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

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Abstract

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

Highlights:

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

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

Keywords:

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

1 Introduction

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

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

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

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

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

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

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

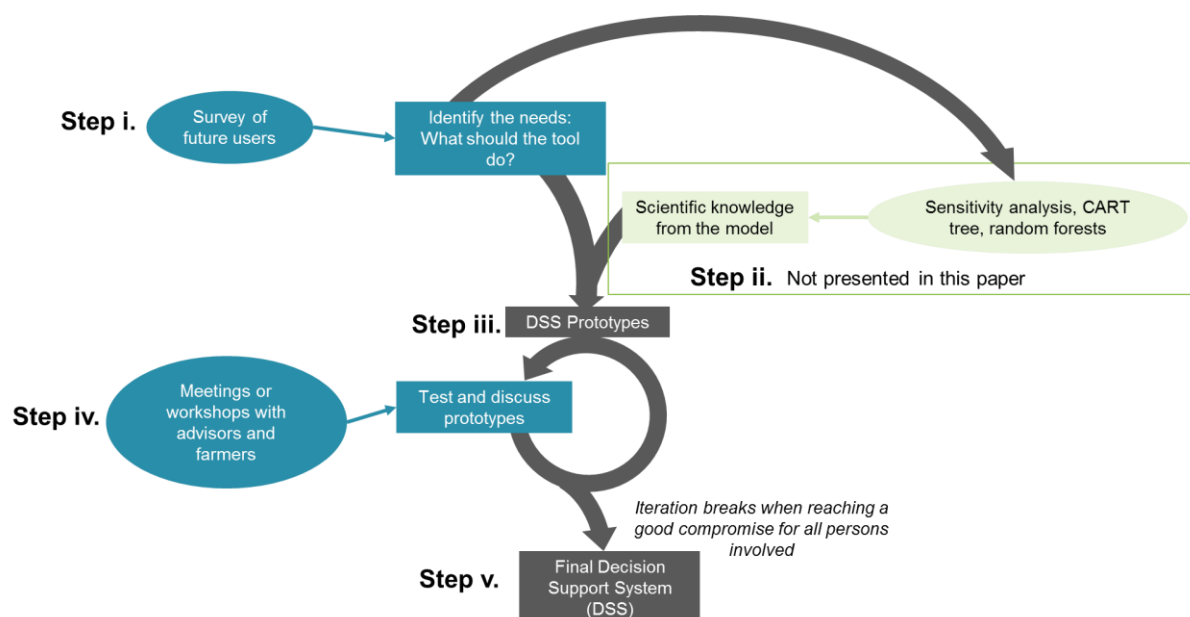


Table 1: Summary of the instances for the development with future users of a decision support system (DSS) for integrated weed management.

