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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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 model-based 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. 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

26 through an increase in the duration of cultivar resistance efficacy have to be managed on a

27 regional scale to minimize disease incidence, helping to stabilize yields and keep oilseed rape

28 economically competitive. With this aim, a spatially explicit numerical model (SIPPOM-

29 WOSR; Lô-Pelzer *et al.*, 2010a; 2010b) has been developed to support the design and

30 assessment of scenarios of regional cropping system management to allow efficient control of

31 the disease and resistance sustainability.

32 To study potential impacts of spatially distributed cropping systems, land use scenarios can be

33 very useful. Van Notten (2005) describes scenarios as "descriptions of possible futures that

34 reflect different perspectives on past, present and future developments", consisting of an

35 initial situation and a description of driving forces inducing a specific future (Alcamo &

36 Henrichs, 2008). Scenarios require identification and consideration of the main drivers of

37 future changes (Dockerty *et al.*, 2006). The causes of change can be physical/ecological (e.g.

38 climate change), social and/or economic (e.g. political, urban). Designing, analysing and

39 assessing future scenarios for phoma stem canker management require consideration of the

40 regional context, together with the spatial extent of the disease and the stakeholders' activities

41 affecting and/or affected by the disease.

42 For issues involving large-scale spatial processes, designing land use scenarios can benefit

43 from a participatory approach: different studies have shown the value of involving

44 stakeholders concerned with the coordination of actions to promote scenarios that are

45 effective with regard to the issue (e.g. on erosive runoff risks, Souchere *et al.*, 2009). Indeed,

46 local stakeholders take or influence decisions for agricultural production and landscape

47 changes (Primdahl, 1999), so it is appropriate for them to propose ways of solving the

48 problems involved (Voinov & Gaddis, 2008); with solutions probably better adapted to local

49 socio-cultural and environmental contexts (Reed, 2008). Cropping system scenarios aimed at

50 controlling a disease without jeopardizing yields or profits are therefore likely to be better

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51 when designed together with stakeholders, whose actions (e.g. input choice, collected crops,

52 advice) and coordination influence cropping systems.

53 In participatory studies, scenarios have often been designed by research teams themselves, for

54 the purpose of analysis, evaluation and/or discussion with various stakeholders (e.g. Bacic *et*

55 *al.*, 2006, Dockerty *et al.*, 2006, Tress & Tress, 2003), sometimes to include stakeholders'

56 preferences (e.g. Tompkins *et al.*, 2008), recommendations (e.g. Lippe *et al.*, 2011) or

57 objectives (e.g. Nidomulu *et al.*, 2007). When scenario design *per se* has been participatory, it

58 has often resulted in qualitative scenarios (e.g. Walz *et al.*, 2007; Kok *et al.*, 2006), i.e.

59 narratives/storylines. Translating these into quantitative scenarios that are required for model

60 simulations can be difficult (Alcamo, 2008). In most studies, this type of conversion has been

61 realized with interactions between stakeholders and modellers occurring prior to modelling,

62 either by co-designing or adapting the modelling framework (e.g. Cornwell, 2004; Therond *et*

63 *al.*, 2009 respectively). However, few procedures have been described in the literature for a

64 (semi-) quantitative description of key variables by stakeholders. "Fuzzy Cognitive Map"

65 (FCM) is the main semi-quantitative method for participatory scenario development (e.g.

66 Kok, 2009; van Vliet *et al.*, 2010). Although this method can improve the consistency

67 between qualitative scenarios and quantitative models, quantifications by stakeholders are

68 relative and mostly concern the relationships between the key variables instead of the

69 variables themselves. The FCM method thus does not provide direct model parameterization

70 by stakeholders. Two methods for direct estimation of scenario key variables have been

71 proposed recently: Fuzzy Sets (Alcamo, 2008; Dubrovsky *et al.*, 2011) and Bayesian

72 statistical reasoning (Kemp-Benedict, 2010). The Fuzzy Sets approach combines a collective

73 description of qualitative changes by stakeholders with "linguistic variables" (e.g.

74 low/moderate/high change); and individual quantifications of these qualitative changes by

75 stakeholders. These individual opinions, resulting in a distribution of values, are then

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76 combined by the research team to be translated into a single variable value (Dubrovsky *et al.*,

77 2011). This last step can hinder the reliability of this value, as extreme opinions can

78 potentially strongly influence it. This problem is partially solved by the Bayesian statistical

79 reasoning, which provides a probability distribution of variable values (Kemp-Benedict,

80 2010), based on the qualitative description of how a variable differs from its reference value.

81 Thus detailed and accurate reference distributions are crucial. Kemp-Benedict (2010)

82 proposed to use historical data to do so, but the availability of such data clearly depends on

83 the considered issue and its working scale. For local issues (e.g. phoma management), the

84 required level of detail on numerous variables could make this method hardly feasible.

85 In this paper, we aimed at designing, directly with stakeholders, diverse scenarios of cropping

86 systems, numerically-described and linked to possible future contexts and their uncertainty.

87 The objectives of this work were twofold. The first objective was to test on a case study a

88 method for the participatory design of quantitative scenarios of local cropping systems and

89 their assessment with an available model. The second objective was to evaluate this method in

90 order to provide recommendations and guidelines for its improvement. The case study

91 concerned the regional management of phoma stem canker and of the sustainability of a new

92 resistant gene. The Rlm7-gene was used as an example; this gene was introduced in some

93 cultivars in 2004 and is still efficient.

94 2.   Materials and methods

95 2.1.   Study area

96 The study area was the "Centre region" of France (46°N, 2°E, Figure 1), which is France's

97 main producer of Winter OilSeed Rape (WOSR), providing 20% of the total French

98 production in 2010 on about 15% of the region's arable land (Agreste, 2011). A threefold

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99 increase in the area cropped with WOSR has occurred in the "Centre region" since the early

100 90s, from 92300 ha in 1990 to 305300 ha in 2010 (Agreste, 2011).

101 This region has experienced numerous phoma stem canker epidemics, which were particularly

102 severe in the late 90s. These large epidemics were due to the rapid loss of a specific resistance

103 efficacy (Rlm1), which has been intensively used in the "Centre region": registered in 1992

104 and widely introduced in 1995, cultivars with this gene represented more than half of the total

105 acreage of WOSR grown in 1998-1999 (Rouxel *et al.*, 2003).

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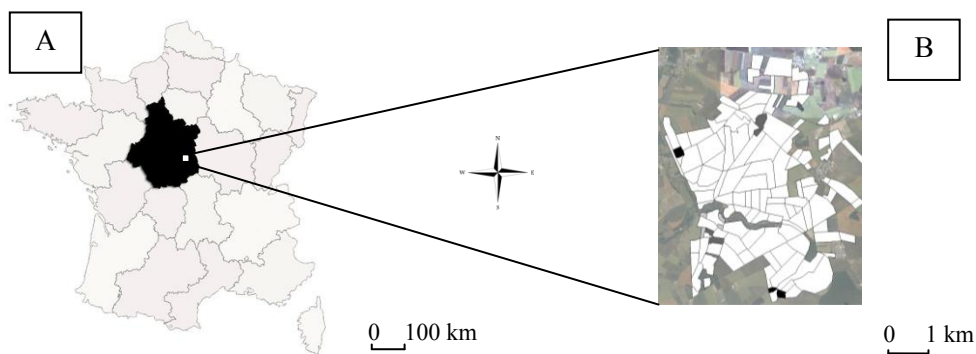
117 Figure 1. Location of (A) study site (white rectangle) and (B) landscape modelling support
118 (white: cropped lands; black: uncropped lands, i.e. farmhouses; forests; fallow lands)
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120 The precise area used for simulations (step 5 of the method, Figure 2) is located in the "Centre

121 region", around Civray (Figure 1). An area of 121 fields was chosen (Lô-Pelzer *et al.*,

122 2010a), whose landscape characteristics and cropping practices are representative of the

123 region according to local experts (Regional Cetiom: the French technical centre for research

124 and development of oilseed production, hereafter referred as the Specialist Technical

125 Organization). Present-day cropping systems, based on local farmers' interviews and

126 described in previous studies (Lô-Pelzer *et al.*, 2010) are composed of about 31% of oilseed

127 rape per year throughout the considered area (Table 1) and mean field size is 14 ha. These

128 data are in accordance with statistical data (analyses performed by the authors on the database

129 Agreste – Enquêtes sur les pratiques culturales, 2006) and expert knowledge (interviews of

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130 the main stakeholders, see description in 2.2.2 and Table 1). This area can thus be considered

131 as representative of the region, with respect to cropping systems and landscape characteristics.

