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# 1 Co-development of a decision support system for 2 integrated weed management: contribution from 3 future users

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24

## 25      **Abstract**

26      Farmers and farm advisors need a decision support system (DSS) to develop multiperformant weed  
27      management strategies adapted to economic, social and environmental stakes and farmers' constraints.  
28      We worked with future users, farmers, and crop advisors to define the uses and type of DSS they  
29      needed, via an online survey, group meetings and workshops. The feedback from future users helped  
30      to define the structure of the DSS with two complementary DSS needed: (1) a synthetic tool working  
31      with meta-decision rules to help with a complete overhaul of a cropping system, and (2) a precise and  
32      detailed tool for fine tuning cropping systems. Here, we present how we interacted with future users to  
33      transform an existing research model into a DSS by (1) defining its goal, application field and  
34      structure, (2) entering into the DSS knowledge on biophysical processes comprised in the mechanistic  
35      weed dynamics model FLORSYS. We selected a more appropriate vocabulary for describing  
36      agricultural practices and formats with future users. Based on their feedback, a large range of weed  
37      impact indicators was included in the DSS so that farmers can choose the most pertinent for their  
38      objectives. Based on workshops with farmers, a decision tree format with numerical values of weed  
39      impact indicators was chosen to demonstrate the impacts of multiple cultural practices combinations.  
40      The DSS also includes an online calculator predicting weed (dis)services from meta-decision rules  
41      which was tested by crop advisors. Responses of the DSS were sometimes not expected by users, but  
42      were still considered interesting highlighting the need of agronomical support while using the tool.

43

## 44      **Highlights:**

- 45      • We developed a Decision-support system (DSS) for integrated weed management
- 46      • Farmers and crop advisors took part via online surveys, group meetings and workshops
- 47      • The DSS goal, application field and structure was defined with future users
- 48      • They proposed two DSS, based on meta-decision rules or detailed farming practices

49 • Biophysical knowledges were fed to the DSS from an existing mechanistic model

50

## 51 **Keywords:**

52 integrated weed management; participatory design; decision aid; agroecology; multivariate output  
53 display; conceptual framework

54

## 55 **1 Introduction**

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56 Weeds are harmful for crop production (Oerke, 2006) but important for plant and functional  
57 biodiversity (Marshall *et al.*, 2003). Global changes and herbicide policies in Europe and France  
58 compel farmers to reduce their herbicide use (Directive 2009/128/CE; Ecophyto, 2017) in order to  
59 limit the impact on human health and environment (Wilson and Tisdell, 2001). In response, farmers  
60 need to replace herbicides with a combination of multiple, mostly preventive and partially efficient  
61 practices (Liebman and Gallandt, 1997; Wezel *et al.*, 2014). The complexity of effects of cultural  
62 practices, combined with climatic uncertainty, on weeds makes these modifications difficult to plan  
63 and risky (Ingram, 2008). Understanding the impacts of agricultural practices, and their interactions,  
64 on weeds is critical to help farmers to develop and implement cropping systems (*i.e.* crop succession  
65 and cropping practices) that reconcile crop production, reduced herbicide use and biodiversity  
66 conservation. Decision support systems can help to tackle this challenge.

67 Various Decision Support Systems (DSS) exist to help farmers to take strategic or tactical decisions to  
68 manage weeds in their fields. DSS are of many forms, ranging from websites to learn about weeds and  
69 get weeding advice such as InfloWeb (Terres Inovia *et al.*), to complex computer-based software to  
70 test different herbicide treatments for weed management, *e.g.* Weed Manager (Parsons *et al.*, 2009) or  
71 WeedSOFT® (Neeser *et al.*, 2004). However, these DSS focus on one particular technique or weed  
72 species and, to date, no DSS assesses the impacts of a combination of multiple and detailed cultural

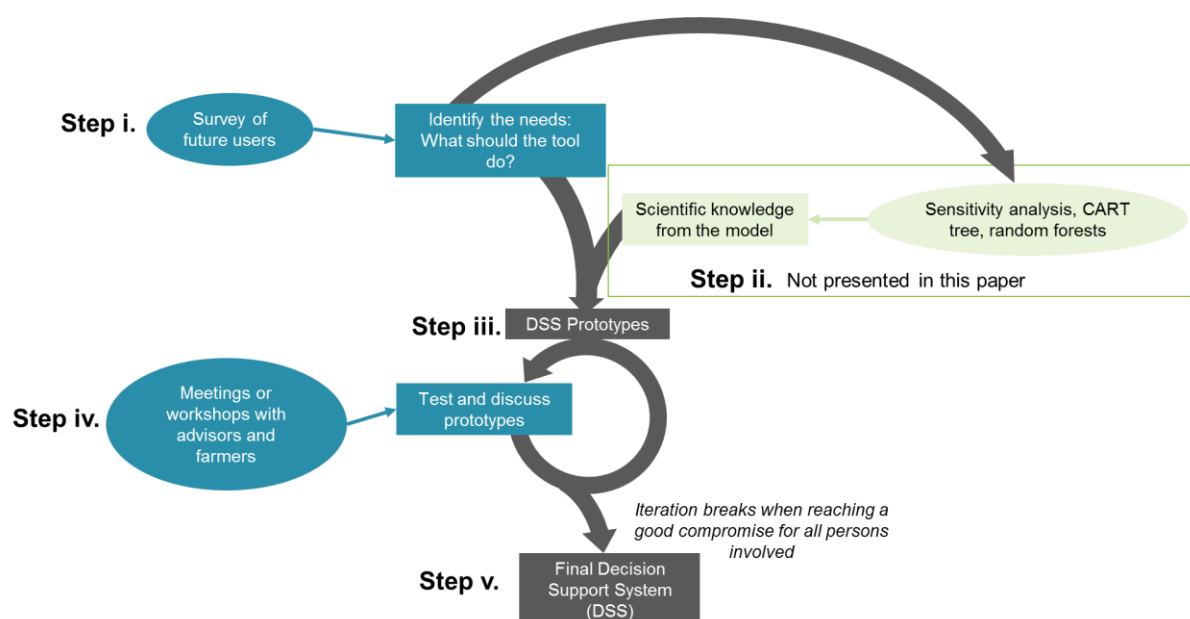
73 practices on many weeds at the long term cropping-system scale, and none considers the multicriteria  
74 impacts of weeds on crop production and biodiversity (Holst *et al.*, 2007; Colbach, 2010). The tool  
75 OdERA (Agro-Transfert Ressources et Territoires) is based on expert knowledge to evaluate the risk  
76 of weeds in a particular cropping system. Being based on expert knowledge, it cannot adapt practices  
77 to the pedoclimate. Thus, a need for a new DSS integrating weed management for strategic decision  
78 was identified (GIS GC HP2E, 2011; Dubrulle *et al.*, 2014).

79 Conversely, process-based cropping system models can be considered as a "virtual field" for  
80 researchers to virtually experiment and evaluate innovative cropping systems. The very detailed weed  
81 dynamics model FLORSYS (Gardarin *et al.*, 2012; Munier-Jolain *et al.*, 2013; Colbach *et al.*, 2014a)  
82 assesses the impact of weeds on both crop production and biodiversity within cropping systems,  
83 translating detailed crop and weed state variables into indicators of weed impact on crop production  
84 and biodiversity according to the cropping system (Mézière *et al.*, 2015b). The high level of detail  
85 needed, the many possibilities of modification of cropping system and the simulation/computation  
86 time are limits to the use of FLORSYS by farmers and crop advisors. Its simplification could make  
87 accessible to farmers and crop advisors the synthetic knowledge embedded in the model (Colbach,  
88 2010; Colas *et al.*, submitted; Colas, 2018). Future possible users, mainly non-researchers, should be  
89 involved during the design and development stages of the DSS, not only to provide expert knowledge,  
90 but also to define the needs and possible uses of the DSS and iteratively to test the prototypes (Voinov  
91 and Bousquet, 2010; Cerf *et al.*, 2012; Prost *et al.*, 2012). In this case, future users correspond to  
92 farmers and crop advisors, stakeholders that can actively help change a cropping system.

93 Participatory design is an efficient way to get the future users involved in the design process of a DSS  
94 they could possibly use (Cerf *et al.*, 2012). The model is tested, improved and validated by the users,  
95 whether the DSS has been developed by researchers (Becu *et al.*, 2008) or co-designed with all  
96 participants (Bah *et al.*, 2006). Surveys allow researchers to collect users' inputs with a large audience,  
97 especially when using semi-open questions that encourage explanations by farmers (Merot *et al.*,  
98 2008). Workshops with users improve their contribution to the DSS development because they allow a  
99 better appropriation of the model and encourage interactions among participants (Patel *et al.*, 2007;

100 Hossard *et al.*, 2013; Figureau *et al.*, 2015). Numerous DSS have been developed for farmers, but are  
101 actually used by crop advisors (Cerf and Meynard, 2006), showing that main users should be first crop  
102 advisors, and then farmers.

103 Here, we propose a conceptual framework of interactions with future users with the aim of developing  
104 a DSS from the model FLORSYS, based on previous methodologies (Cerf *et al.*, 2012; Zulkafli *et al.*,  
105 2017). Those interactions will put milestones on our path to the final DSS, to define and understand  
106 why and how future users would use such a DSS and to improve the DSS by users testing it. The  
107 objective of this work was to develop a DSS by combining two approaches: (1) defining its goal,  
108 application field and structure questioning future users, and (2) implementing the DSS with knowledge  
109 on biophysical processes comprised in the mechanistic weed dynamics model FLORSYS. These two  
110 approaches were performed in four steps (Figure 1). Step i used online surveys to define what the DSS  
111 should do. The results contributed to the choice of methods to extract the scientific biophysical  
112 knowledge comprised in FLORSYS (in step ii) where data mining was applied to a large set of  
113 contrasting cropping systems simulated with FLORSYS (details in (Colas *et al.*, submitted; Colas,  
114 2018)). Data mining methods were chosen considering their ability to extract and synthesize data as  
115 well as to communicate these results to non-researchers. The results from steps i and ii produced a  
116 DSS prototype (step iii) which was then tested with future users during six instances (Table 1) in  
117 group meetings and workshops (step iv), to (1) observe how the users would use the model, feed the  
118 inputs and interpret the outputs, (2) test different model structures and output formats, proposed by  
119 both users and ourselves. The feedback helped us to define the structure of the final DSS, the  
120 vocabulary for describing agricultural practices, and output formats (step iv).