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

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

2 Material and methods

2.1 The complex model to simplify: FLORSYS

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

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

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

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

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

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

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

2.3 Group meetings with farmers and advisors (step iv)

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

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

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

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

2.3.2 Second meeting: testing formats for the visual decision guide

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

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

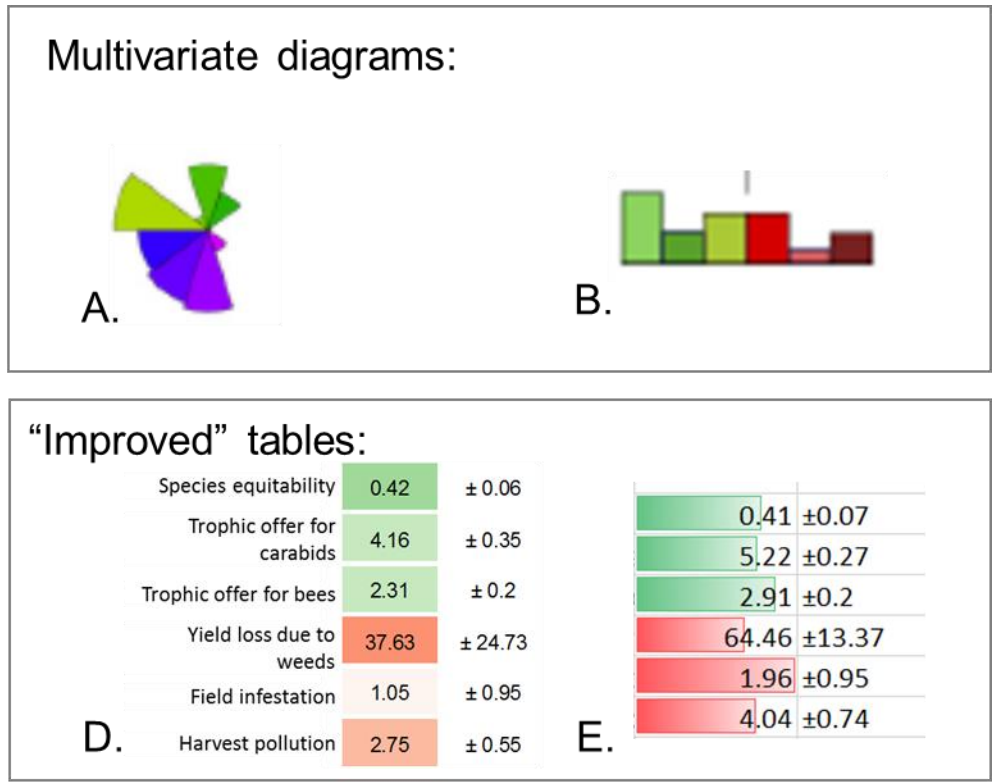


Figure 2: Different output formats of the decision support prototype that were evaluated with future users of the decision support system. A: polar area diagrams, each circular sector being an indicator of the performance of a cropping system; B: bar plots, each bar being again an indicator; C: table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