132 This 17 km^2 zone extends from 46°56'07.05'' to 46°59'42.4''N and from 02°07'10.3'' to

133 02°11'26.9''E (Figure 1). It is composed of 21 ha of forests (3 plots), 12.4 ha of farmhouses

134 (2 plots), 9.2 ha of fallows (4 plots) and 1656.8 ha of cropland (112 plots). Five main soil

135 types have been identified in the studied area by field regional monitoring (189 fields). At

136 each field was attributed one of the five soil types, according to their regional importance (Lô-

137 Pelzer *et al.*, 2010a).

138 Weather data for this zone provided by Meteo France were used (weather station located at

139 46°59'30" N 02°10'54" E). This zone often experiences mild wet autumns, which can favour

140 phoma stem canker development on WOSR leaves (e.g. in controlled environment

141 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

142 Table 1. Main characteristics of reference situation of the study area in "Centre region"
143 (France), based on farmers' interviews about their cropping practices during the period 2004-
144 2008

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

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

150 steps, which are detailed below.

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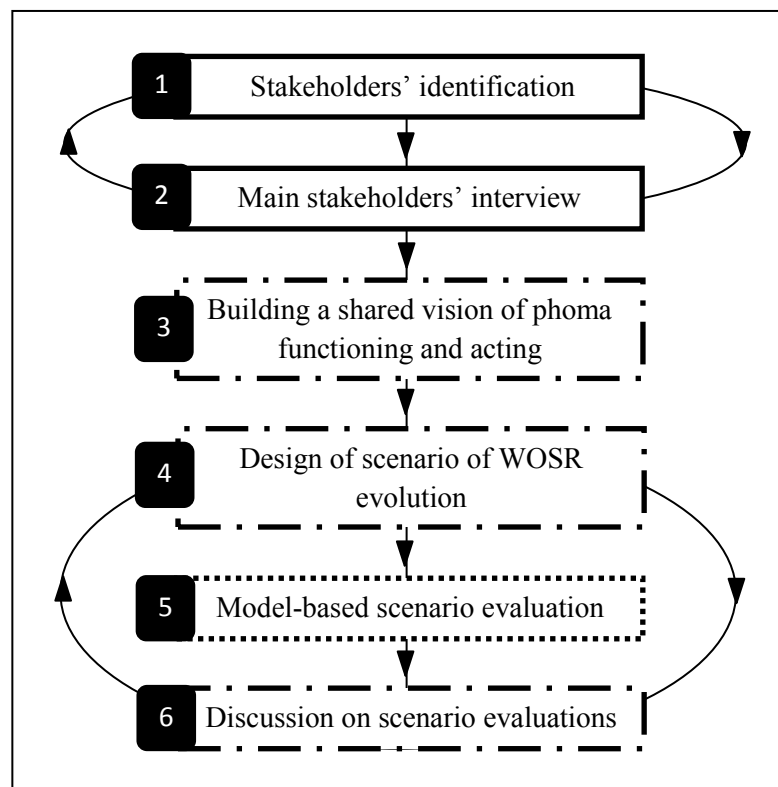
164 Figure 2. Schematic representation of the methodological approach developed in this study.
165 Circular arrows represent feedback loops.
166 Box lines reflect the involvement of stakeholders in the different steps: boxes bordered by
167 dotted lines indicate no interaction with stakeholders; boxes bordered by solid lines represent
168 involvement of some stakeholders, with information derived from other sources (e.g.
169 literature, national statistics); boxes bordered by dashed+dotted lines represent participatory
170 workshops.

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171 ### 2.2.2. Identification of relevant stakeholders

172 The first step to implement a local participatory scenario design is the identification and

173 selection of all stakeholders whose activities could be substantial for local management of the

174 concerned issue. The research team first determined the stakeholders to be involved, based on

175 their impacts on the possible technical levers for the disease control.

176 ### 2.2.3. Interview of stakeholders

177 After identification of the main stakeholders to be engaged in the study, gaining knowledge

178 on local practices and local stakeholders is necessary, in order not to omit stakeholders who

179 could be relevant and not pre-identified by research team (Reed, 2008). Thus, we interviewed

180 the local stakeholders who have an in-depth knowledge of WOSR growing in the region: the

181 local Specialist Technical Organization, the main technical advisors (the local Chamber of

182 Agriculture) and the main crop collector. They were interviewed on two items: (1) local

183 cropping systems and (2) identification of the different stakeholders to be involved in the

184 study, with information on their concerns and courses of action (e.g. van den Belt *et al.*, 2010)

185 over phoma stem canker.

186 ### 2.2.4. Building a common scheme of phoma behaviour and of stakeholders' effects on

187 phoma management

188 Once all stakeholders were identified and the research team gained insight into regional

189 cropping and organisational characteristics through interviews, the challenge was how to

190 involve stakeholders and build a common background on the disease functioning. Since no

191 serious phoma epidemic has occurred in the region since 2002, the control of phoma stem

192 canker by lengthening the duration of effective resistance is now an academic topic. Thus, in

193 order to involve stakeholders in this issue, and make them aware of the possible consequences

194 of a return of phoma stem canker on WOSR, we decided to build with them a scheme of their

195 shared vision of phoma stem canker, taking inspiration from the ARDI (Actors, Resources,

196 Dynamics and Interactions) method (Etienne *et al.*, 2011). The objectives of this scheme were

197 fourfold: (i) for the stakeholders to identify the cultivation techniques (under their control)

198 which might affect the disease; (ii) to give stakeholders confidence in the modelling

199 framework supporting simulations and its underlying hypotheses, through a comparison of the

200 scheme on resources and dynamics they created and the SIPPOM-WOSR functioning scheme;

201 (iii) to ensure stakeholder representativeness and (iv) to involve stakeholders in a learning

202 process regarding the processes involved in stem canker management. During a four-hour

203 collective working session, participants were invited to present their visions of the behaviour

204 of the disease and potential technical levers, and of the stakeholders whose actions may

205 impact phoma control methods (e.g. cultivar choice, residue management), i.e. to represent

206 their mental model on disease functioning and acting stakeholders.

207 2.2.5.   Scenario design of winter oilseed rape evolution

208 After a consensus has been reached among participants on the important levers for phoma

209 stem canker management, a second four-hour working session was devoted to the scenario

210 design of future WOSR cropping conditions. A scenario is composed of necessary detailed

211 inputs for SIPPOM-WOSR simulations, i.e. specification (value) for the seven variables,

212 defined yearly at field and/or at regional scale: WOSR acreages, sowing dates, sowing

213 densities, cultivars (with or without the RlmX-gene), nitrogen fertilization at sowing (product

214 type and fertilization rate), autumn fungicide application (date) and tillage after WOSR

215 harvest.