121  
 122 Figure 1: Conceptual framework to co-design, with future users, a decision support system from an  
 123 existing biophysical model. Ellipses represent the methods, rectangles the objectives, contents of the  
 124 future DSS are in light green, the structure and outline of the DSS designed with the stakeholders are  
 125 shown in blue, the different versions of the DSS are shown in dark grey. (Floriane Colas © 2018)

126 Table 1: Summary of the instances for the development with future users of a decision support system  
 127 (DSS) for integrated weed management.

Objective (corresponding step in Figure 1)	Instances	Number of farmers and advisors	Location	Methods of data collection	Farming systems and main productions
Identify the type of DSS in terms of use, inputs and outputs (i)	Crop advisors	40	All France	Online survey	Arable crop and mixed cropping- livestock
	Farmers	4 full answers; 2 partial	All France	Online survey	Arable crop and mixed cropping- livestock
	Group's meeting with watershed management local	~15 farmers; 2 consultants	Picardie	Feedback from participants of the meeting	Arable crop

	authority				
Identify how users would handle the different tools in the DSS and interpret their output formats (iv)	Group's meeting with GRCETA* Aube	~ 50 farmers; 2 crop advisors	Aube	Small survey and feedback from participants of the meeting	Arable crop
	Workshop	5 crop advisors	Champagne (Aube, Haute-Marne)	Workshop to test DSS prototypes	Mixed cropping-livestock
	Online tests	2 of the 5 previous crop advisors	Champagne (Aube, Haute-Marne)	Test of the random forest of the DSS	Mixed cropping-livestock

128 \*GRCETA: Groupement Régional des Centres d'Etudes Techniques Agricoles, *i.e.* Regional group of  
 129 study centers of agronomic techniques, usually managed by one or two crop advisors.

130

## 131 2 Material and methods

### 132 2.1 The complex model to simplify: FLORSYS

133 FLORSYS is a “virtual field” testing the impacts of cropping systems on crop growth and weed  
 134 dynamics depending on the pedoclimate (Gardarin *et al.*, 2012; Munier-Jolain *et al.*, 2013; Colbach *et*  
 135 *al.*, 2014a; Colbach *et al.*, 2014b; Munier-Jolain *et al.*, 2014; Mézière *et al.*, 2015b; Colbach *et al.*,  
 136 2016). It is a dynamic model, at a daily time step, where cropping systems are described by a detailed  
 137 list of operations with dates of occurrences and options, including the crop succession (*i.e.* species,  
 138 variety, mix of species or varieties), sowing (*e.g.* seed density, row orientation, sowing depth), harvest  
 139 and mowing (*e.g.* date, cutting height), tillage and mechanical weeding (*e.g.* tool, depth, speed),  
 140 herbicides (*e.g.* product, dose, spraying options), mineral and organic fertilization, irrigation, and other  
 141 pesticides. The soil is described in terms of physical and chemical characteristics (*e.g.* texture, depth,  
 142 rate of stones, pH). The initial weed flora present at the onset of the simulation is described via the  
 143 seed bank, with weed species and seed densities at different soil depths. Finally, daily weather inputs,



144 usually extracted from weather stations records, are used for each simulated day (*e.g.* daily radiation,  
145 rainfall and temperature).

146 Each day, these inputs' variables influence weeds and crops. Pre-emergent stages (surviving, dormant  
147 and germinating seeds, emerging seedlings) are driven by soil structure, temperature and water  
148 potential. Post-emergent processes (*e.g.* photosynthesis, respiration, growth, etiolation) are driven by  
149 light availability and air temperature. At plant maturity, weed seeds are added to the soil seed bank;  
150 crop seeds are harvested to determine crop yield. Life cycle processes also depend on the dates,  
151 options and tools of management practices, in interaction with weather and soil conditions on the day  
152 the operations are carried out (supplementary material online section A).

153

## 154 2.2 Online survey of crop advisors and farmers (step i)

155 A survey was conducted aiming first at crop advisors, and then at farmers, to identify the type of  
156 required DSS in terms of use, inputs and outputs. This step was essential to determine which data and  
157 knowledge to extract from FLORSYS and in which format. The survey was a semi-structured online  
158 questionnaire (extract in supplementary material online, section B) sent in March 2015 via e-mails to  
159 200 crop advisors from chambers of agriculture, technical institutes and agricultural cooperatives all  
160 over France. The emailing list was established with the help of the main French crop institutes and  
161 cooperatives reaching different kinds of crop advisors. Crop advisors can give advice at different  
162 scales: for individual farmers, for small groups of farmers in a small area or for big groups in entire  
163 regions.

164 The online survey remained open for one month and included four parts to identify: (1) the  
165 interviewed persons (*e.g.* which production system, which use of already existing DSS); (2) the aims,  
166 contents and structure of a DSS they would like to use for weed management advice: the criteria for  
167 evaluating cropping systems (*e.g.* weed harmfulness, food offer for pollinators), the temporal scale  
168 (*e.g.* one year, one rotation) and the description of farming practices (*e.g.* detailed list of cultural  
169 operations or meta-decision rules, for example plough every two years); (3) the constraints for model

170 use, *i.e.* the availability and difficulty to fill in the different types of input variables; (4) the  
171 functionality and readability of inputs and outputs of the future DSS, *i.e.* the ability to understand why  
172 a given input leads to the resulting output. Questions on type and level of details of inputs and outputs  
173 were based on the kind of information fed into and provided by FLORSYS (section 2.4.1). Other  
174 questions were based on our need to better understand the way users would like to use a DSS and how  
175 they perceive weed management. Structured answers were analysed by counting occurrences for each  
176 proposal and compared to the underlying crop advisor profile. For example, the advisors that answered  
177 “*Detailed list of operations*” to the question “*How much data are the users ready to provide for a*  
178 *decision-support system?*” were they the same ones answering “*Crop management sequences*” to  
179 “*Which decisions to take with the DSS?*” Farmers' answers to the online survey were too scarce for a  
180 quantitative analysis and were analysed in a qualitative way, their answers were used here to illustrate  
181 some examples.

182

## 183 2.3 Group meetings with farmers and advisors (step iv)

184 From future users, as a result of the needs found in step i and the simplification we built different tools  
185 to be used as a prototype of the DSS (step iii). This prototype was tested in order to be improved with  
186 future users in group meetings.

### 187 2.3.1 First meeting: real-time feedback from farmers to crop advisors' 188 answers at the online survey

189 During the first meeting, we took advantage of the group that was already acquainted with FLORSYS to  
190 present the advisors' answers from the online survey in order to collect the farmers' feedback. The  
191 group was composed of approximately 10 farmers from the Picardie region (North of France), with  
192 their two consultants from the watershed management local authority and a consulting company. The  
193 two consultants were using FLORSYS to test alternative practices proposed by farmers to reduce  
194 herbicide use.

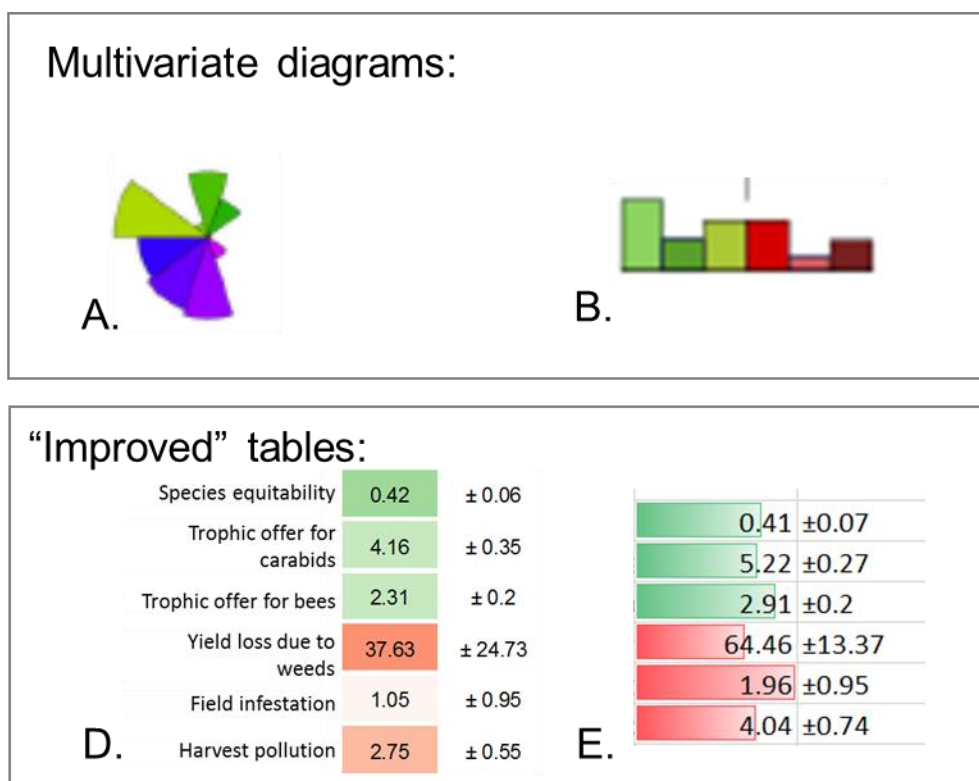
195 We presented part of the answers from the online survey to the farmers and recorded their answers via  
196 a questionnaire and an open discussion. We focused on questions relevant to what kind of DSS the  
197 crop advisors would like to have, and only the answers to the following questions were shown to the  
198 farmers: how much details to describe a cropping system, which level of disruption in the existing  
199 cropping system level is acceptable or required, what are the constraints of weed management, which  
200 weed impact indicators are useful to evaluate weed management tactics. In addition, we collected  
201 feedback of farmers on a decision tree with two options for displaying outputs (options A and B,  
202 Figure 2).