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

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

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

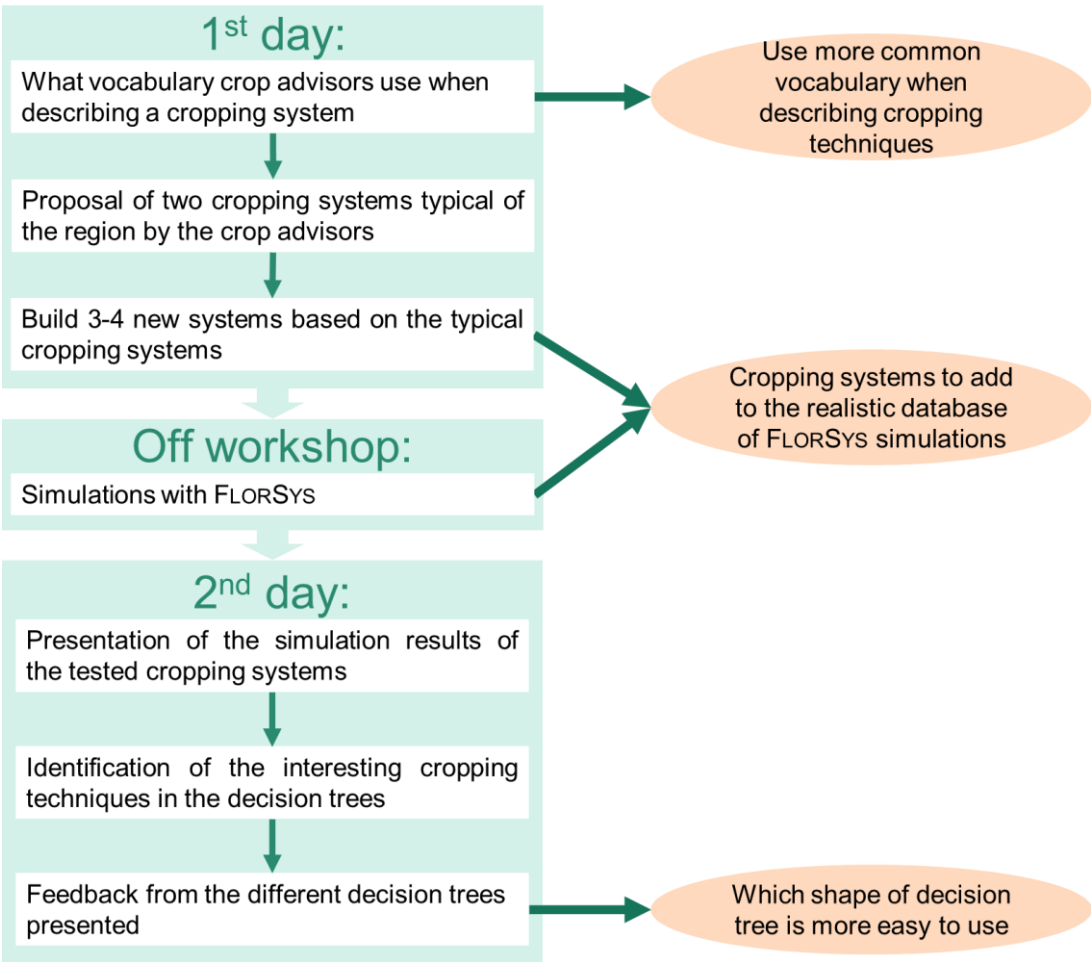


Figure 3 : Framework of the workshop testing the future Decision Support Systems. Rectangles show the conduct of the workshop, ellipses describe the improvement for the decision support system from the workshop (Floriane Colas © 2018)

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

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

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

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

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

2.5 Transforming the research model to make it more accessible to users

2.5.1 Indicators for assessing weed impacts on crop production and biodiversity

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

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

2.5.2 Visual guides for pinpointing pertinent changes in cultural practices

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

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

2.5.2.1 Format for cultural practice combinations

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

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

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

2.5.2.2 Format for displaying the weed impact indicators

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

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

2.5.3 A fast predictor to metamodel FLORSYS

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

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

3 Results

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

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

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

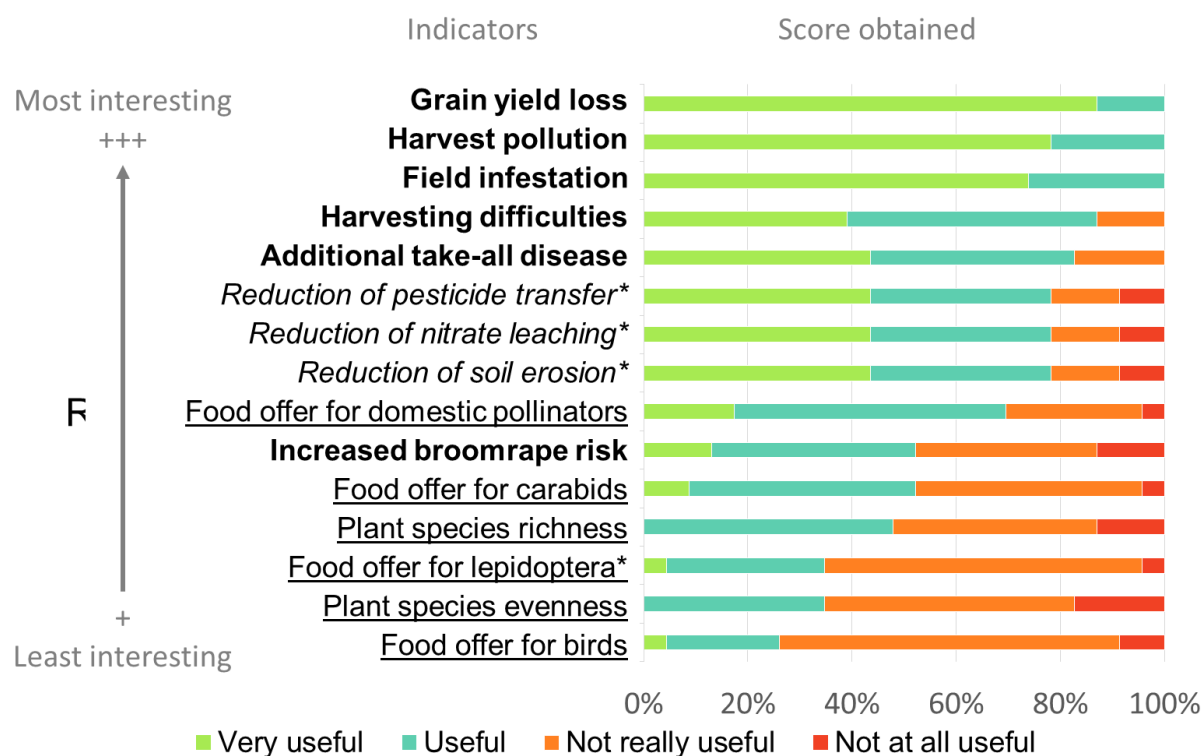


Figure 4 : Which weed impacts interest crop advisors? Percentage of the 23 answers in the online survey assessing the usefulness of the weed impact indicators available in FLORSYS. Indicators of weed harmfulness for crop production (**in bold**), of weed contribution to limiting environmental impacts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