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

217 - Describe model behaviour, required inputs and possible outputs, and identify precisely

218   the variables on which the scenarios could differ (i.e. variables described in Table 1)

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219   -   Present characteristics of the simulation support landscape

220   -   Present a reference situation representing recent local practices (Table 1): cropping

221   systems and WOSR cultivation techniques, as well as cultivars (based on earlier

222   interviews with farmers whose cropped fields in 2004-2008 were considered in the

223   simulation support landscape) and numerical simulation results of this scenario.

224 Then, stakeholders were asked to imagine futures/trends for WOSR in their region and to

225 describe what contextual changes, either local or global (e.g. political, economic,

226 epidemiological, etc.), would be necessary for such futures to materialize. To illustrate French

227 national tendencies, national acreages of WOSR since 1989 (data Agreste) were presented.

228 Finally, stakeholders were asked in an open discussion to illustrate the identified futures with

229 detailed WOSR acreages (linked with crop sequences) and cultivation techniques, that could

230 affect phoma stem canker control, i.e. cropping characteristics corresponding to model inputs

231 (variables of Table 1), including their quantitative assessments. As phoma stem canker

232 control can depend on interactions between techniques (e.g. cultivar and sowing date,

233 Aubertot *et al.*, 2004), stakeholders were asked about combinations of cultural practices, as

234 well as about the factors governing the location of cropping systems and crop management

235 (e.g. relationships between soil types and cultivation techniques).

236 2.2.6.   Scenario simulation with SIPPOM-WOSR

237 In order to assess consequences of management scenarios designed by stakeholders,

238 numerical simulations of these scenarios were realized using the numerical modelling

239 framework SIPPOM-WOSR; a Simulator for Integrated Pathogen Population Management

240 (Lô-Pelzer *et al.*, 2010a; Figure 2). It is a spatially explicit model simulating the dynamics of

241 pathogen population evolution (size and genetic structure) and consequent effects of phoma

242 stem canker on yield resulting from spatially-distributed cropping systems. This model

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243 highlighted stable ranking of a wide range of oilseed rape management strategies, ranking

244 being consistent with experts' opinions (Lô-Pelzer *et al.*, 2010b). It integrates five sub-

245 models: (i) production of the primary inoculum, (ii) dispersal of the pathogens, (iii) genetics

246 of the pathogen population, (iv) crop growth, and (v) plant infection and calculation of the

247 subsequent yield losses.

248 Model inputs are a map of detailed cropping systems for each field (which is the simulation

249 unit), weather data, and the initial size and genetic structure of pathogen populations. Outputs,

250 for each simulation year at field scale, are disease severity, yield losses due to phoma stem

251 canker, and the genetic structure of the pathogen population (i.e. frequencies of virulent and

252 avirulent pathogen for a major resistance gene that are able and unable respectively to infect

253 WOSR varieties with this resistance gene). Initial frequency of virulent pathotypes on RlmX-

254 gene cultivars has been fixed to 10^{-7} of total pathogen population size.

255 Scenarios defined by stakeholders were run with the model for simulations of five years (one

256 year for model initialization and four years of simulations). When no specific rule was

257 available for crop or crop management allocation, these were allocated at random to fields

258 using R software V2.10.0 (R Development Core Team, 2009) to obtain a mixed landscape,

259 changing every year according to crop rotations, for both WOSR cropped area and WOSR

260 management techniques. There were three replicates for these allocations.

261 2.2.7. Discussion on scenario evaluations

262 Finally, the last step of the method was comprised of a third four-hour workshop. It presented

263 and discussed the numerical evaluation of scenarios. After a brief presentation of model

264 characteristics and of the previously designed scenarios, scenario simulation results for the

265 last simulation year and the whole landscape were presented. This included graphical

266 representations of all scenarios for the output variables Yield losses, Size of pathogen

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267 population and Frequency of virulent pathogen; and a summary of the more important input

268 variables (i.e. cropping characteristic) that impacted these outputs).

269 After the presentation, stakeholders were asked to share their analysis on the scenario

270 simulations and other scenarios they could imagine, to initiate an iterative process between

271 scenario design and discussions.

272 3. Results

273 3.1. Characteristics of the stakeholders, derived from interviews

274 Three types of stakeholders were interviewed: the main crop collector (representing 65% of

275 oilseed rape collection in the area), the local Specialist Technical Organization (two persons:

276 the regional advisor and the manager of local crop experiments) and the main extension and

277 advisory service, i.e. the local Chamber of Agriculture (Table 2).

278 Their visions of current agricultural systems and crop management strategies for WOSR were

279 largely in agreement with each other and with detailed data collected on the simulation area

280 (Table 1). The general vision of stakeholders' organization for WOSR production/collection

281 and involvement in phoma stem canker management were also consistent: the interviewed

282 stakeholders considered that (i) policy makers have moderate courses of action and are not

283 concerned by phoma management; (ii) extension and advisory services are highly concerned

284 but have limited courses of action; (iii) crop collectors (cooperatives and retailers) are highly

285 concerned and have several courses of action; and (iv) breeders have the most concern about

286 phoma management and the most courses of action. According to the interviewed

287 stakeholders, farmers' behaviour is more contrasting. Farmers' concern on phoma may

288 depend on their experience, i.e. if their crop already suffered from phoma stem canker.

289 Interviewed stakeholders had different opinions on the Specialist Technical Organization

290   (Cetiom) behaviour: its courses of action were considered to be few by the main crop

291   collector and many by the Chamber of Agriculture.

292   According to the different interviews, the identified stakeholders affect WOSR management

293   in different ways. Breeders influence cultivar characteristics (e.g. sensitivity to disease) and

294   their potential availability for cooperatives/retailers. Crop collectors affect crop management

295   by restricting farmer choice through the inputs they sell (e.g. fungicides and cultivars) and by

296   their advice on cultivar choice. Farmers are the final decision makers for oilseed rape cultivar

297   choice and practices. Their practices can be constrained by policy, e.g. on dates for tillage

298   practices. They are advised by the extension and advisory services, who communicate

299   experiments results on WOSR cultivar and crop management strategies. These experiments

300   are mainly conducted by the local Specialist Technical Organization (Cetiom) and influence

301   breeder strategies.

302   Degree of stakeholder involvement in/concern about WOSR crop management for phoma

303   stem canker depends on the possible consequences of the disease's return: Yield loss for

304   farmers (and indirectly for advisory services), crop collectors and Cetiom; need for innovation

305   for crop breeders in case of resistance failure.

306   Stakeholders' courses of action will impact phoma stem canker management either directly

307   (e.g. farmers' choices of cultivation practice) or indirectly (e.g. communication). Although

308   these courses of action cannot be directly taken into account in the model SIPPOM-WOSR,

309   they are translated into actions on cropping systems, which are the main inputs of the model

310   (cf. Part 3.4). Stakeholder concerns will impact the model output to be studied by the research

311   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 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

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

316 3.2.   Study participant vision of phoma behaviour and stakeholders' management options

317 This step resulted into two schemes presenting (a) resource dynamics (resources: cultivation

318 techniques, stubbles, etc.) affecting phoma stem canker and the type of relationships between

319 the resources; and (b) stakeholders' impacts on cultivation practices (e.g. testing, regulation)

320 and type of relationships between stakeholders (e.g. communication).These schemes,

321 collectively constructed during the first workshop, showed that the main relevant stakeholders

322 were involved in the study, i.e. every stakeholder included in the stakeholders' scheme (b)

323 was identified in steps 1 and 2 (Figure 2) and invited to workshops. Direct comparison

324 between the resource dynamics scheme of the model (based on Lô-Pelzer *et al.*, 2010a;

325 2010b) and the one designed by stakeholders (scheme a) highlighted that the model structure

326 was in accordance with stakeholders' vision of the disease (although some factors are absent

327 from the model, e.g. working time, machine availability). Attendance at this workshop was

328 high (15 people), with representativeness of all stakeholder type and some diversity within

329 type (e.g. two crop breeders, four for extension and advisory services) (Table 2).