203

### 204 2.3.2 Second meeting: testing formats for the visual decision guide

205 The objective of the second meeting was to test possible formats for the visual decision guide of the  
206 DSS. Based on past experience from both researchers and farm advisors, we proposed a table format  
207 (details in 2.4.3 and Table A. 1 in Appendix). The meeting took place in the Champagne region  
208 (North-East of France), during the annual meeting of a GRCETA, a regional group of about 50  
209 farmers aiming to innovate in their farming practices, helped by two crop advisors. The FLORSYS  
210 model was presented to make them understand its functioning and the biophysical knowledge that  
211 would be behind the future DSS. They were asked to answer a short questionnaire testing their  
212 understanding and the ease of handling the table DSS output format (Table A. 1, Appendix) on a paper  
213 sheet. Instead of answering individually as expected, the farmers spontaneously gathered into small  
214 groups of 3-4 participants, which stimulated their discussions and resulted in 10 complete answers out  
215 of 50 farmers. First, we evaluated the farmers' understanding in terms of decisions and weed impacts  
216 of the table format by grading their answers as entirely correct, partially correct (*i.e.* correct answer  
217 with additional wrong elements) or incorrect. Then, they were asked to evaluate how easy it was to  
218 handle and understand the content of the table (*e.g.*, finding a cropping system in the table is: really  
219 easy, easy, difficult and really difficult). Then, we showed an example of a decision tree (Figure A. 1,

220 Appendix) and their comparative reaction to this option against the table was recorded in writing.  
 221 Finally, we wrote down farmers' comments and suggestions for the development of the DSS.



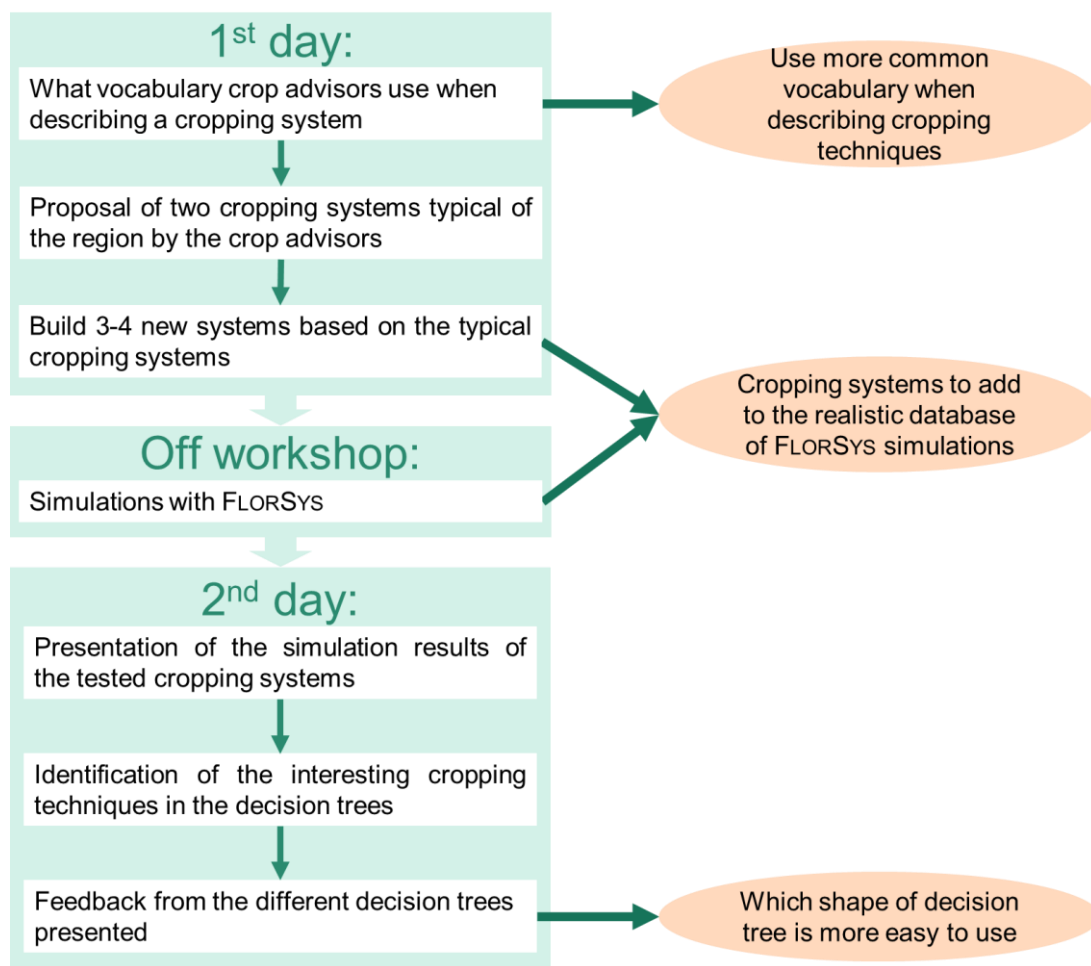
222  
 223 Figure 2: Different output formats of the decision support prototype that were evaluated with future  
 224 users of the decision support system. A: polar area diagrams, each circular sector being an indicator of  
 225 the performance of a cropping system; B: bar plots, each bar being again an indicator; C: table  
 226 improved with colour gradients, presenting mean value and standard deviation of the indicators; and  
 227 D: table integrating bar plots. (Floriane Colas © 2018)

228

## 229 2.4 Workshops with future users of the decision support 230 systems (step iv)

231 The actual manipulation of the DSS can bring out the different usages that users are susceptible to  
 232 have and that we are not expecting (Cerf *et al.*, 2012). Hence, based on Lefèvre *et al.*(2014), we  
 233 proposed a workshop to design cropping systems while using the prototype of the DSS with crop

234 advisors (Figure 3). The DSS was a preliminary decision tree built from a cropping-system database  
 235 for a similar production situation (in terms of pedoclimate) of the workshop's participants (Colas *et*  
 236 *al.*, submitted; Colas, 2018) and simulated with FLORSYS during step ii (Figure 1). Different formats  
 237 for presenting the "leaves" were tested for the decision tree (Figure 2).



238

239 Figure 3 : Framework of the workshop testing the future Decision Support Systems. Rectangles show  
 240 the conduct of the workshop, ellipses describe the improvement for the decision support system from  
 241 the workshop (Floriane Colas © 2018)

242

243 The workshop was organized over two days, with time in-between to simulate the cropping systems  
 244 designed during the first day. The vocabulary used by the crop advisors was put in writing to ensure  
 245 that it corresponded to the one used in FLORSYS. Moreover, the crop advisors chose a set of weed

246 impact indicators among the ones available in FLORSYS to evaluate the tested cropping systems  
247 (section 2.4.2).

248 During the second day, the results of the FLORSYS simulations were shown to evaluate the proposed  
249 cropping systems. Then, the DSS prototypes were tested by evaluating the same cropping systems, i.e.  
250 by locating the systems in the decision tree, based on the associated combination of cultural practices.  
251 At the end of the second day, participants were asked to assess their satisfaction with the different  
252 decision trees.

253 The two-day workshop was held in spring 2017 in the Champagne region, with five crop advisors. We  
254 worked with a small number of participants highly interested in the prototype to make it easier for all  
255 participants to speak out and express their opinions. The small group size also made it easier to fully  
256 record all the reactions of crop advisors.

257 Finally, in November 2017, the participants of the workshop were asked to use an online application  
258 (section 2.4.4). The prototype consisted of the decision tree shown during the workshop and a  
259 metamodel built from cropping-system database (Colas *et al.*, submitted; Colas, 2018) during step ii  
260 (Figure 1). This metamodel quickly and easily predicts the weed impact indicators from synthetic  
261 cropping system descriptors, using a fast predictor (see section 2.4.4). To evaluate their experience  
262 with the DSS prototype, a short online survey with a semi-structured question assessed: (1) the ease of  
263 use of this prototype, *i.e.* of entering new data, (2) the user's confidence in the cropping system  
264 descriptors ranks and in the results of the prediction and (3) what improvements users would like to  
265 have.

266

## 267 2.5 Transforming the research model to make it more 268 accessible to users

269

## 270 2.5.1 Indicators for assessing weed impacts on crop production and 271 biodiversity

272 To simplify the evaluation of cropping systems, many crop and weed state variables predicted by  
273 FLORSYS are transformed into weed impact indicators (Mézière *et al.*, 2015a; Colbach *et al.*, 2017b).  
274 The weed harmfulness indicators were developed with farmers and consider direct harmfulness for  
275 crop production (crop yield loss, harvest pollution by weed seed and debris), technical harmfulness  
276 (harvesting problems due to green weed biomass blocking the harvest combine), and sociological  
277 harmfulness (field infestation by weed biomass during crop growth) which reflects the farmers' worry  
278 of being thought incompetent by their peers even if there is no effect on yield loss. We added two  
279 indirect harmfulness indicators due to pest survival and dispersal by weeds (increase in yield loss due  
280 to weed-borne take-all disease in cereals, and parasite risk due to the holoparasitic plant *Phelipanche*  
281 *ramosa*) (Mézière *et al.*, 2015b; Colbach *et al.*, 2017a).