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

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

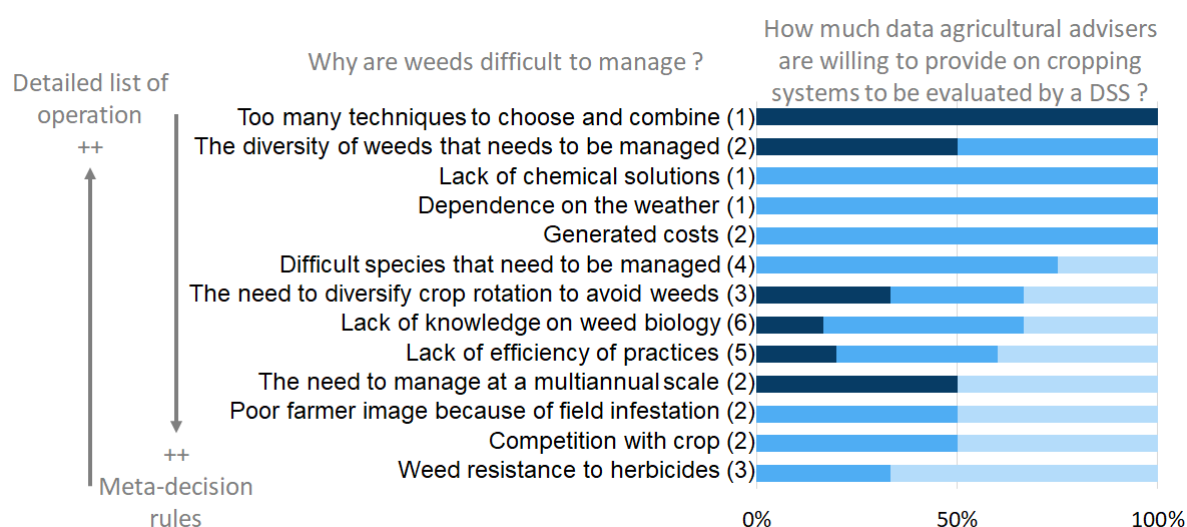


Figure 5 : Association between the degree of detail the crop advisors are willing to provide on cropping systems to be evaluated by a decision-support system (DSS), and their perception of weed control issues. Percentage of advisors willing to provide detailed lists of operations (dark blue), synthetic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

