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**DEVELOPPEMENT D'UN OUTIL D'AIDE A LA DECISION POUR LA GESTION INTEGREE DES
ADVENTICES**

F. COLAS⁽¹⁾, S. CORDEAU⁽¹⁾, M.-H. JEUFFROY⁽²⁾, S. GRANGER⁽¹⁾, W. QUEYREL⁽¹⁾, O. POINTURIER⁽¹⁾,
A. RODRIGUEZ⁽³⁾, J. VILLERD⁽⁴⁾ ET N. COLBACH⁽¹⁾

⁽¹⁾ Agroécologie, AgroSup Dijon, INRA, Univ. Bourgogne Franche-Comté, F-21000 Dijon, France
(Nathalie.Colbach@dijon.inra.fr)

⁽²⁾ UMR Agronomie, INRA, AgroParisTech, Université Paris Saclay, 78 850 Thiverval-Grignon, France

⁽³⁾ Acta, 31450, Baziège, France

⁽⁴⁾ LAE, INRA, Univ. Lorraine, F-54500 Vandœuvre-lès-Nancy, France

RÉSUMÉ

La gestion intégrée des adventices consiste à combiner de nombreuses pratiques agricoles en anticipant leurs effets à long terme. La multitude de combinaisons possibles rend les systèmes de culture difficiles à concevoir et l'interaction avec le climat rend les systèmes difficiles à mettre en œuvre. Les agriculteurs et conseillers agricoles ont donc besoin d'outils d'aide à la décision leur permettant de développer des stratégies adaptées à l'aspect multicritères/multiobjectifs de la gestion de la flore adventice, aux enjeux économiques, sociaux et environnementaux et aux moyens disponibles et objectifs particuliers de chaque agriculteur. Un tel outil d'aide à la décision est développé à partir du modèle mécaniste de dynamique de la flore adventice FLORSYS. Ce modèle simule une "parcelle virtuelle" et permet l'évaluation des performances de systèmes de culture sur une large gamme de situations agricoles et pédoclimatiques. Différents acteurs sont associés au développement de l'outil afin d'adapter les prototypes aux objectifs et contraintes des agriculteurs, via des enquêtes, des rencontres et des ateliers avec les futurs utilisateurs.

Mots-clés : outil d'aide à la décision, adventices, modèle, développement, cadre conceptuel.

ABSTRACT

DEVELOPMENT OF A DECISION SUPPORT SYSTEM FOR INTEGRATED WEED MANAGEMENT

Integrated weed management consists in using several weed management techniques in a long-term approach. The vast number of techniques precludes cropping systems from being easily conceived and climatic interactions render the systems difficult to pursue. Farmers and farm advisors need decision support systems (DSS) to develop weed management strategies adapted to multicriteria/multiobjectives of weed management, to the economic, social and environmental stakes and to the constraints of farmers. Such a DSS is developed from the mechanistic weed dynamic model FLORSYS. This model is a "virtual field" allowing the evaluation of the performance of agricultural systems over a large range of agricultural and pedoclimatic situations. Different stakeholders are associated with the tool development in order to adapt the prototypes to the farmers' objectives and constraints, via surveys, meetings and workshops with the future users.

Keywords: decision support system, weeds, model, development, conceptual framework.

INTRODUCTION

Weeds are harmful for crop production (Oerke, 2006) but important for vegetal and functional biodiversity (Marshall et al., 2003). Global changes and herbicide policies compel farmers to reduce their herbicide use. In response, farmers replace herbicides with a combination of multiple, mostly preventive and partially efficient practices. The complexity of effects of cultural practices mixed with climatic uncertainty on weeds renders those modifications difficult to plan and risky (Ingram, 2008). Understanding the impacts of agricultural practices, and their interactions, on weeds is critical to help farmers develop cropping systems that reconcile crop production, biodiversity and reduced herbicide use.