282 A second series of indicators concern weed-mediated ecosystem services. Functional biodiversity is  
283 assessed via weed related trophic resources for birds, granivore carabids and pollinators. Two other  
284 indicators assess weed contribution to wild plant biodiversity maintenance, via species richness and  
285 evenness (Pielou's equitability index). A last set of indicators is still being developed and will assess  
286 the contribution of weeds to limiting environmental impacts of cropping systems *e.g.* reduction of soil  
287 erosion. The combination of all or some of these indicators constitute performance profiles of  
288 evaluated cropping systems. These performance profiles were the output presented in step ii of Figure  
289 1 to evaluate cropping systems in both decision trees (section 2.4.3) and a fast predictor (section  
290 2.4.4).

291

## 292 2.5.2 Visual guides for pinpointing pertinent changes in cultural 293 practices

294 Based on the results of step i (section 3.1), the visual guides aim to support users when choosing  
295 which cultural practices to change and how to combine them in order to reach a given weed-impact  
296 goal. These visual guides are based on multivariate classification and regression (CART) trees  
297 (Breiman *et al.*, 1984) fitted on a large and diverse cropping-system database in step ii (Colas *et al.*,  
298 submitted; Colas, 2018). To simplify, CART trees are referred as “decision trees” thereafter. To take  
299 account of the local constraints of farmers, we developed a series of different decision trees  
300 corresponding to contrasting pedoclimatic conditions as well as for different combinations of weed-  
301 impact indicators (Colas *et al.*, submitted; Colas, 2018).

302 In contrast to FLORSYS, with its detailed lists of operations (section 2.4.1), the decision trees use  
303 synthetic cropping system descriptors as proxies for meta-decision rules (Aubry *et al.*, 1998). During  
304 the construction of the trees from FLORSYS simulations, these descriptors were computed from the  
305 detailed FLORSYS inputs, either at the level of the crop rotation (e.g. average tillage frequency or  
306 proportion of spring crops in the rotation) or per cropping period of each crop (e.g. average wheat  
307 sowing date, average tillage frequency in oilseed rape).

308

### 309 2.5.2.1 Format for cultural practice combinations

310 The various output format options were inspired by the results of the online survey of section 2.1, past  
311 research studies, feedback from technical institutes and cooperatives as well as participants in the  
312 group meetings. For instance, the results of FLORSYS simulations were often synthesized as decision  
313 trees (Figure A. 1, Appendix), identifying combinations of cultural practices resulting in different  
314 performances in terms of weed impact on crop production and biodiversity (Mézière *et al.*, 2015a;  
315 Colbach and Cordeau, 2018). The tree shape representation has the additional advantage of presenting  
316 the results in a format similar to what is already used for guiding farmers' decisions related to crop



317 protection (*e.g.* slug control (Bodilis *et al.*, 2017)) or environmental impacts (*e.g.* risk of run off in  
318 potatoes (Arvalis-Institut du Végétal and Bayer, 2016)).

319 These decision trees may not always be easy to read for everyone and indeed, participants of the first  
320 group meeting proposed an alternative format based on tables. Consequently, we transformed the  
321 decision trees into a table showing the same information as trees (Table A. 1, Appendix), with the first  
322 column showing the performance in terms of weed impact and the subsequent columns showing  
323 cultural practices (*e.g.* sowing date of cash crops, proportion of winter crops in rotation). Each line  
324 described the complete list of combined cultural practices associated to a given performance profile.

325

#### 326 2.5.2.2 Format for displaying the weed impact indicators

327 The DSS will be used as a support to design multiperformant-cropping systems, where several  
328 performance indicators must be considered simultaneously. We chose here to work with all weed  
329 harmfulness and biodiversity indicators as well as herbicide use intensity but future users will be able  
330 to choose those indicators that are most relevant for their own situation.

331 In previous studies using the indicators computed by FLORSYS, polar area diagrams (Mézière *et al.*,  
332 2015a) and barplots of probabilities of multicriteria scores were used (Colbach *et al.*, 2017b; Colbach  
333 and Cordeau, 2018). Here, we wanted to keep the details of all indicators as experience with other  
334 multicriteria tools such as DEXiPM (Pelzer *et al.*, 2012) showed that users are often more interested in  
335 individual scores than in the final score. Consequently, we tested four kinds of multi-criteria diagrams  
336 (Figure 2): polar area diagrams (A), bar plots (B) and different tables improved with colour gradients  
337 (C) or integrated bar plot (D). Options A and B required rescaling the different indicators to a common  
338 [0, 1] scale to make them comparable (Colas *et al.*, submitted; Colas, 2018).

339

### 340 2.5.3 A fast predictor to metamodel FLORSYS

341 Because of its complexity, FLORSYS is slow to simulate cropping systems (*e.g.* 40 minutes for a 13-  
342 years long simulation, (Colas *et al.*, submitted; Colas, 2018)) and cannot be used in workshops for  
343 real-time evaluation of cropping systems. Moreover, step i showed the need for a simpler DSS that  
344 was fed by meta-decision rules instead of detailed list of cropping operations. Thus, in step ii (Colas *et*  
345 *al.*, submitted; Colas, 2018), we used the random forest method to produce a metamodel, *i.e.* a model  
346 of the initial FLORSYS model, predicting weed impact indicators from the same synthetic cropping  
347 system descriptors as the decision trees. Random forests rely on classification and regression trees  
348 methodology. As an ensemble learning method, they improve prediction capacities of single trees by  
349 averaging the predictions of a multitude of trees (Breiman, 2001).

350 The R-shiny application (Chang *et al.*, 2017) of the DSS prototype (see screenshots in supplementary  
351 material online section D) consisted of two tables, the first listing all the synthetic cropping system  
352 descriptors as proxies of meta-decision rules. The cropping systems descriptors were ranked according  
353 to their importance on the variation of the weed impact indicators, corresponding to the VIP estimated  
354 with the random forest. This table was pre-filled with the mean values of the descriptors from the  
355 cropping-system database, and users could change one or several of these descriptors at a time. A  
356 simple click runs the random forest (hence "fast predictor") and the second table shows the resulting  
357 weed-impact indicators, together with the minimum and maximum values recorded in the database. In  
358 the test with the crop advisors, we used the fast predictor simultaneously predicting all weed  
359 harmfulness and biodiversity indicators as well as herbicide use intensity.

360

## 361 3 Results

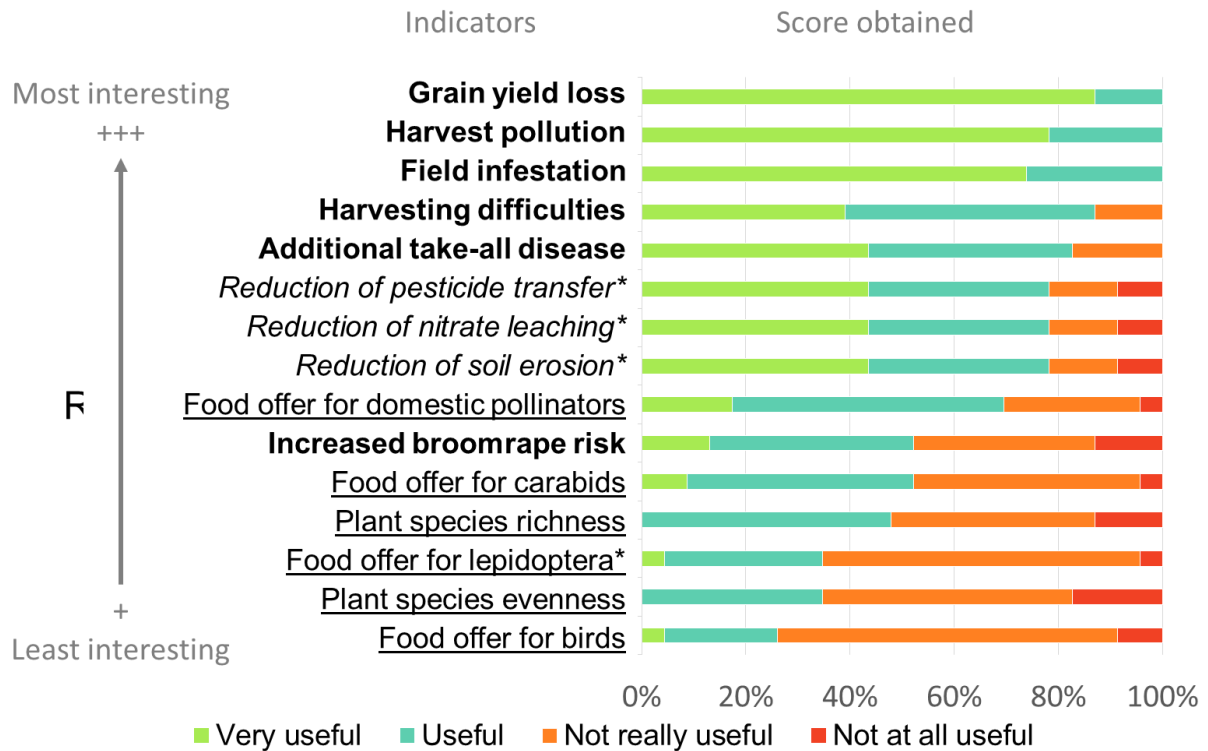
---

### 362 3.1 Crop advisors' needs and constraints to use a decision 363 support system

364 Forty crop advisors from all over France (16 regions) answered the online survey (supplementary  
365 material online section B). Weed harmfulness indicators were considered the most useful by crop  
366 advisors, especially grain yield loss, harvest pollution and field infestation (Figure 4). Pest problems  
367 specific to certain regions or crops (*i.e.* weed-borne take-all disease and broomrape risks) interested  
368 fewer advisors. Ecosystem service indicators were judged less important than harmfulness ones, but  
369 still considered useful by 30 to 70 % of the respondents, with food offer for domestic bees scoring  
370 best. In terms of ecosystem services provided by weeds, advisors were much more interested in the  
371 potential contribution of weeds, particularly during summer fallow, to reduce environmental impacts  
372 of cropping systems, *i.e.* pesticide transfer, nitrate leaching and soil erosion. When asked how many  
373 indicators the DSS should have as output, 71% of the crop advisors were interested in having multiple  
374 indicators, without any aggregation of the results, the same proportion of crop advisors also wanted to  
375 choose from the pool of indicators. Nearly all (91%) were interested in two indicators summarizing,  
376 respectively, harmfulness and ecosystems services indicators. Only 25% would rather prefer a global  
377 score aggregating all indicator performances.

