitability and realization problems, as farmers would have to grow for instance sunflower [i.e. to add it in the crop sequence], which is less profitable (its price is falling and it competes with winter wheat) and hard to grow due to its susceptibility to bird damage and water requirement [that may not be fulfilled under local weather conditions]". Study participants lacked economic information to judge scenarios, to be able to put into perspective yield losses due to stem canker and profitability at the rotation scale.

Finally, the participants suggested broadening the study object, by coupling SIPPOM-WOSR with models simulating other diseases, insects and weeds. They pointed out that tackling a disease, in this case phoma stem canker, could affect the control of other pests, e.g. weed control. They concluded that focusing on one issue may have undesirable effects on another one, thus requiring enlarging the scope of the topic.

4. Discussion

In this section we will discuss the tested method, and not the results that are mainly casespecific.

In this paper we have tested a method of participatory quantitative scenario design, with
phoma stem canker management as a case study. This method includes stages for
stakeholders' identification, analysis of their courses of action, collective discussions on the
issue functioning, and finally the design, model-based evaluation and discussion of future
scenarios implying cropping system change and subsequent effects on phoma stem canker
management. Using this method, the case study for the "Centre region" highlighted
possibilities to directly derive quantitative scenarios with a participatory approach,
overcoming the classic problem of converting narratives into quantitative data (Alcamo, 2008;

Walz et al., 2007) in spite of the topic's complexity. This participatory future development provided insight into different types of drivers for the future: global vs. local changes (e.g. economic, political or regulatory, vs. epidemiological drivers respectively). These drivers were associated to different types of scenarios (as defined in Borjeson *et al.*, 2006): predictive forecasting scenarios (e.g. current economic trends), predictive "what-if" scenarios (e.g. regulatory change) and exploratory external scenarios (i.e. policy change). These futures led to diverse impacts on the agricultural context (crops and cropping practices). Biological processes of phoma stem canker evolution were thus considered in this study, as proposed by Blackstock et al. (2007), "in the context of their social-economic drivers and responses", taking into account local knowledge (Patel *et al.*, 2007) and local needs and priorities (Dougill et al., 2006).

Although we invited all types of stakeholders to join in the study, and most attended at least one workshop, attendance dropped after the first meeting on disease behaviour (Table 2). A reason for this decline is that since the disastrous phoma epidemics that occurred prior to 2002, the disease has been perceived as less serious in the region due to the use of new resistant cultivars harbouring RlmX-gene (Rlm7 being the gene presented as an example to stakeholders), whose resistance has not yet broken down. Thus the priorities of many of the stakeholders did not match those of the research team. The research team was unknown to stakeholders prior to the study and had not received adequate publicity before the project began. Building a robust partnership, at the beginning of the study, with a key local actor could have helped to overcome this problem (Ericson, 2006), even when using a pre-developed model. Trust between the research team and stakeholders is indeed a key element for a successful participatory study (Voinov & Gaddis, 2008). Study institutionalization may also have helped participation (Cornwell, 2004; Reed, 2008). Although participation was relatively low (Table 2), a diverse set of stakeholders was present at each step of the

workshop (Wallerstein, 1999). The most influential of institutions on the local WOSR growing conditions were present at each step (e.g. the main crop collector; the Chamber of Agriculture). These institutions can be considered as the most relevant stakeholders on this issue; their participation being of prime importance (Reed, 2008; Voinov & Bousquet, 2010). The systematic attendance of scientists with a deep understanding of the issue was also useful for scenario design (Pahl-Wostl, 2008). An increased participation of farmers may have led to better structured scenarios, reflecting a more systemic point of view on interlinked cropping practices. This could also had been achieved by creating Fuzzy Cognitive Maps with stakeholders (e.g. van Vliet et al., 2010), in order to highlight relationships and feedbacks between key variables (e.g. WOSR acreages and tillage). However, the large scope of scenarios designed by stakeholders may not have been improved by a larger participation, as the consequences on phoma management were already very large (Figures 4 and 5). This large scope, with different values tested per variable for each scenario, allowed to take implicitly into account "uncertainty", as proposed in Bayesian statistical reasoning (Kemp-Benedict, 2010).

The "trust" issue also led to model "testing" resulting in some exaggerated aspects of scenarios, such having only one WOSR cultivar grown or 2-years rotation in the whole area; leading to some kind of "sensitivity analysis" on cropping systems' inputs. Such scenarios were exploratory and led to extreme scenario assessment for the considered output variables. These evaluations, although biologically sound and in accordance with the functioning of the SIPPOM-WOSR model based on system dynamics, would most probably not occur in reality as there is little chance that those scenarios would happen. These evaluations often showed a strong increase in disease pressure in comparison with the reference situation. This led study participants to want to update the reference situation. Indeed, they considered that it underestimated risks of phoma epidemics because of its local peculiarities. This issue might