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

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

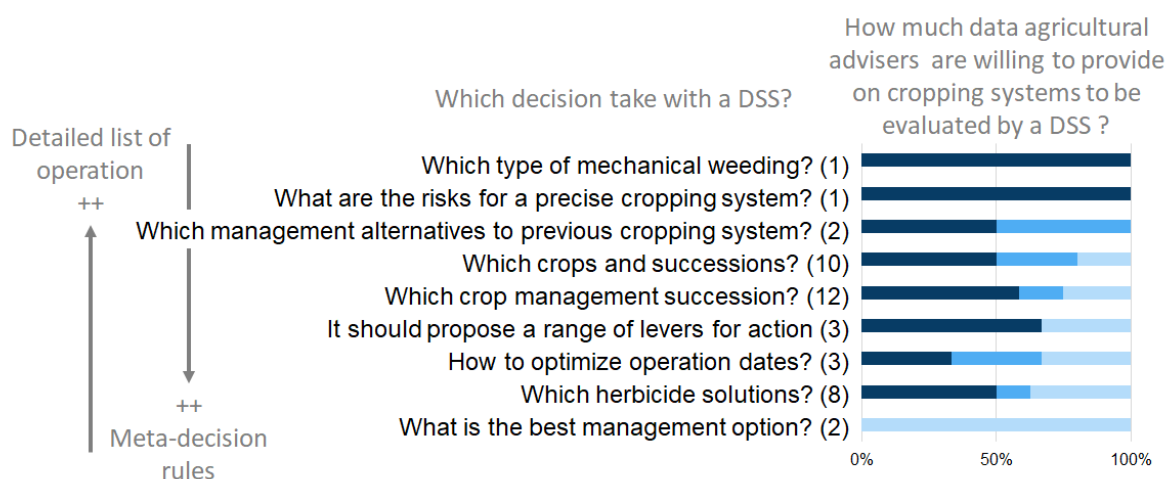


Figure 6 : Association between the degree of detail the crop advisors are willing to provide on cropping systems to be evaluated by a decision-support system (DSS), and the decision they would like to take with the DSS. Percentage of answers of how much data crop advisors are willing to provide for a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

3.2 Contributions of the group meetings

3.2.1 Farmers' reactions to the advisors' responses to the online survey

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

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

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

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

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

3.3 Workshops to improve the prototype of the DSS

3.3.1 Vocabulary to describe cropping systems

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

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

3.3.2 Display of weed impact indicators and use of decision trees

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

3.3.3 Use of the fast predictor

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

3.3.4 Overall use of the DSS and trust in results

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

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

4 Discussion

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

4.1 A novel tool tailored to end-users' requirements

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

4.2 Weed management vision of crop advisors and farmers

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

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

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

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

4.3 Contribution of future users for the type and format of the DSS

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

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

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

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

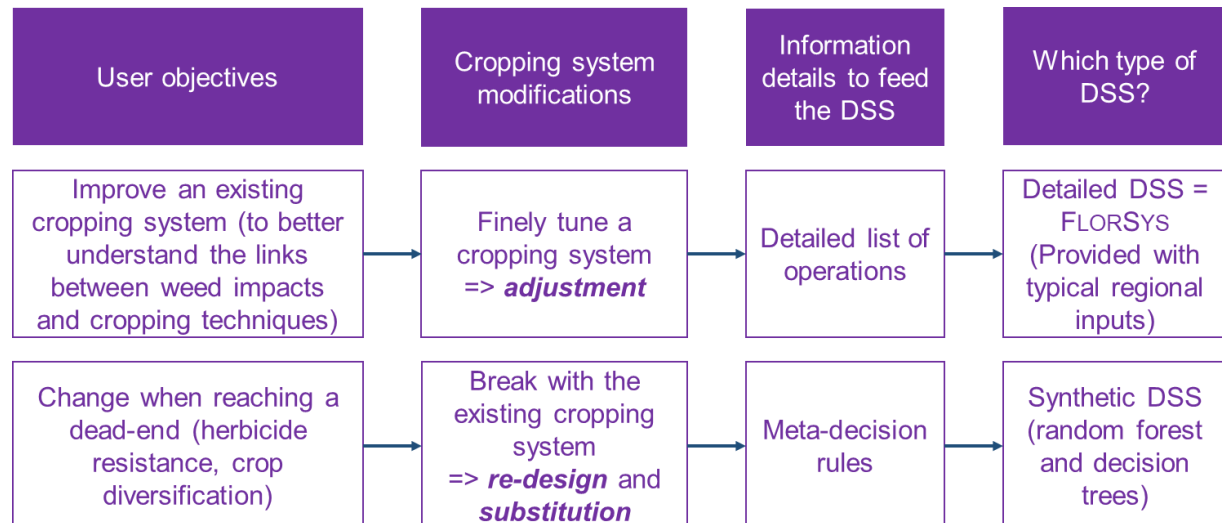


Figure 7 : Diagram representing the two types of decision support system (DSS) depending on the user objective and the level of details that the user is ready to feed to the DSS as well as Hill's efficiency-substitution-resign approach (Hill and MacRae, 1996; Hill, 1998) for food system design (Floriane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

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

Helping users with easier-to-handle inputs applies even more to FLORSYS, which is intended for fine-tuning cropping systems. It requires, for instance, the density of an initial weed seed bank present at the onset of a FLORSYS simulation, a variable notoriously difficult to access, even for scientists (Dessaint *et al.*, 1986), let alone for farmers or crop advisors. In order to reconcile usability of the tool and quality of prediction, we propose to offer a regional set of options for these difficult variables from which the user can choose. In the example of the weed seed banks, we thus already produced a list of regional weed seed bank estimated from regional weed flora assessments and checked the adequacy of this approach with independent field observations (Colbach *et al.*, 2016). Using recommended sowing date per region from technical institutes as Arvalis (<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 FLORSYS with a set of regional inputs would transform the model into the more detailed tool requested for fine-tuning (Figure 7).