378 The major reason why advisors considered weeds difficult to manage was the lack of biological  
379 knowledge (*e.g.* How long do weed seeds persist in the soil? When and how fast do they emerge?)  
380 (Figure 5). The low or unknown efficiency of some practices (*e.g.* mechanical weeding, tillage) and  
381 the existence of particularly difficult weed species (*e.g.* perennial plants) were two other frequently  
382 cited answers.

383



384

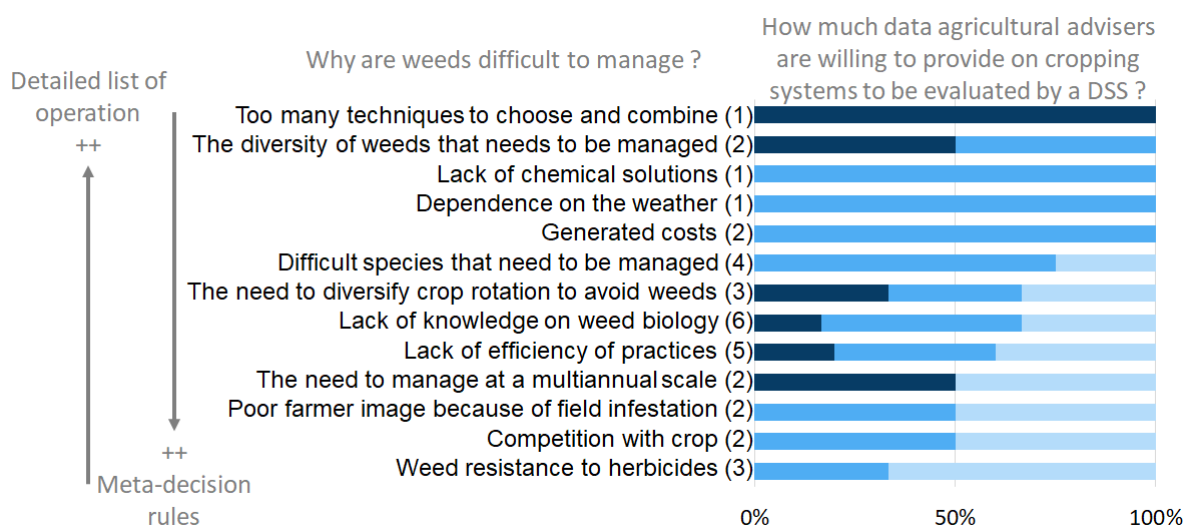
385 Figure 4 : Which weed impacts interest crop advisors? Percentage of the 23 answers in the online  
 386 survey assessing the usefulness of the weed impact indicators available in FLORSYS. Indicators of  
 387 weed harmfulness for crop production (**in bold**), of weed contribution to limiting environmental  
 388 impacts of cropping systems (*in italics*), of weed contribution to biodiversity (underlined). \* indicators  
 389 that are still in development. (Floriane Colas © 2018)

390

391 The issues the advisors had with weed control influenced the data they wanted to provide in order to  
 392 feed a DSS (Figure 5). The same was true when looking at the kind of decisions that the advisors  
 393 would like to take with a DSS (Figure 6). The combination of the two analyses led to the identification  
 394 of different needs in terms of DSS: (1) users confronted with major problems such as herbicide  
 395 resistance, presence of highly competing weeds or the need to manage infestations at a multiannual  
 396 scale preferred to focus on meta-decision rules for the DSS (Figure 5) and would be ready to radically  
 397 change their practices (*e.g.* diversification of crop succession) (Figure 6); (2) users deploring the lack  
 398 of knowledge on how to combine a multitude of techniques and how to efficiently manage a diversity

399 of weeds, both in terms of costs and robustness facing changing weather over years (Figure 5), were  
 400 ready to understand and modify their practices. They would modify their practice before reaching an  
 401 obstacle and would provide a detailed description of the practices (e.g. crop succession, list of  
 402 operations) to finely tune their system in terms of options and timings of operations (e.g. which  
 403 practices, which mechanical weeding) (Figure 6).

404



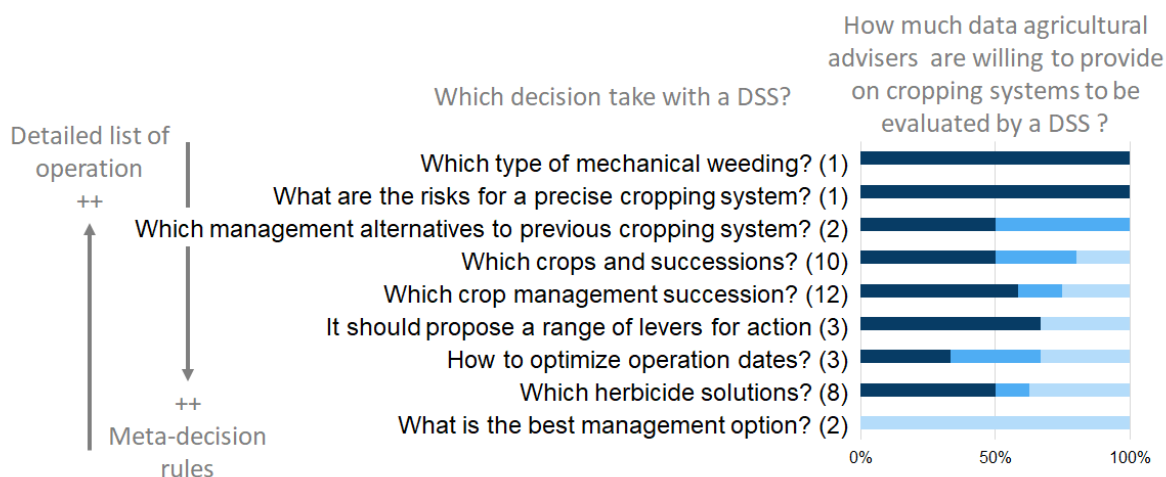
405  
 406 Figure 5 : Association between the degree of detail the crop advisors are willing to provide on  
 407 cropping systems to be evaluated by a decision-support system (DSS), and their perception of weed  
 408 control issues. Percentage of advisors willing to provide detailed lists of operations (dark blue),  
 409 synthetic meta-decision rules (light blue) or both (intermediate blue) depending on why they consider  
 410 weeds difficult to manage (in brackets: number of advisors, of the 15 full answers, having mentioned  
 411 the reason). Respondents were free to complete in their own answers with “weed resistance to  
 412 herbicide” and “long persisting seeds in the soil” given as examples in the statement of the question.  
 413 (Floriane Colas © 2018)

414

415 The few farmers that answered the survey confirmed these two contrasting needs for a DSS. A farmer  
 416 from northern France stated that “*weed growth phase and its sensitivity to herbicides*” was the major  
 417 obstacle to efficient weed management. A DSS should “*target the best herbicide possible*”. He then

418 declared that “it is important to provide data on all management practices” when asked which the  
 419 level of detail that he was ready to provide to the DSS. A farmer from Picardie had different needs in  
 420 terms of DSS. For him, a DSS should assess “the effect of crop rotation in order to control a given  
 421 weed species” and it should use “the major management rules”. Another farmer from Brittany had  
 422 similar views on a DSS and weed management constraints. He considered that weeds “affect the whole  
 423 crop management plan and [that] no technique is as efficient as herbicides” and for that reason “meta-  
 424 decision rules” were needed for the DSS.

425



426 Figure 6 : Association between the degree of detail the crop advisors are willing to provide on  
 427 cropping systems to be evaluated by a decision-support system (DSS), and the decision they would  
 428 like to take with the DSS. Percentage of answers of how much data crop advisors are willing to  
 429 provide for a DSS depending on the decisions they would like to take with it. Dark blue: detailed list  
 430 of operations, light blue: synthetic meta-decision rules, intermediate blue: both; in brackets: number of  
 431 advisors, of the 15 full answers, having mentioned the decision in their answer. (Floriane Colas ©  
 432 2018)

434

## 435 3.2 Contributions of the group meetings

### 436 3.2.1 Farmers' reactions to the advisors' responses to the online 437 survey

438 Generally, the farmers of the Picardie group meeting agreed with the crop advisors' answers to the  
439 online survey. For example, when asked why weed management was difficult, they talked about the  
440 lack of active ingredients, of alternative efficient and of easy-to-implement solutions. The lack of  
441 information on weed species and biology was also stressed out, with precise examples, *e.g.*  
442 allelopathy. Farmers also mentioned climate change and inter-annual weather variations.

443 The farmers were, however, more open to innovation than the crop advisors thought. They suggested  
444 more and more diverse modifications of cultural techniques when asked what level of disruption in the  
445 existing cropping system they are willing to put up with the DSS. Conversely, they were less disposed  
446 to changes in crop rotation, because of a missing outlet for the new production in the region. Farmers  
447 were also more sensitive to the weather influence and furthermore, it was difficult to project further  
448 than three years because of the frequent changes in policies.

449 The DSS outputs, presented in the shape of polar area diagrams (Figure 2.A) were hard to understand  
450 by farmers. The decision tree presented as an example confused some farmers who suggested a table  
451 format which was tested in the next group meeting (section 3.2.2). Finally, they stated that the future  
452 DSS needed both a detailed version of the inputs and a synthetic one “*depending on the user and the*  
453 *available time*” for designing new cropping systems.