have been avoided by building confidence with stakeholders earlier in the process (e.g. Therond *et al.*, 2009), illustrating model functioning by giving more details on the relationships between the key processes and variables (Lô-Pelzer et al., 2010a; 2010b) therefore providing more transparency of the system representation in the model (Leenhardt *et* al., 2012), or by building the reference situation during a workshop (Leenhardt *et al.*, 2012). However, the desire to reconsider the reference situation could also be linked to the arrival of new participants in the last workshop (albeit not new stakeholder types or institutions, see Table 2), who did not participate in the scenario elaboration and were less willing to accept the scenario evaluations (Patel et al., 2007). As highlighted by Peterson et al. (2004), unstable participation may indeed be a challenge, threatening consensus reaching, by orienting discussions towards a single interest at the expense of a more systemic view. This was the case here, as discussions were shifted at the last workshop by new participants from the considered issue to other crop-related problems (e.g. weeds).

Finally, the methodological framework tested in this paper allowed us to build quantitative scenarios directly with stakeholders for their model-based assessment. The model had to be accepted by the stakeholders, as the method involved the use of a pre-existing model, instead of co-designing or co-adapting the modelling framework (e.g. Vayssieres *et al.*, 2011). Methods for group model building are numerous, aiming at either building qualitative models (Causal Loop Diagrams, Videira et al., 2012), semi-quantitative models (Fuzzy Cognitive Maps, van Vliet et al., 2010) or formal models (Bayesian Belief Networks, Pollino et al., 2007). Although the first two methods structure and (partly) quantify the system dynamics, with a focus on feedbacks, their complexity can quickly increase so that they become hard to explain and thus to quantify. Bayesian Belief Networks require high-knowledge stakeholders; and time and efforts for its parameterization can often be overwhelming. Although these methods will facilitate scenario construction and quantification for the co-developed models,

they may not achieve the necessary numeric variable estimation. Moreover, several models, designed by scientists only, are available to deal with scenario simulation of complex issues. For these models to be used in participatory studies, model acceptance by stakeholders can be challenging, leading in some participatory studies to the necessity of co-developing a new model (e.g. Pedersen & Grant, 2004). In our study, model acceptance was partly the result of collective discussions about disease processes (model processes) and model outputs in an iterative dialogue. Such dialogue is recognized as necessary for both improving information exchanges and building trust with stakeholders (Parker et al., 2002; Leenhardt et al., 2012). Discussions on output customisation could also have increase model acceptance, through an adaptation of raw model outputs into indicators easier to interpret (Leenhardt *et al.*, 2012). An integrated analysis of scenarios could have helped the evaluation of the trade-offs between the different model outputs, thus providing information for disease "risks" in front of contextual change.

610 5. Conclusion

The proposed and tested participatory method combined the involvement of a diversity of stakeholders, the design of qualitative and quantitative scenarios and their evaluation with a pre-existing model. In spite of the complexity and scale of the studied system, the tested method made it possible for stakeholders to build a range of scenarios with highly diverse impacts on phoma stem canker management. This method proposes a "package" ranging from the identification of a local problem by researchers to the exploration, analysis and discussion with stakeholders of potential future levers for its management. The method could be used for quantitative scenario design for problems whose processes are strongly influenced by stakeholders seeking a sustainable solution. To improve the implementation of the method for scenario design presented here, we would recommend, for participation improvement and easier model acceptance, to (1) build a partnership with a local key actor, who could locally

promote the study and participate to build trust between the local stakeholders and the
research team (in case the team is locally unknown); (2) give more insight to stakeholders on
model functioning and processes instead of only key variables; and (3) facilitate
interpretation on scenario assessment through model output customization.

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Figure 1. Location of (A) study site (white rectangle) and (B) landscape modelling support (white: cropped lands; black: uncropped lands, i.e. farmhouses; forests; fallow lands)



Figure 2. Schematic representation of the methodological approach developed in this study. Circular arrows represent feedback loops.

Box lines reflect the involvement of stakeholders in the different steps: boxes bordered by dotted lines indicate no interaction with stakeholders; boxes bordered by solid lines represent involvement of some stakeholders, with information derived from other sources (e.g. literature, national statistics); boxes bordered by dashed+dotted lines represent participatory workshops.

Variable	Value
WOSR frequency	31%
Sowing dates	from 22/08 to 09/09; about 86% of WOSR areas sown between 25/08 and 04/09
Mean sowing densities	44 seeds.m ⁻² for hybrids and 62 seeds.m ⁻² for lines
Nitrogen fertilisation	13% of WOSR areas with organic nitrogen fertilisation at sowing
Cultivars	19% of WOSR areas sown with Rlm7-cultivars; 75% of WOSR areas sown with high level of quantitative resistance cultivars; 5% with cultivars with a low level of quantitative resistance; 1% of WOSR areas sown with susceptible cultivars
Tillage after WOSR harvest	28% of WOSR mouldboard ploughed after harvest; 21% with one stubble breaking operation, followed by one harrow operation and one chisel operation; 21% with one stubble breaking operation only; 12% with one harrow operation only; 18% with one stubble breaking operation followed by one chisel operation (7%), one harrow operation (7%) or one stubble breaking operation (4%)
Autumn application of Fungicide/growth regulator	On 63% of WOSR areas
Table 1. Main characteristics	of reference situation of the study area in "Centre region"
(France), based on farmers' in	nterviews about their cropping practices during the period 2004-