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

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

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

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

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

5 Conclusion

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

749

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6 Appendix

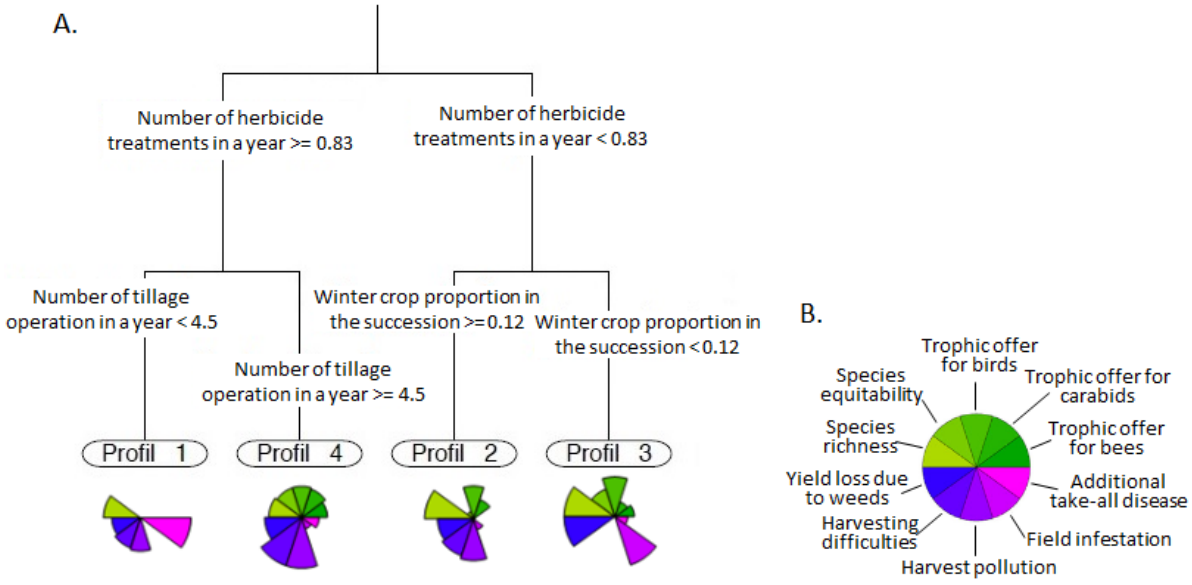


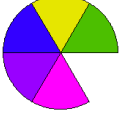


Figure A. 1: Extract of a classification tree model as a possible visual guide of the decision support system for identifying innovative combinations of cultural practices. A. Tree presenting polar area diagrams showing the weed impact indicators values corresponding to combinations of cultural practices.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

Table A. 1: Extract of the translated table given to farmers during the meeting in Aube (France) as a possible visual guide of the decision support system for identifying innovative combinations of cultural practices. The table was based on a decision tree and was tested as an alternative visualisation format, based on the proposal by a farmer participating in one of the workshops. Each row corresponds to a meta-decision rule describing a cropping system. Each cropping system is evaluated and the results are presented in a diagram presenting their performances in terms of weed impact indicators; pink: yield loss, purple: field infestation, blue: harvest pollution, yellow: nitrate leaching limitation, green: food offer for domestic bees, gray: herbicide use intensity. "Nothing in common" means that the cropping systems corresponding to this weed impact indicator profile have nothing in 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 th January	before 10 th July	$< 1/3$	nothing in common
	$< 1/30$: monoculture	after 15 th January	before 10 th July	$< 1/3$	nothing in common
	nothing in common	after 15 th January	before 10 th July	$\geq 1/3$	nothing in common
	$< 1/30$: monoculture	after 15 th January	before 10 th July	$< 1/3$	nothing in common
	no information	before 15 th January	after 10 th July	nothing in common	< 11 cm
	no information	after 15 th January	before 10 th July	$\geq 1/3$	nothing in common

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