454

## 455 3.2.2 Farmers' feedback to improve the format of the decision support 456 system

457 The tabular visual guide for identifying pertinent changes in cultural practices based on feedback  
458 from the previous meeting (section 3.2.1) was presented (Table A. 1 in Appendix) and its evaluation  
459 was two-fold: first, we assessed whether the farmers were able to identify the correct combination of  
460 different cultural practices corresponding to a given cropping system in the table. The participants  
461 considered this to be difficult (70% of the answers) or very difficult (20%). Then, we checked whether  
462 the participants understood the table correctly, *i.e.* whether they drew the correct conclusions in terms  
463 of decisions and weed impacts. There were only 20 % correct answers, the rest being totally wrong (45  
464 %) or comprising partially incorrect answers (35 %). Conversely, for this group of farmers, when a  
465 decision tree was shown, its principle was immediately understood and approved by all farmers.  
466 During the questionnaire time, farmers were discussing together, helping each other to understand and  
467 propose interpretations. To encourage discussions, we subsequently preferred to work with small  
468 groups of participants.

469

## 470 3.3 Workshops to improve the prototype of the DSS

### 471 3.3.1 Vocabulary to describe cropping systems

472 The design of cropping systems during the first day and the handling of the decision-tree prototype  
473 (section C in supplementary material online) triggered a discussion on more efficient ways to describe  
474 cropping systems in a synthetic way. This resulted in: (1) new ideas for cropping system descriptors to  
475 add to the existing ones in FLORSYS: *e.g.* crop rotation length, alternation of spring and winter crops,  
476 frequency of farming tool use to justify the possible purchase of the farming tool (*e.g.* frequency of  
477 hoe), composition of the crop rotation (*e.g.* proportion of cereal crops or legumes crops), return time of  
478 ploughing. (2) As crop advisors usually referred to cultural techniques in association with a given crop  
479 species, we subsequently computed cropping system descriptors not only as averages over the rotation



480 but also per crop species *e.g.* frequency of ploughing in wheat, number of herbicide operations in  
481 oilseed rape. (3) Other proposals were actually already included in the initial decision tree but their  
482 labelling was unclear, *e.g.* the proportion of (perennial) fodder crops in the rotation was labelled  
483 initially as the proportion of multiannual crops. (4) Some proposals were too vague to become usable  
484 inputs for the decision tree. For instance, the participants proposed an input qualifying whether sowing  
485 was early or late. But the decision tree and the underlying FLORSYS simulations require actual  
486 calendar dates to correctly predict effects. Moreover, the early or late character of a sowing (or any  
487 operation) not only depends on the crop but also on the region. Consequently, we decided to keep the  
488 calendar date at present as actual input and to plan a future “layer” to put on top of the DSS to  
489 transform qualitative inputs into quantitative ones, considering regional specificities, and based on  
490 expert knowledge.

491

### 492 3.3.2 Display of weed impact indicators and use of decision trees

493 In order to choose the best way to display the cropping system performance in terms of weed impact  
494 indicators, the crop advisors were shown three different displays (B, C and D in Figure 2). All five  
495 participants considered the format C to be the best and the multivariate barplot B the worst. A colour-  
496 blind participant found option D as good as option C because he could not discriminate the colour  
497 variation of C, in contrast to the bar heights of format D. The crop advisors also suggested an  
498 additional indicator assessing the dynamics of weed biomass over the years, to discriminate those  
499 cropping systems that decreased weed infestation over time from those that were unable to avoid an  
500 increase. When working as a group, half the workshop participants considered the decision tree to be  
501 quite easy to use and the rest did not find it easy. Working with the tree alone was more difficult,  
502 either not easy (40% of the participants) or not easy at all (60%) (online supplementary material  
503 C.3.2.).

504

### 505 3.3.3 Use of the fast predictor

506 After the workshop, the link to the R-shiny online prototype of the fast predictor (supplementary  
507 material online section D) was sent to the participants of the workshop. The application takes  
508 approximately three seconds to predict weed impact indicators for a set of cropping system descriptors  
509 entered by the user. Only two of the previous workshop participants gave feedback on the easiness of  
510 use, both stating that they found it easy to fill in the inputs. However, they disagreed on the current  
511 approach where the table listing the cropping descriptors was pre-filled with average descriptor values  
512 so that users only have to modify the one or several descriptors they are most interested in, instead of  
513 having to fill in the whole list. However, the fault-finding respondent did not suggest a better solution.

514

### 515 3.3.4 Overall use of the DSS and trust in results

516 The crop advisors were asked how confident they were in the DSS results to see how the DSS is  
517 perceived and what support to provide to users with the DSS. The workshop participants, who tested  
518 the decision trees and the fast predictor simultaneously predicting weed harmfulness, biodiversity and  
519 herbicide use, considered that the agronomical results were moderately interesting (online  
520 supplementary material C.3.2.). They expected a stronger impact of crop rotation and a better  
521 performance of diverse rotations, which is the case in the trees considering only weed harmfulness.  
522 One participant wrote in the comments section of the survey that “*Surprising results considering the*  
523 *diversity of the rotations which led here to an average performance*”. Similarly, the two crop advisors  
524 testing the R-shiny FLORSYS’s fast predictor were surprised by the ranking of input variables,  
525 especially by the low sensitivity of weed impacts to the proportion of winter crops and multiannual  
526 crops in the rotation. Again, these variables are much more influential in the predictor limited to weed  
527 harmfulness. But the users probably also forgot to adapt the other cultural techniques to changes in  
528 rotation-linked variables, e.g. timing of tillage when increasing the proportion of spring crops in the  
529 rotation. This points to another improvement needed in the future DSS, helping to take into account  
530 logical correlations among inputs.

531 However, the crop advisors mostly encouraged the continuing development of the DSS. Three of them  
532 would use and recommend the future DSS, only one would probably not recommend the DSS and one  
533 did not respond (online supplementary material C.3.2.). In the comment section of the survey, crop  
534 advisors ready to use and recommend the DSS specified that “*the current version is too complicated to*  
535 *use and to understand*” but the DSS once “*improved in terms of visual display*” and “*adapted*  
536 *according to end user*” could be interesting. One crop advisor specified how the decision trees and  
537 FLORSYS’s fast predictor should be used with FLORSYS simulations: the decision tree should be a  
538 “*tool to use within working groups aiming to [radically] change the system*” and the fast predictor  
539 should “*rather be used individually to test changes in a given system*”. The group dynamic was  
540 important to help to use the DSS (online supplementary material C.3.2.).

541

## 542 4 Discussion

---

543

544 The present study proposed and applied a methodology to combine participatory decision support  
545 system (DSS) design with data mining to transform an existing mechanistic research model into a  
546 DSS. The resulting DSS comprises different elements to help to design agroecological cropping  
547 systems reconciling weed control, weed contribution to biodiversity and reduced herbicide use. It  
548 comprises (1) a ranking of the most influential cultural practices on weeds impacts to help users to  
549 decide which techniques to focus on changing first, (2) a decision tree to help users to combine  
550 cultural practices, (3) a web application to test and evaluate in a few seconds combinations of meta-  
551 decision rules. The first two elements are visual guides to design cropping systems and the third one  
552 helps to select the best system.

## 553 4.1 A novel tool tailored to end-users' requirements

554 We interacted with crop advisors and farmers, first to determine which data to extract from the  
555 existing FLORSYS research model and how to extract them, and then to transform the resulting  
556 decision trees and the fast predictor (produced in a previous study, (Colas *et al.*, submitted; Colas,  
557 2018)) into a prototype of the decision support system. Our online survey aiming at both farmers and  
558 crop advisors led us to identify the type of DSS in terms of use, inputs and outputs. The group  
559 meetings allowed us to assess what farmers thought of crop advisors' mental models, and to observe  
560 how users would handle different tools inside the DSS and interpret their output formats, ranging from  
561 the virtual field model FLORSYS to visual decision trees on paper. Finally, the ergonomics and  
562 applicability of a prototype of the DSS was tested in workshops. During all the different steps, we not  
563 only collected technical data on how to organize inputs and outputs, but also assessed how crop  
564 advisors and farmers see weed and weed management, and how far they are ready to go when  
565 innovating their practices etc.

566

## 567 4.2 Weed management vision of crop advisors and farmers

568 A crucial first step of our approach was to evaluate the stakeholders' mental model of weeds and their  
569 management. When asked why they considered weed management to be difficult, crop advisors  
570 focused on lack of knowledge, both their own and the current knowledge, whether on weed biology or  
571 on efficiency of techniques, pointing out that more information on weeds needs to be transmitted to  
572 farmers and crop advisors. Our online survey did not collect sufficient farmers' responses to directly  
573 compare their attitude to that of crop advisors, but the first group meeting which submitted the crop  
574 advisors' responses to a group of farmers did not identify any major dissension.

575 Conversely, other studies that specifically questioned farmers in face-to-face interviews on the  
576 probable causes of weed infestations in their fields came up with slightly different answers. Farmers  
577 often blamed the infested fields on events outside of their control (Wilson *et al.*, 2008), *e.g.* weather

578 events, neighbours and neighbouring fields (Pasquier and Angevin, 2017) as well as technical failures,  
579 *e.g.* herbicide failure, inefficient mechanical weeding or the existence of difficult weed species  
580 (Wilson and Tisdell, 2001; Pasquier and Angevin, 2017). The technical failure aspects were also cited  
581 by the crop advisors in our online survey but were considered less important.