3.3. Participatory scenario design

331 A summary of the future trends imagined by the stakeholders was made in order to get

332 structured scenarios with all the details required for model inputs. Quantifications of model

333 inputs were designed as implicit comparisons (i.e. "increase" or "decrease") with the

334 reference situation (Table 1), as expressed by stakeholders during the workshop (Table 2).

335 Three main trends were identified (Table 3), corresponding to different contextual changes

336 (political, epidemiological, economic or regulatory contexts). Trend A assumes an increase in

337 WOSR area (in comparison with the reference situation), which seems the most plausible to

338 the different stakeholders, in accordance with the national trend and the development of

339 biofuels. This global trend results in shorter crop rotations (e.g. WOSR-Winter Wheat-Barley

340 becomes WOSR-Winter Wheat), which are associated with varieties containing quantitative

341 and/or qualitative resistance, different areas with mouldboard ploughing, and an increase in

342 autumn nitrogen applications. Trend B assumes a decrease in WOSR area, which might occur

343 if WOSR became less profitable or if policies were to change, e.g. if nitrate regulations were

344 to increasingly restrict the time window for tillage practices, work organization could need to

345 diversify crops to decrease working pressure at a certain time. This trend was associated with

346 longer crop sequences, current varieties and cultivation practices; except for autumnal

347 nitrogen applications. Trend C assumes a significant increase in areas with mouldboard

348 ploughing after WOSR harvest, which would occur either if the current qualitative resistance

349 would quickly be overcome and thus become inefficient, or if the herbicide glyphosate would

350 be banned, in conformity with current policies to reduce pesticides. This trend is associated

351 with cultivars with quantitative resistance and an increase in autumnal nitrogen applications

352 (Table 4).

353 Workshop participants (Table 2) associated the three trends with two climatic datasets: (1)

354 current data (2003-2008); and (2) weather data favouring development of phoma stem canker

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355   epidemics (i.e. with wet mild autumns). Participants associated fungicide applications on

356   WOSR with the second weather dataset. They asked the research team to define this weather

357   dataset as the repetition of the year presenting the highest temperatures and rainfalls in

358   September and October in the last ten years.

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
B. Decrease of WOSR areas (in comparison with the reference situation)	WOSR net return decrease 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
WOSR: Winter Oilseed Rape; RlmX: specific resistance currently cropped; s.m^{-2}: seeds per square meter

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361 For the three trends, stakeholders identified soil type as the location factor for crop rotation,

362 tillage practices, nitrogen fertilization and fungicide applications. No association between

363 cropping practices was suggested at this stage, except for the sowing densities, which were

364 determined by cultivars.

365 For the three trends, stakeholders suggested extreme values for the different variables. For

366 instance, for trend A, stakeholders proposed an increase from 33% to 50% of the whole

367 cropped area sown with WOSR. A 50% WOSR frequency corresponds to a two-year crop

368 rotation (WOSR – Winter Wheat) on the whole area, already occurring locally in some farms.

369 As some stakeholders questioned the sustainability of such a crop rotation, stakeholders also

370 decided on a three-year crop rotation (WOSR – Winter Wheat – Barley) with up to 33% of the

371 local area cropped with WOSR. In order to compromise between the two WOSR acreages, the

372 research team suggested scenarios with intermediate variable values (e.g. 42%), to try

373 considering more plausible regional configurations and explore the consequences of making

374 smaller changes.

375 Once workshop participants had defined the main variable specification for a trend (i.e.

376 WOSR crop areas for trends A and B vs. mouldboard-tilled areas for trend C; Tables 2 and 3),

377 ranges for other variables were defined. Participants decided to define these ranges

378 independently for each variable. All combinations were thus simulated.

379 For instance, for trend A, stakeholders defined (Table 4): (i) three specifications for sown

380 cultivars; (ii) one specification of WOSR sowing date; (iii) one specification for sowing

381 density; (iv) three specifications for organic nitrogen fertilization at sowing; (v) two

382 specifications for fungicide treatment depending on weather conditions; and (vi) three

383 specifications for mouldboard tillage practices after WOSR harvest. As stakeholders did not

384 mention links between variable values, all combinations of variable specifications lead to 162

18

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

386 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 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

387   3.4.   Model-based scenario simulation

388   Simulations of the 234 scenarios had to be performed with the modelling framework

389   SIPPOM-WOSR. As stakeholders did not define specific localization factors for WOSR

390   and/or practices during the scenario construction workshop (except for tillage and nitrogen

391   fertilization, linked with soil type), three replicates for the random spatial distribution of crop

392   and practices were used, leading to 702 scenarios (234 scenarios x 3 replicates) (Figure 3).

	Uncropped area
	High quantitative resistance Cv.
	Cv. with RlmX-gene
	Other crop than WOSR
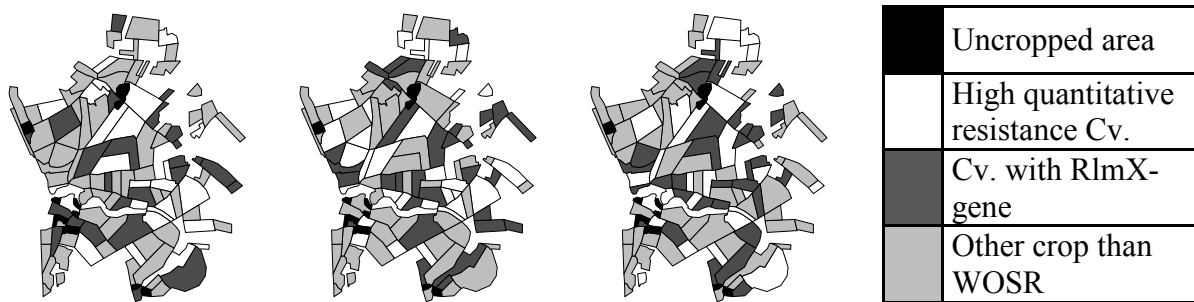
393

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

396   3.5.   Scenario evaluation and discussion with stakeholders

397   3.5.1.   Model-based scenario evaluation

398   Model-based simulation of co-designed scenarios resulted in very diverse results for the three

399   main output variables, i.e. frequency of virulent pathotypes on RlmX-cultivars, yield losses

400   and size of the total pathogen population, i.e. including all pathotypes (Figures 4 and 5, -only

401   one replicate presented for trends A and C for brevity-). Trends B and C (decrease in WOSR

402   acreages and increase in mouldboard ploughed areas respectively) showed lower yield losses

403   and sizes of total pathogen population than trend A (increase in WOSR acreages) (Figures 4

404   and 5). Trend C showed lower frequency of virulent pathotypes on RlmX-cultivars than trend