Various tools or Decision Support Systems (DSS) exist to help farmers to take strategic or tactical decisions to manage their fields. DSS are of many forms, ranging from small in field tests to assess the nitrogen contents of the crop to decide if fertilization is necessary (as N-Tester® (Yara)) to complex softwares to test on a computer different herbicides treatment for weed management (as Weed Manager (Parsons et al., 2009) or WeedSOFT® (Neeser et al., 2004)). However, these tools focus on one particular technique and to date, no DSS assesses the impacts of a combination of multiple and detailed cultural practices on weeds at the long term cropping-system scale, and none considers the multicriteria impacts of weeds on production and biodiversity.

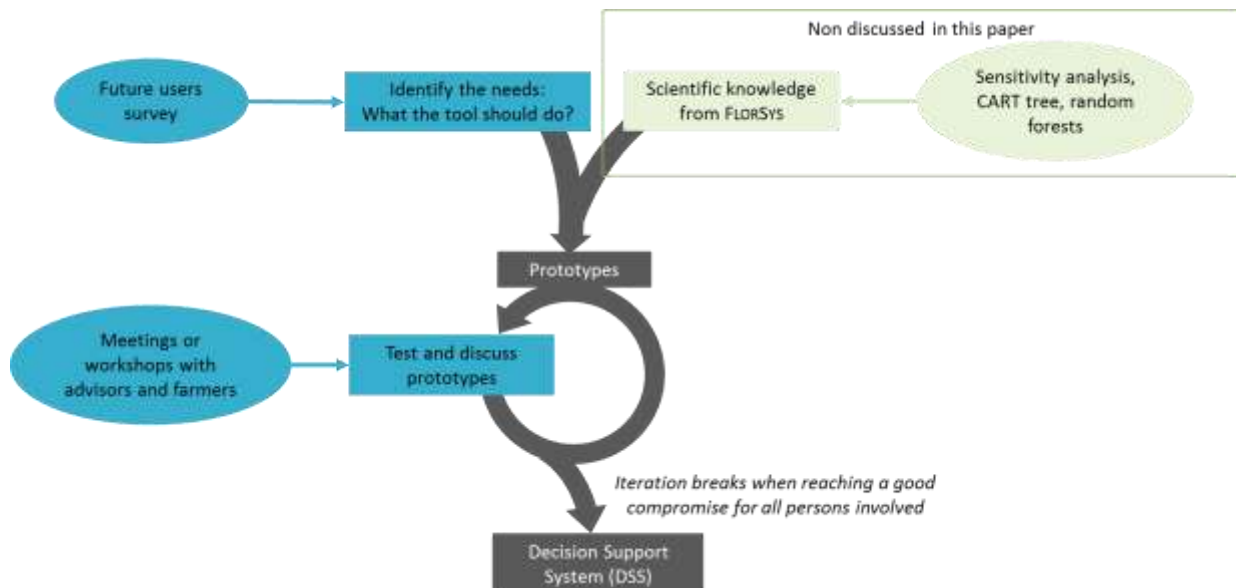
The mechanistic weed dynamics model FLORSYS (Colbach et al., 2014) is a "virtual field" for researchers to experiment and evaluate the impact of weeds on both crop production and biodiversity within cropping systems. Its outputs are weed impact indicators (Mézière et al., 2015b) that assesses the nuisibility and biodiversity effect of weeds according to the cropping system. The high level of details needed, the many possibilities and its simulation/computation time are limits to the use of FLORSYS by farmers and crop advisors. Its modification and simplification are an interesting way of making available to farmers and crop advisors the synthetic knowledge embedded in the model (Colbach, 2010). To accommodate the model application to non-researchers, future possible users should be involved during the design and development phases, not only to provide expert knowledge, but also to participate to define the needs and possible uses of the DSS and tests iteratively the prototypes (Voinov and Bousquet, 2010; Cerf et al., 2012; Prost et al., 2012).