582 The differences between our survey and literature studies cannot be attributed only to a different  
583 stakeholder type, *i.e.* crop advisors vs farmers, or questions that were differently formulated, as  
584 identified by Vissoh *et al.* (2007). The method of interview is another factor, as answers to anonymous  
585 online surveys tend to be more open than when facing a human interview partner or a group of peers.  
586 Moreover, diverse attitudes exist even within a given stakeholder group. Indeed, both our online  
587 survey and previous literature working with diverse interview methods reported farmers to have a  
588 more herbicide-oriented and short term vision (Wilson *et al.*, 2008), in contrast to crop advisors and  
589 farmers in the group meeting focusing on agronomical knowledge and techniques to the detriment of  
590 herbicides (Doohan *et al.*, 2010; Pasquier and Angevin, 2017). Conversely, some of our group  
591 meetings showed farmers to be more open to innovation in cropping practices than crop advisors. This  
592 is consistent with the many farmer groups setting up all over France to test innovative practices, such  
593 as the GRCETA which participated in the present study or GEDAs (Groupe d'Étude et de  
594 Développement Agricole, *i.e.* study group on agricultural development) focusing on direct sowing.  
595 Farmers that are part of agricultural development groups are more eager to change their practices than  
596 randomly sampled farmers. However, feedback from farmers also highlighted that cropping system  
597 innovation not only requires decision support but also the necessary socio-economic environment,  
598 particularly outlets for the resulting production (Meynard *et al.*, 2013).

599

## 600 4.3 Contribution of future users for the type and format of the 601 DSS

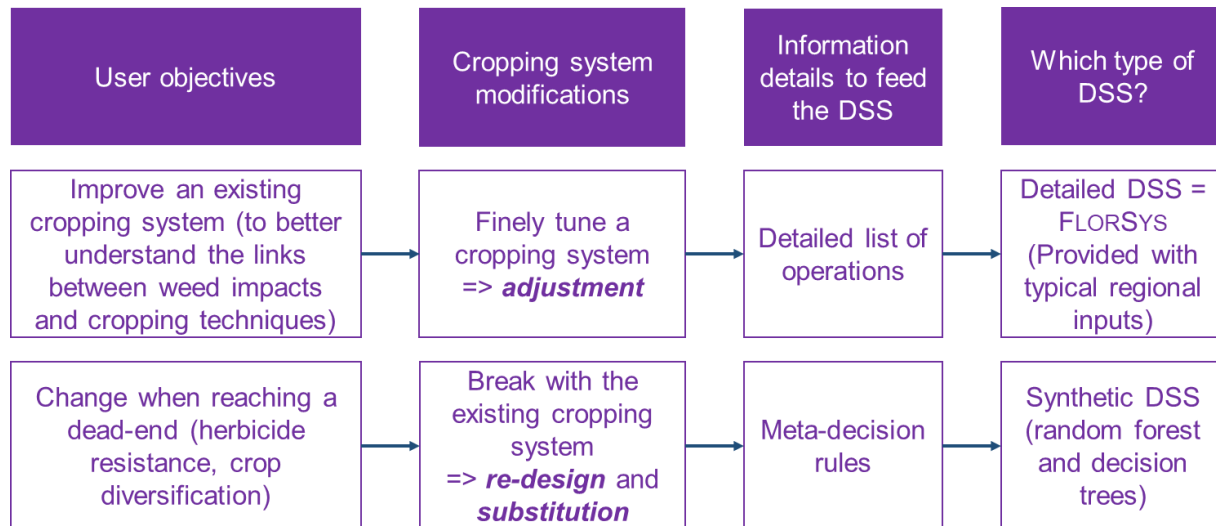
602 The identification of the different profiles and needs for a DSS by crop advisors, via the online survey  
603 and group meetings, led us to propose two types of DSS, depending on the situation (Figure 7): (1) a  
604 synthetic tool, with meta-decision rules for a radical change in cropping systems when faced with a  
605 deadlock (due to herbicide resistance, high weed infestation etc.); (2) a detailed tool, describing  
606 cropping systems with detailed lists of crops and operations and aiming to adjust practices before  
607 reaching a dead-end. The use of one or the other may depend on the advisor profile, the farmer and the  
608 context where the tool is used. When providing precise and individual advice for one particular  
609 situation, the detailed tool would be better, whereas the synthetic tool would be more appropriate for  
610 group advice that needs to fit a larger range of goals and constraints (Dubrulle *et al.*, 2014). This  
611 reflects the fact that farmers have different needs of decision support tools depending on where they  
612 are in terms of the change of their cropping system (Prost, 2008). During the transition from the initial  
613 to a novel cropping system in a farmer's field (e.g. when switching from conventional to organic  
614 farming), different types of decisions and adjustments are necessary, *e.g.* to design and evaluate the  
615 different options, to check the reliability of the cropping system candidate, to adapt the cropping  
616 system to a deteriorated situation... (Cerf and Meynard, 2006). Either farmers want to design and  
617 evaluate solutions, to explore the flexibility and robustness of a cropping system or to counteract the  
618 deteriorations of the weed management in the cropping system. This DSS was designed to help  
619 farmers achieve the designing and evaluation part for changing their cropping system.

620 Our online survey concluded on two contrasting uses and needs for the DSS but more diverse  
621 situations are possible. We may have missed this diversity by insisting on the strategic and  
622 multiannual scale of the DSS, which is crucial for weed management because of weed seeds persisting  
623 over several years in farm field soils (Burnside *et al.*, 1996; Gardarin *et al.*, 2010). It is also possible  
624 that we did not survey sufficiently diverse users to capture all possible uses (Cerf and Meynard, 2006).  
625 However, we benefitted from a diverse network of technical institutes, cooperatives and chambers of

626 agriculture when setting up the online survey and were able to identify the two most contrasting case  
 627 uses, resulting into two contrasting tools. Consequently, a judicious combination of the two tools,  
 628 combined with further *in situ* testing with future users would be an efficient way of refining the DSS.

629 A bottom-up approach designing the whole DSS (including the biotechnical content) with users and  
 630 experts from the start would have assured a better usability of the DSS. However, while experts are  
 631 highly knowledgeable on the effects on individual techniques on a few weed species in the short term  
 632 in a given location, they are unable assess the effects of numerous interactions techniques on multi-  
 633 species weed floras in the longer term. The use of a mechanistic model allowed us to account for these  
 634 multi-dimensional and long-term effects and thus to determine emergent properties going beyond  
 635 expert knowledge. The main difficulty was to bridge the gap between the mechanistic knowledge and  
 636 inputs of the model and the more integrative expertise and needs of future users. Continuous  
 637 interaction with future users to adapt the DSS to more uses would further narrow the gap.

638



639

640 Figure 7 : Diagram representing the two types of decision support system (DSS) depending on the user  
 641 objective and the level of details that the user is ready to feed to the DSS as well as Hill's efficiency-  
 642 substitution-resign approach (Hill and MacRae, 1996; Hill, 1998) for food system design (Floriane

643 Colas © 2018)

644

645 The synthetic DSS is composed of charts of the most important cropping system practices (not  
646 presented here), decision trees, and a metamodel, *i.e.* a fast predictor of FLORSYS based on random  
647 forests. The format of the new synthetic DSS tool was selected by the future users. For the visual  
648 guide, the tree format accommodated the majority of users, in contrast to the table. The table format  
649 included information that was not parsimonious as two lines can have many practices in common,  
650 which, in the tree, are merged into a common branch segment. The table also comprised empty cells  
651 when practices have no significant effect on weed depending on the other cultural practices of the  
652 combination. For the display of weed impact indicator results in both the visual guide and FLORSYS's  
653 fast predictor, the users preferred a display showing values for all weed impact indicators, highlighted  
654 with colour codes, instead of bars or aggregated scores. Combining the same ensemble values that  
655 need to be maximized with values to be minimized was always harder to be understood by crop  
656 advisors and farmers in our workshops and meetings. This is why polar diagrams or bar plots were not  
657 selected. The colour code was judged helpful to visually and fast extract the results, even though  
658 multivariate decision making based on colour seems to be only useful when the level of data  
659 complexity is low and mostly for females (Stella and Malcolm, 2002). Indeed, the red/green  
660 dichotomy is not adapted to colour-blind people, as we observed with one of the crop advisors in the  
661 workshops. Using colours others than red and green could help the 8% men and 0.5% women that are  
662 colour blind (Colour blind awareness, 2017) but the green-red scale is commonly used in many DSS  
663 (Sadok *et al.*, 2009). For the finishing touch of the development of the decision support system, intake  
664 from a human-computer interaction specialist would be best.

665

## 666 4.4 Towards the future decision support system

667 Users' advice is essential to design a decision support system but not all the suggestions of future users  
668 are relevant or possible to follow. For instance, the content of the DSS was derived from the research  
669 model FLORSYS, with a sensitivity analysis performed on FLORSYS identifying the inputs essential for



670 predicting weed impact on crops (Colas *et al.*, submitted; Colas, 2018). These very influential inputs  
671 must be included in the DSS, even if they are difficult to handle by the users. To help future users  
672 utilise those difficult cropping system meta-decision rules, we need to work on a common language  
673 logical for all users (Van Meensel *et al.*, 2012).

674 Helping users with easier-to-handle inputs applies even more to FLORSYS, which is intended for fine-  
675 tuning cropping systems. It requires, for instance, the density of an initial weed seed bank present at  
676 the onset of a FLORSYS simulation, a variable notoriously difficult to access, even for scientists  
677 (Dessaint *et al.*, 1986), let alone for farmers or crop advisors. In order to reconcile usability of the tool  
678 and quality of prediction, we propose to offer a regional set of options for these difficult variables  
679 from which the user can choose. In the example of the weed seed banks, we thus already produced a  
680 list of regional weed seed bank estimated from regional weed flora assessments and checked the  
681 adequacy of this approach with independent field observations (Colbach *et al.*, 2016). Using  
682 recommended sowing date per region from technical institutes as Arvalis ([https://www.arvalis-  
683 infos.fr/orges-de-printemps-semis-des-que-possible-mais-dans-de-bonnes-conditions--@/view-9412-  
684 arvarticle.html](https://www.arvalis-infos.fr/orges-de-printemps-semis-des-que-possible-mais-dans-de-bonnes-conditions--@/view-9412-arvarticle.html)) could help the cropping systems data entering into FLORSYS. Ultimately, filling in  
685 FLORSYS with a set of regional inputs would transform the model into the more detailed tool requested  
686 for fine-tuning (Figure 7).