405   B. Trend B mean frequency of virulent pathotypes on RlmX-cultivars was lower than for

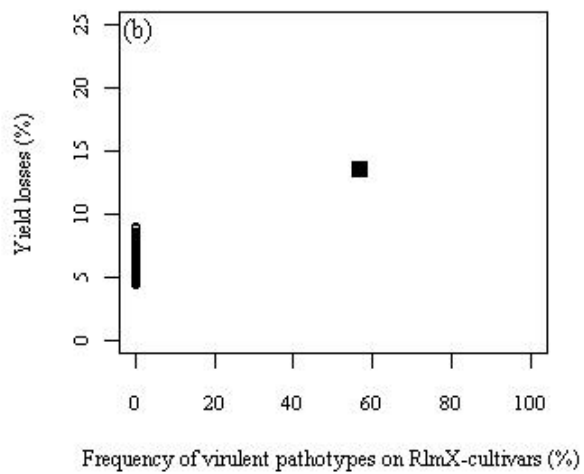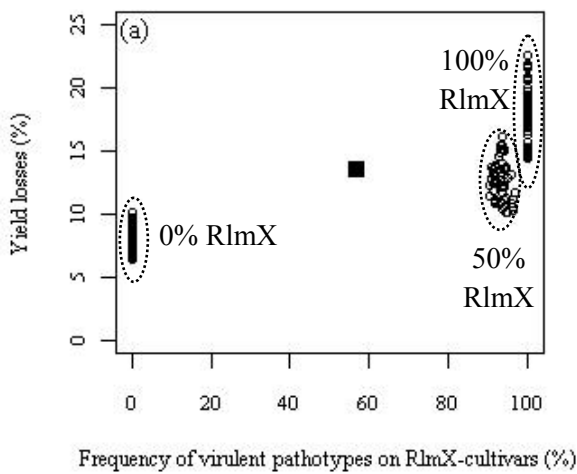406   trend A. Trend A displayed very variable results for frequency of virulent pathotypes on

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407 RlmX-gene, from 0 to 100% of virulent pathogen (Figure 4). This is due to the large extent

408 explored for the model input frequency of RlmX-cultivars in the area in this trend (Table 4,

409 Figure 4). For trend A, only scenarios with no RlmX-cultivars had lower frequency of virulent

410 pathotypes on RlmX-gene than the reference situation (Figure 4).

411 Trends B and C had lower yield losses and sizes of the total pathogen population than the

412 reference situation (Figures 4 and 5). Trend C had mostly lower frequency of virulent

413 pathotypes on RlmX-gene than the reference, due to the absence of RlmX-cultivars in this

414 trend, consistent with trend A results with the same cultivar configuration. Trend B displayed

415 different frequencies (but rather high) of virulent pathotypes on RlmX-cultivars, which

416 highlighted the importance of rules for locating and combining crops and practices (Figure 5).

417 Main explanatory variables differed between model outputs (Figure 4) but were consistent

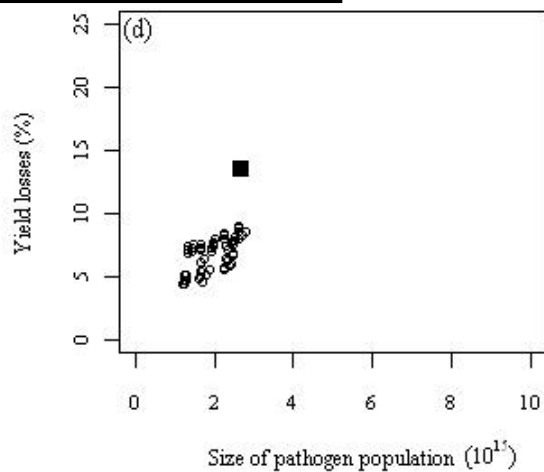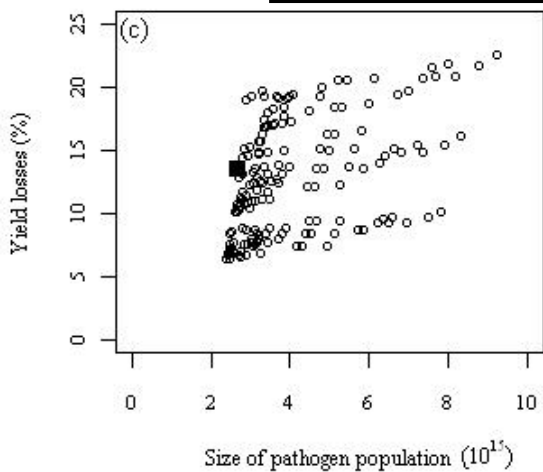418 between trends (data not shown).

419

Figure 4. Scenario simulation results and their main explanatory variables (only one replicate presented): Yield losses depending on frequency of virulent pathotypes on RlmX-cultivar (figures a, b) and size of total pathogen population (figures c, d) for trends A and C.

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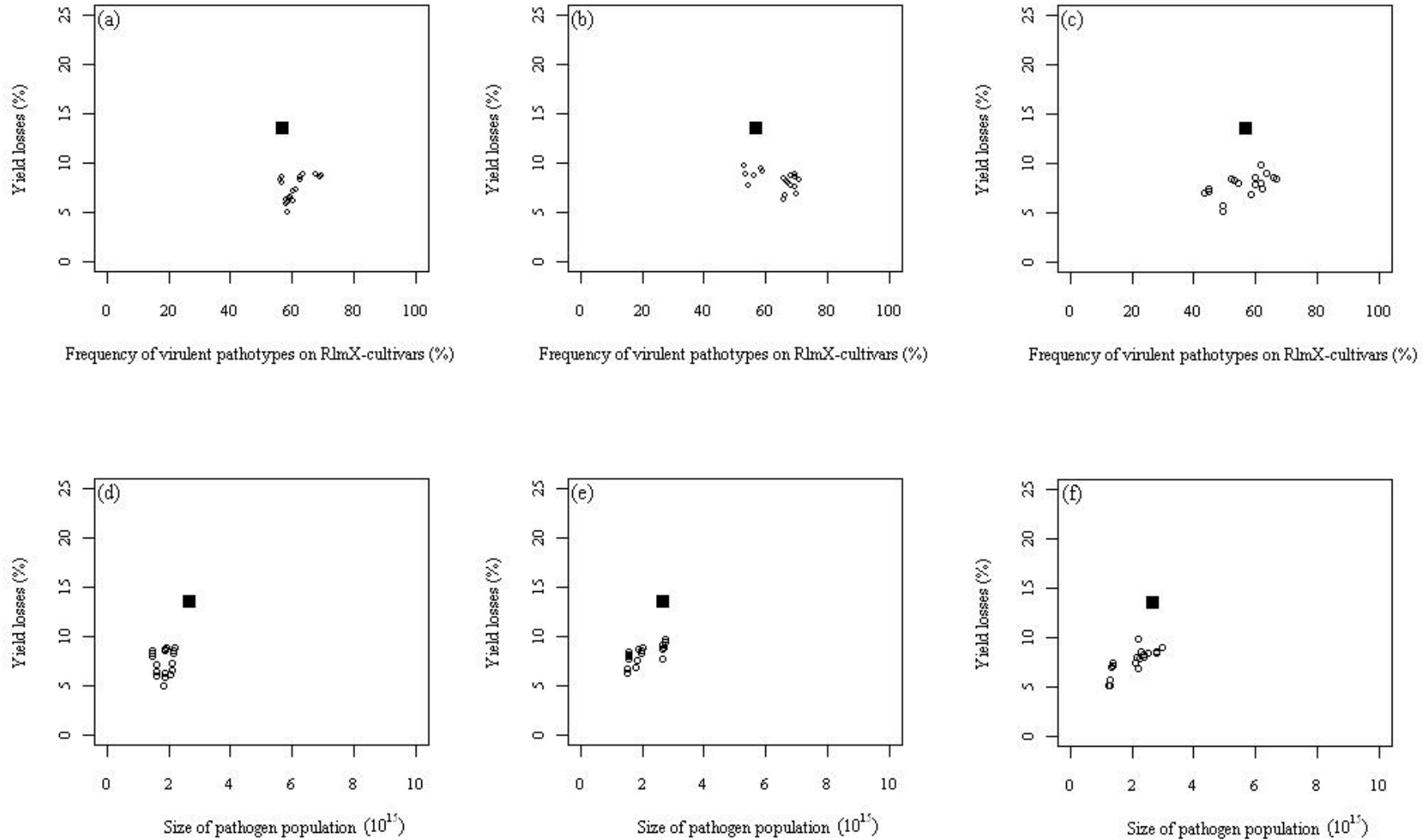
Figure 5. Scenarios simulation results (three replicates): Yield losses depending on Frequency of virulent pathotypes on RlmX-cultivar (figures a, b, c) and Size of total pathogen population (figures d, e, f) for trend B. Trend B (18 scenarios): Decrease of WOSR areas in link with economical/political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