Participatory design is an efficient way to involve the future users in the design process of a possible tool for them (Cerf et al., 2012). The model used is tested, improved and validated by the users, whereas it consist of a researcher developed tool (Becu et al., 2008) or a model built with all the participants (Bah et al., 2006). Users' participation allows a better appropriation of the model and encourages interactions between participants and social learning (Patel et al., 2007). This process relies mostly on participants' knowledge and can give a false sense of certainty, lacking of objectivity. It is essential to add impartial and quantitative tools to secure the outputs of participatory actions (Strauss 1987).

Our objective was to develop a DSS combining the knowledge of biophysical processes from the FLORSYS model with the needs of users, *i.e.* agricultural advisers and farmers, by developing the structure and outline of the DSS (Fig. 1). To access in a simpler way the scientific knowledge in FlorSys, the mechanistic model can be emulated by statistical models based on existing simulations of FLORSYS. For example, decision trees, with CART (Breiman et al., 1999) as in (Mézière et al., 2015a) can be used to find the best management practices and combinations thanks to the classification of evaluated cropping systems. On the other hand, random forests (Breiman, 2001), thanks to their good capacity of prediction can emulate FLORSYS and help to quickly evaluate cropping systems without using the model. Here we propose a conceptual framework of interactions with future users with the aim of developing a DSS from FLORSYS, based on previous methodology (Cerf et al., 2012). Those interactions consist of online surveys, group meetings and workshops, they are putting milestones on our path to the final DSS, to define and understand why and how future users would use such a tool.

Figure 1 : Conceptual framework to co-design with future users, a decision support system from an existing biophysical model. Ellipses represent the methods, the rectangles the objectives, the light green is for the contents and the blue is the structure and outline with the implication of the stakeholders.

Trame conceptuelle pour la co-construction avec les futurs utilisateurs d'outils d'aide à la décision à partir d'un modèle biophysique. Les ellipses représentent les méthodes, les rectangles les objectifs, le vert clair concerne le contenu de l'outil et le bleu concerne la structure et le format ainsi que l'implication des acteurs.



MATERIAL AND METHODS

CONSULTANT AND FARMERS ONLINE SURVEY

A survey was conducted with a semi-structured online questionnaire sent in March 2015 via e-mail to 200 agricultural advisers from chambers of agriculture and technical institutes all over France. The online survey remained open during one month. The survey included four parts to identify: (1) the interviewed persons; (2) the aims, contents and structure of the DSS: the criteria for evaluating cropping systems (*e.g.* weed harmfulness, resource for pollinators), the temporal scale (*e.g.* one year, one rotation) and the description of farming practices (*e.g.* detailed list of cultural operations, meta decision rules); (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 tool, *i.e.* the ability to understand why a given input leads to the resulting output. Structured answers were analysed by counting occurrences for each proposition and compared to bring out the underlying agricultural adviser profile. For example did the advisers answering “Detailed list of operation” to the question “How much data are the users ready to provide for a decision-support system?” are the same than the ones answering “Crop management sequences” to “Which decisions take with the DSS?”.

GROUP MEETINGS WITH FARMERS AND ADVISORS

We interacted with two groups of French famers and their advisers, first by presenting the FlorSys model and our aim at developing a DSS, and then by requesting suggestions and improvements for the structure and outline.




First meeting: real time feedback from farmers to consultant answers at the survey

During the first meeting, we took advantage that the group was already acquainted with FLORSYS to present the advisers’ answers from the survey in order to collect farmers feelings. The group was

composed of about 10 farmers from the Picardie region with their two consultants of the water regulatory authority and a consulting company. The two consultants were using FLORSYS to test alternative practices to reduce weeds while reducing herbicide use, that farmers were interested into testing. We only present, in this paper, answers to the questions concerning the aims, contents and structure of the DSS.