Та	ble	2
	210	_

Type of stakeholder	Step 2. Interviews	Step 3. Scheme building	Step 4. Scenario design	Step 6. Scenario result discussion
Decision makers				
Farmers	-	1	1	1
Crop collectors	1	1	2	2(1)
Crop breeder	-	2	0	0
Specialist Technical Organization	2	2	0	1
Extension and advisory services	1	4	2	1
Policy makers	-	1	1	0
Other stakeholders				
Researchers	-	5	3	3
Total	4	15	8	7

Table 2. Type and number of stakeholders attending to the four steps of the method stakeholders were involved in (c.f. Figure 2 and paragraph 3.1. for details on the types of stakeholders). Italics underline the participation of a new stakeholder from an organization that had already attended to a previous workshop.

Main trend	Context change	Main variable changed	Other changed variables
A. Increase of WOSR areas (in comparison with the reference situation)	Present economic trend; biofuel production increase	Crop sequences	Cultivars, tillage, sowing dates, nitrogen fertilisation frequency, fungicide frequency, climate
	WOSR net return decrease		
B. Decrease of WOSR areas (in comparison with the reference situation)	Nitrate regulation change, restricting time-windows for tillage Policy change to promote longer crop rotations	Crop sequences	Nitrogen fertilisation frequency, fungicide frequency, climate
C. Increase of areas with mouldboard ploughing after WOSR harvest	Overcome of currently used qualitative resistance (RlmX) Banning of glyphosate	Tillage frequency after WOSR harvest	WOSR frequency, nitrogen fertilization, fungicide frequency, climate
Table 3 Main characteristics of the	three trends collectively designed during	the first workshop	

Table 3. Main characteristics of the three trends collectively designed during the first workshop WOSR: Winter Oilseed Rape; RlmX: specific resistance currently cropped; s.m⁻²: seeds per square meter

Variable	Trend A: Increase of WOSR acreages	Trend B: Decrease of WOSR acreages	Trend C: Increase of mouldboard ploughing after WOSR cultivation
WOSR frequency -% of total area-	33; 42; 50%	26.7; 28.9; 30%	30; 33; 42%
Sowing dates	From 15/08 to 05/09 (peak between 20 and 30/08)	Reference values	Reference values
Mean sowing densities	45 s.m ⁻² for line cultivars; 35 s.m ⁻² for hybrid cultivars	45 s.m ⁻² for line cultivars; 35 s.m ⁻² for hybrid cultivars	45 s.m ⁻² for line cultivars; 35 s.m ⁻² for hybrid cultivars
Nitrogen fertilisation - % of total area- (on shallow; deep soils)	10% (20; 0); 22.5% (35; 10); 35% (50; 20)	10% (20; 0); 22.5% (35; 10); 35% (50; 20)	10% (20; 0); 22.5% (35; 10); 35% (50; 20)
Cultivars	100% RlmX-cultivars; 100% with high partial resistant cultivars; 50% RlmX and 50% of high partial resistant cultivars	Reference proportions for RlmX and non-RlmX cultivars	100% of high partial-resistant cultivars
Tillage	0; 10; 20% of WOSR acreages	Reference values	30; 40; 50% of WOSR acreages
Fungicide	On 10% of WOSR acreages if wet and warm climate option; 0 otherwise	On 10% of WOSR acreages if wet and warm climate option; 0 otherwise	On 10% of WOSR acreages if wet and warm climate option; 0 otherwise
Weather	Current; warm and wet	Current; warm and wet	Current; warm and wet
Number of scenarios	162	18	54

Table 4. Characteristics of the various scenarios constructed by participants of the second workshop WOSR: Winter Oilseed Rape; reference: values of reference situation; current weather: 2003-2008. Total number of scenarios per trend is obtained by multiplying the number of possibilities for each variable



Figure 3. Example of one year-random cultivar allocation (3 replicates of the same scenario). Cv : cultivar ; WOSR: Winter OilSeed Rape





represent scenarios). Ing. a and c, frend C (54 scenarios). Ing. c and d. Round symbols represent scenarios of trends A and C; square symbols are for the reference situation (see Tables 1 and 4 for description). Main cropping variables (i.e. explanatory variables) impacting outputs are summarized in the black boxes.



Figure 5. Scenarios simulation results (three replicates): Yield losses depending on Frequency of virulent pathotypes on RlmX-cultivar (figures a, b, c) and Size of total pathogen population (figures d, e, f) for trend B. Trend B (18 scenarios): Decrease of WOSR areas in link with economical/political changes. Round symbols hold for scenarios of trend B; squared symbol holds for reference situation.