474   3.5.2.   Scenario collective discussion

475   During the workshop, study participants (Table 2) expressed to the research team that

476   scenarios evaluations highlighted relevant features to them. For instance, they highlighted that

477   the information on cropping practices' ranking for phoma stem canker management could

478   help them to adapt their technical advices (see Figure 4). They recognized the temporal and

479   spatial scales of the model as valuable to see consequences of individual choices on phoma

480   stem canker management. Indeed, although they acknowledged that field scale is their main

481   working scale; past phoma epidemics showed them the necessity of considering the inter-

482   annual and inter-fields processes, for which the modelling approach is very informative.

483   Moreover, discussions also highlighted some elements stakeholders found missing in the

484   model (e.g. intercropping practices, crop mixtures, partial resistance behaviour over time) that

485   could affect phoma management.

486   During the discussion of the simulation results the reference situation was challenged.

487   Although it had been presented to stakeholders during the second workshop, prior to the

488   participatory scenario design, stakeholders asked for its reappraisal, concerning cultivars, as

489   well as types and dates of tillage operations. This reference situation was considered too local,

490   i.e. taking into account very local contextual issues as for instance the nearby presence of pig

491   farms affecting the type, level and frequency of organic nitrogen fertilization. Thus, study

492   participants were willing to explore a new reference situation, that differed for some cropping

493   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

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498 of increasing crop rotation duration" with regard to phoma stem canker management but put it

499 into perspective with economic and agronomic contexts: "such an option would face

500 profitability and realization problems, as farmers would have to grow for instance sunflower

501 [i.e. to add it in the crop sequence], which is less profitable (its price is falling and it competes

502 with winter wheat) and hard to grow due to its susceptibility to bird damage and water

503 requirement [that may not be fulfilled under local weather conditions]". Study participants

504 lacked economic information to judge scenarios, to be able to put into perspective yield losses

505 due to stem canker and profitability at the rotation scale.

506 Finally, the participants suggested broadening the study object, by coupling SIPPOM-WOSR

507 with models simulating other diseases, insects and weeds. They pointed out that tackling a

508 disease, in this case phoma stem canker, could affect the control of other pests, e.g. weed

509 control. They concluded that focusing on one issue may have undesirable effects on another

510 one, thus requiring enlarging the scope of the topic.

511 4. Discussion

512 In this section we will discuss the tested method, and not the results that are mainly case-

513 specific.

514 In this paper we have tested a method of participatory quantitative scenario design, with

515 phoma stem canker management as a case study. This method includes stages for

516 stakeholders' identification, analysis of their courses of action, collective discussions on the

517 issue functioning, and finally the design, model-based evaluation and discussion of future

518 scenarios implying cropping system change and subsequent effects on phoma stem canker

519 management. Using this method, the case study for the "Centre region" highlighted

520 possibilities to directly derive quantitative scenarios with a participatory approach,

521 overcoming the classic problem of converting narratives into quantitative data (Alcamo, 2008;

522 Walz *et al.*, 2007) in spite of the topic's complexity. This participatory future development

523 provided insight into different types of drivers for the future: global vs. local changes (e.g.

524 economic, political or regulatory, vs. epidemiological drivers respectively). These drivers

525 were associated to different types of scenarios (as defined in Borjeson *et al.*, 2006):

526 predictive forecasting scenarios (e.g. current economic trends), predictive "what-if" scenarios

527 (e.g. regulatory change) and exploratory external scenarios (i.e. policy change). These futures

528 led to diverse impacts on the agricultural context (crops and cropping practices). Biological

529 processes of phoma stem canker evolution were thus considered in this study, as proposed by

530 Blackstock *et al.* (2007), "in the context of their social-economic drivers and responses",

531 taking into account local knowledge (Patel *et al.*, 2007) and local needs and priorities (Dougill

532 *et al.*, 2006).

533 Although we invited all types of stakeholders to join in the study, and most attended at least

534 one workshop, attendance dropped after the first meeting on disease behaviour (Table 2). A

535 reason for this decline is that since the disastrous phoma epidemics that occurred prior to

536 2002, the disease has been perceived as less serious in the region due to the use of new

537 resistant cultivars harbouring RlmX-gene (Rlm7 being the gene presented as an example to

538 stakeholders), whose resistance has not yet broken down. Thus the priorities of many of the

539 stakeholders did not match those of the research team. The research team was unknown to

540 stakeholders prior to the study and had not received adequate publicity before the project

541 began. Building a robust partnership, at the beginning of the study, with a key local actor

542 could have helped to overcome this problem (Ericson, 2006), even when using a pre-

543 developed model. Trust between the research team and stakeholders is indeed a key element

544 for a successful participatory study (Voinov & Gaddis, 2008). Study institutionalization may

545 also have helped participation (Cornwell, 2004; Reed, 2008). Although participation was

546 relatively low (Table 2), a diverse set of stakeholders was present at each step of the

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547 workshop (Wallerstein, 1999). The most influential of institutions on the local WOSR

548 growing conditions were present at each step (e.g. the main crop collector; the Chamber of

549 Agriculture). These institutions can be considered as the most relevant stakeholders on this

550 issue; their participation being of prime importance (Reed, 2008; Voinov & Bousquet, 2010).

551 The systematic attendance of scientists with a deep understanding of the issue was also useful

552 for scenario design (Pahl-Wostl, 2008). An increased participation of farmers may have led to

553 better structured scenarios, reflecting a more systemic point of view on interlinked cropping

554 practices. This could also had been achieved by creating Fuzzy Cognitive Maps with

555 stakeholders (e.g. van Vliet *et al.*, 2010), in order to highlight relationships and feedbacks

556 between key variables (e.g. WOSR acreages and tillage). However, the large scope of

557 scenarios designed by stakeholders may not have been improved by a larger participation, as

558 the consequences on phoma management were already very large (Figures 4 and 5). This

559 large scope, with different values tested per variable for each scenario, allowed to take

560 implicitly into account "uncertainty", as proposed in Bayesian statistical reasoning (Kemp-

561 Benedict, 2010).

562 The "trust" issue also led to model "testing" resulting in some exaggerated aspects of

563 scenarios, such having only one WOSR cultivar grown or 2-years rotation in the whole area;

564 leading to some kind of "sensitivity analysis" on cropping systems' inputs. Such scenarios

565 were exploratory and led to extreme scenario assessment for the considered output variables.

566 These evaluations, although biologically sound and in accordance with the functioning of the

567 SIPPOM-WOSR model based on system dynamics, would most probably not occur in reality

568 as there is little chance that those scenarios would happen. These evaluations often showed a

569 strong increase in disease pressure in comparison with the reference situation. This led study

570 participants to want to update the reference situation. Indeed, they considered that it

571 underestimated risks of phoma epidemics because of its local peculiarities. This issue might

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572 have been avoided by building confidence with stakeholders earlier in the process (e.g.

573 Therond *et al.*, 2009), illustrating model functioning by giving more details on the

574 relationships between the key processes and variables (Lô-Pelzer *et al.*, 2010a; 2010b)

575 therefore providing more transparency of the system representation in the model (Leenhardt *et*

576 *al.*, 2012), or by building the reference situation during a workshop (Leenhardt *et al.*, 2012).