687 The reaction of crop advisors to the ranking of cropping system descriptors in terms of multicriteria  
688 weed impact when testing the online FLORSYS's fast predictor demonstrates that it is essential to  
689 provide more instructions and support with the DSS. This step is crucial to build the users' confidence  
690 in the DSS. Here, for instance, the R-shiny online test illustrated that the testers were not sufficiently  
691 aware that the ranking was based on a multicriteria assessment of weed impacts and not solely on  
692 weed-borne yield loss or field infestation, which explained the discrepancy between their perception of  
693 reality and the advice proposed by the DSS. To remedy this lack of confidence, the input ranking  
694 could be completed using information on the causes of the different effects with technical datasheets  
695 on weed biology and main effects of different cropping practices. This would also provide the kind of  
696 missing knowledge that many advisors required during the online survey (section 3.1). This

697 information exists but is not always known by farmers or not organised by weed species. Providing  
698 sources of information existing on weeds, like the French website Infloweb (Terres Inovia *et al.*) or the  
699 guide for sustainable weeding (Jouanneau and Verger, 2018), could help this lack of knowledge.  
700 Moreover, the final DSS will let the user choose the kind of weed impacts that should be included  
701 when ranking the cropping system descriptors and running the predictions. This means, for instance,  
702 that advisors focusing solely on controlling weed harmfulness would find the kind of input ranking  
703 with which they are familiar.

704 The steps presented in the paper are the first steps of participatory design presented by Zulkafli *et al.*  
705 (2017). We focused here on the methodology to transform a process-based research model into a DSS.  
706 Even though we did not investigate a large range of use cases, our work is a proof of concept,  
707 demonstrating the feasibility of the approach and the interest to stakeholders. As such, it will be useful  
708 to make available to outsiders the knowledge comprised in many other research models.

709 Further work is still needed to move from the present prototype to a functional DSS. Rose *et al.* (2016)  
710 produced a checklist for good design of decision support tools. In our study, we started on the first  
711 four items of the checklist, *i.e.* performance (is the tool functioning and useful?), ease of use (are the  
712 user interface, the trees and forest easy to navigate?), peer recommendation (is it possible to encourage  
713 knowledge exchange with the tool?) and trust (is the tool evidence-based and do we have the trust of  
714 users?). These items still need some work, especially in the presentation of the tool to gain the trust of  
715 the users. Moreover, we need to complete the rest of Rose *et al.*'s checklist (*e.g.* is the tool matching  
716 habits of farmers? how far is the tool applicable to all types of farming?) by running more workshops.  
717 Here, we voluntarily ran workshops with a small group of relatively homogenous participants to  
718 facilitate exchanges and individual expressions. This helped a great deal to uncover the limits and  
719 possibilities of the prototypes. The various group meetings and workshops also demonstrated the  
720 usefulness of group interactions, *e.g.* leading to a better understanding of the proposed tools formats  
721 and triggering ideas on novel tools formats. Group meetings also helped farmers improve their  
722 knowledge of weed management via the social learning (*e.g.* learning together to improve the  
723 acquisition of knowledge) occurring among participants of meetings (Patel *et al.*, 2007).

724 Group dynamics is a well-known advantage of workshops, for instance to help farmers to distance  
725 themselves from their current situation and to explore new ideas (Lefèvre *et al.*, 2014) or to assist the  
726 learning of a new technology and facilitate its adoption (Labarthe, 2010). So, we need to put the DSS  
727 through a broader range of future users to develop the plasticity needed for the different usages that  
728 users will have (Cerf *et al.*, 2012), especially since farmers sometimes only use a part of the DSS  
729 (Toffolini *et al.*, 2017) or since DSS design and underlying methods are often disconnected from the  
730 way farmers take their decisions (Ravier *et al.*, 2016). Only by including more and more diverse users  
731 and by confronting the DSS to the way they design cropping systems we will refine the cropping  
732 system descriptors to the most useful variables and produce a definitive decision support system.

733

## 734 5 Conclusion

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735 The development of a Decision Support System (DSS), whether from existing models or *de novo*,  
736 needs many interactions with the future users. Here, we proposed and applied a methodology  
737 combining online surveys, group meetings and workshops to integrate crop advisors and farmers into  
738 this process, showing what they brought to the development of the DSS. Based on the users' needs and  
739 objectives for the future DSS, we identified two different types of prototypes, depending on the users'  
740 openness to change, their willingness to invest in the use of the DSS and the challenges they faced in  
741 terms of weed management. Together, we identified the structure of the DSS and how to display  
742 outputs. The workshops helped us to test the prototypes and to improve the vocabulary to use in the  
743 DSS. The study also identified the limits of the DSS, not only intrinsically in terms of user friendliness  
744 or quality but also in terms of possible use. Feedback from farmers highlighted that cropping system  
745 innovation also requires a suitable socio-economic environment, for instance an outlet for novel crops.  
746 Further back and forth runs between users and developers (both scientists and software engineers) are  
747 still needed to polish the DSS and satisfy both parties, *i.e.* crop advisors and farmers on one hand, and  
748 researchers on the other hand.

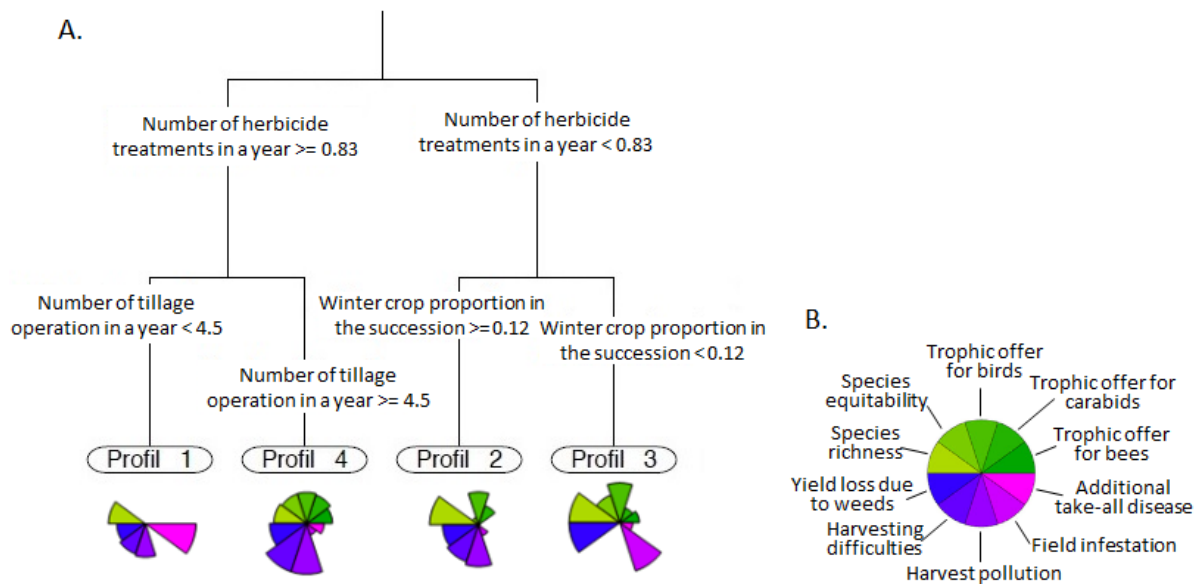
749

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757 6 Appendix



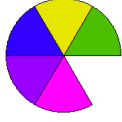
758



759

760 Figure A. 1: Extract of a classification tree model as a possible visual guide of the decision support  
761 system for identifying innovative combinations of cultural practices. A. Tree presenting polar area  
762 diagrams showing the weed impact indicators values corresponding to combinations of cultural  
763 practices. B. Legend of weed impact indicators. (Adapted from Mézière *et al.*, 2015a)

764 Table A. 1: Extract of the translated table given to farmers during the meeting in Aube (France) as a  
765 possible visual guide of the decision support system for identifying innovative combinations of  
766 cultural practices. The table was based on a decision tree and was tested as an alternative visualisation  
767 format, based on the proposal by a farmer participating in one of the workshops. Each row  
768 corresponds to a meta-decision rule describing a cropping system. Each cropping system is evaluated  
769 and the results are presented in a diagram presenting their performances in terms of weed impact  
770 indicators; pink: yield loss, purple: field infestation, blue: harvest pollution, yellow: nitrate leaching  
771 limitation, green: food offer for domestic bees, gray: herbicide use intensity. "Nothing in common"  
772 means that the cropping systems corresponding to this weed impact indicator profile have nothing in  
773 common for the given cultural practice, those are remnants of the decision tree algorithm.

Cropping system performance profile	Combinations of cultural practices				
	Diversity of crop species or varieties in the crop succession	Sowing date of cash crops	Harvest date of winter crops	Winter crop proportion in the succession	Mean tillage depth
	>= 1 species /30 years	after 15 <sup>th</sup> January	before 10 <sup>th</sup> July	< 1/3	nothing in common
	< 1/30 : monoculture	after 15 <sup>th</sup> January	before 10 <sup>th</sup> July	< 1/3	nothing in common
	nothing in common	after 15 <sup>th</sup> January	before 10 <sup>th</sup> July	>= 1/3	nothing in common
	< 1/30 : monoculture	after 15 <sup>th</sup> January	before 10 <sup>th</sup> July	< 1/3	nothing in common
	no information	before 15 <sup>th</sup> January	after 10 <sup>th</sup> July	nothing in common	< 11 cm
	no information	after 15 <sup>th</sup> January	before 10 <sup>th</sup> July	>= 1/3	nothing in common

774

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781 [ruissellement-en-pomme-de-terre\\_3262/](https://www.bayer-agri.fr/cultures/arbre-de-decision-pour-la-gestion-du-risque-ruissellement-en-pomme-de-terre_3262/) (accessed 11.12.19).
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