577 However, the desire to reconsider the reference situation could also be linked to the arrival of

578 new participants in the last workshop (albeit not new stakeholder types or institutions, see

579 Table 2), who did not participate in the scenario elaboration and were less willing to accept

580 the scenario evaluations (Patel *et al.*, 2007). As highlighted by Peterson *et al.* (2004), unstable

581 participation may indeed be a challenge, threatening consensus reaching, by orienting

582 discussions towards a single interest at the expense of a more systemic view. This was the

583 case here, as discussions were shifted at the last workshop by new participants from the

584 considered issue to other crop-related problems (e.g. weeds).

585 Finally, the methodological framework tested in this paper allowed us to build quantitative

586 scenarios directly with stakeholders for their model-based assessment. The model had to be

587 accepted by the stakeholders, as the method involved the use of a pre-existing model, instead

588 of co-designing or co-adapting the modelling framework (e.g. Vayssieres *et al.*, 2011).

589 Methods for group model building are numerous, aiming at either building qualitative models

590 (Causal Loop Diagrams, Videira *et al.*, 2012), semi-quantitative models (Fuzzy Cognitive

591 Maps, van Vliet *et al.*, 2010) or formal models (Bayesian Belief Networks, Pollino *et al.*,

592 2007). Although the first two methods structure and (partly) quantify the system dynamics,

593 with a focus on feedbacks, their complexity can quickly increase so that they become hard to

594 explain and thus to quantify. Bayesian Belief Networks require high-knowledge stakeholders;

595 and time and efforts for its parameterization can often be overwhelming. Although these

596 methods will facilitate scenario construction and quantification for the co-developed models,

597 they may not achieve the necessary numeric variable estimation. Moreover, several models,

598 designed by scientists only, are available to deal with scenario simulation of complex issues.

599 For these models to be used in participatory studies, model acceptance by stakeholders can be

600 challenging, leading in some participatory studies to the necessity of co-developing a new

601 model (e.g. Pedersen & Grant, 2004). In our study, model acceptance was partly the result of

602 collective discussions about disease processes (model processes) and model outputs in an

603 iterative dialogue. Such dialogue is recognized as necessary for both improving information

604 exchanges and building trust with stakeholders (Parker *et al.*, 2002; Leenhardt *et al.*, 2012).

605 Discussions on output customisation could also have increase model acceptance, through an

606 adaptation of raw model outputs into indicators easier to interpret (Leenhardt *et al.*, 2012). An

607 integrated analysis of scenarios could have helped the evaluation of the trade-offs between the

608 different model outputs, thus providing information for disease "risks" in front of contextual

609 change.

610 5. Conclusion

611 The proposed and tested participatory method combined the involvement of a diversity of

612 stakeholders, the design of qualitative and quantitative scenarios and their evaluation with a

613 pre-existing model. In spite of the complexity and scale of the studied system, the tested

614 method made it possible for stakeholders to build a range of scenarios with highly diverse

615 impacts on phoma stem canker management. This method proposes a "package" ranging from

616 the identification of a local problem by researchers to the exploration, analysis and discussion

617 with stakeholders of potential future levers for its management. The method could be used for

618 quantitative scenario design for problems whose processes are strongly influenced by

619 stakeholders seeking a sustainable solution. To improve the implementation of the method for

620 scenario design presented here, we would recommend, for participation improvement and

621 easier model acceptance, to (1) build a partnership with a local key actor, who could locally

622 promote the study and participate to build trust between the local stakeholders and the

623 research team (in case the team is locally unknown) ; (2) give more insight to stakeholders on

624 model functioning and processes instead of only key variables ; and (3) facilitate

625 interpretation on scenario assessment through model output customization.

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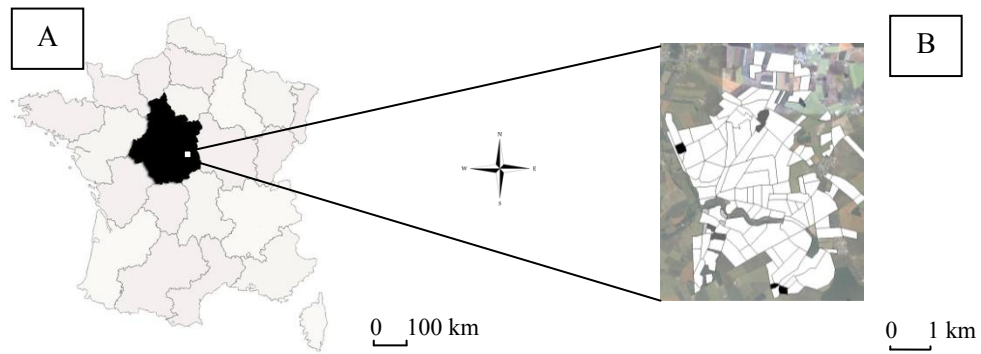Planning 81(1/2):114-131.

Figure1

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)
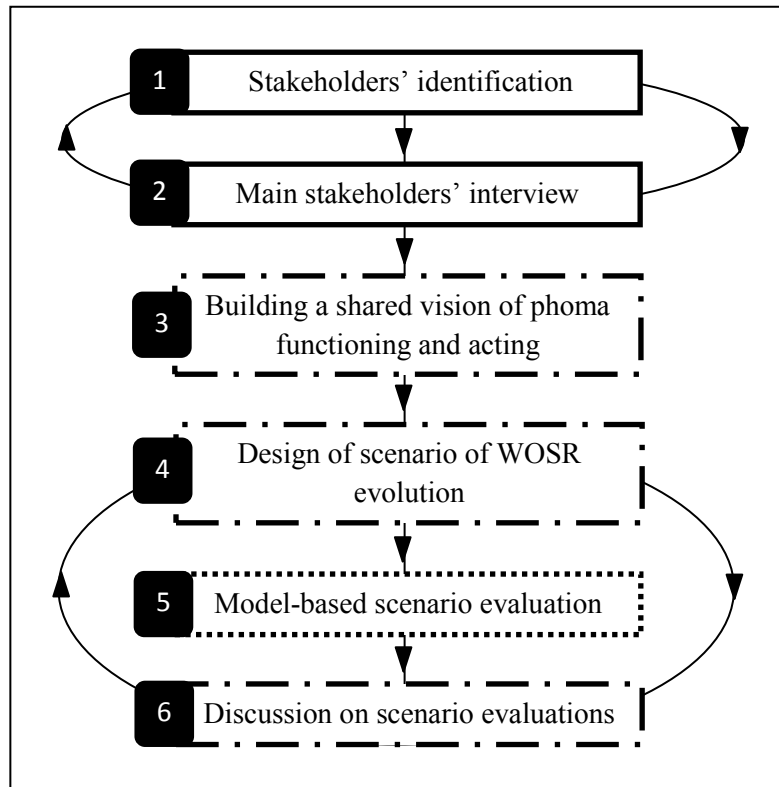
Figure2

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.

Table 1

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 2004-2008

Table 2

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.

Table 3

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
B. Decrease of WOSR areas (in comparison with the reference situation)	WOSR net return decrease 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
WOSR: Winter Oilseed Rape; RlmX: specific resistance currently cropped; s.m^{-2}: seeds per square meter

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 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

Figure3

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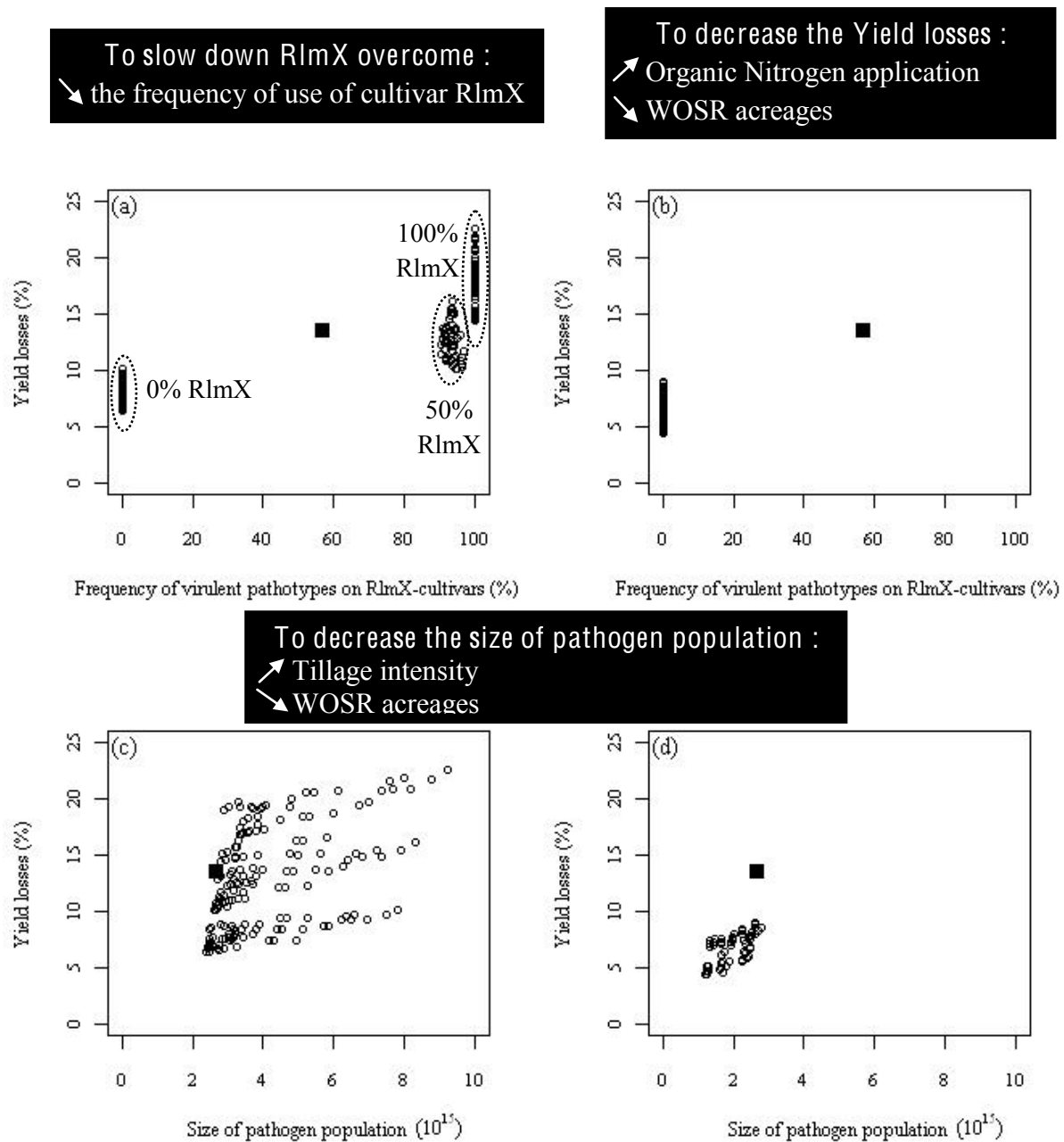Cv : cultivar ; WOSR: Winter OilSeed Rape

Figure4

Figure 4. Scenario simulation results and their main explanatory variables (only one replicate presented): Yield losses depending on frequency of virulent pathotypes on RlmX-cultivar (figures a, b) and size of total pathogen population (figures c, d) for trends A and C.
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.
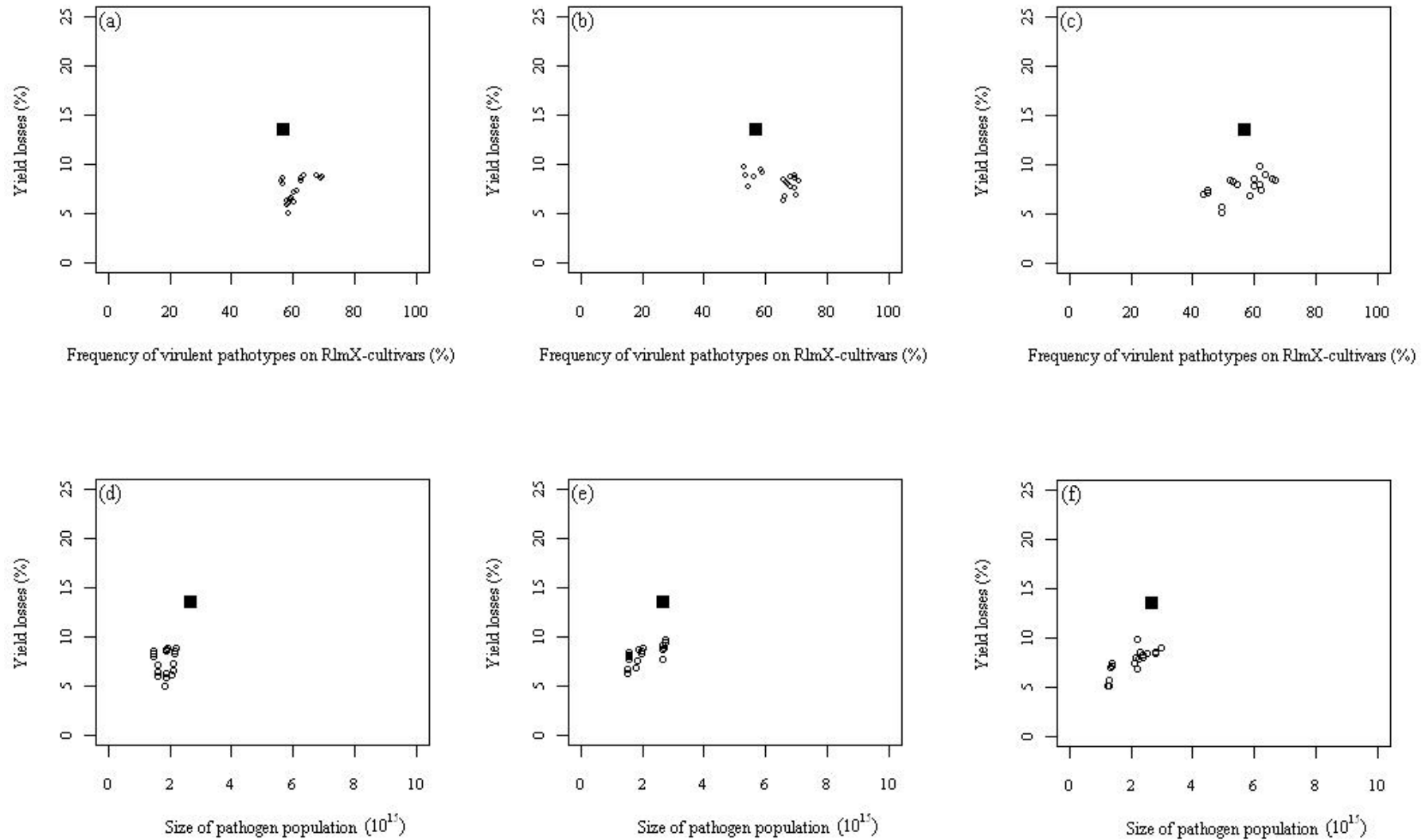
Figure5

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.