Table I: Extract of the table given to farmers during the meeting in Aube (France) to inquire for the possible output shape of the decision support system. Each row corresponds to a cropping system associated to a diagram presenting their performances in the form of weed impacts indicators; pink: yield loss, purple: field infestation, blue: harvest pollution, yellow: lixiviation limitation, green: pollinator resources, gray: treatment frequency index for herbicides.

Extrait du tableau représentant une possible forme des sorties de l'outil d'aide à la décision donné aux agriculteurs lors de la réunion dans l'Aube. Chaque ligne correspond à un système de culture associé à un diagramme présentant les performances du système sous la forme d'indicateurs d'impacts de la flore adventice, rose : perte de rendement, violet : salissement de la parcelle, bleu : pollution de la récolte, jaune : limitation de la lixiviation des nitrates, vert : ressource pour les pollinisateurs, gris : indice de fréquence de traitement herbicide.

| Profile (Cropping system performances) | Combinations of cropping practices | | | | |
|---|--|-------------------------------------|-------------------------------------|---|---------------------------|
| | <i>Diversity of crop species or varieties in the crop succession</i> | <i>Sowing date of primary crops</i> | <i>Harvest date of winter crops</i> | <i>Winter crop proportion in the succession</i> | <i>Mean tillage depth</i> |
|  | $\geq 1/30$ | after 15th january | before 10th july | $< 1/3$ | no information |
| | $< 1/30$: monoculture | after 15th january | before 10th july | $< 1/3$ | no information |
| | no information | after 15th january | before 10th july | $\geq 1/3$ | no information |
|  | $< 1/30$: monoculture | after 15th january | before 10th july | $< 1/3$ | no information |
|  | no information | before 15th january | after 10th july | no information | < 11 cm |
| | no information | after 15th january | before 10th july | $\geq 1/3$ | no information |

Second meeting: presentation of a possible output of the decision support system

The objective of the second meeting was to present a possible format of outputs of the DSS. It took place in the Champagne region during the annual meeting of a GRCETA (~50 farmers). In FLORSYS, the effects of cultural practices on weed-impact indicators identified from simulations are usually synthesized as decision trees (Mézière et al., 2015a). Here, we followed one of Aube farmers' suggestions on the possible outline of outputs and we tested a table format (Table I). The table comprised many empty cells representing non-significant practice x weed-impact results of cropping systems combinations. The members of the meeting were asked to answer a short questionnaire testing their understanding and the ease of handling this DSS output formats. Instead of answering

individually the questionnaire, as it was originally intended, the farmers answered by spontaneous small groups of 3-4 farmers, hence the 10 of full written answers out of 50 farmers. On the questionnaire, questions to estimate farmers' understanding of the table were evaluated if they were entirely correct, partially correct (*i.e.* with the correct answer but added with wrong elements) or incorrect. Occurrences of the different possible answers of the question to estimate the usage of the table were counted (*e.g.*: finding a cropping system in the table is: really easy, easy, difficult, really difficult). We wrote down farmers' comments as suggestions for the development of the DSS. During the discussions, we took the opportunity to show an example of a regression tree and see how farmers reacted to this other outline possibility.

WORKSHOPS WITH FUTURE USERS OF THE DECISION SUPPORT SYSTEMS

The surveys and group meetings gave us precious advices to develop the DSS, but the absence of "in situ" test of a prototype limited the improvement of the tool. The actual manipulation of the tool can bring out the different use cases that users are susceptible to have and that we are not expecting (Cerf et al., 2012). Hence, to test the developed tools we wanted to use a scheme for a workshop that could use the DSS once it is developed, with farmers, being the end users of tool's advices. According to (Lefèvre et al., 2014) for cropping system design, we proposed a workshop to conceive cropping systems with farmers, thanks to the existing tool Ecoherbi (Rodriguez et al., 2014), and test the prototypes of the DSS (Fig. 2). The workshop was held in the fall 2016 in Toulouse region and in Burgundy, when farmers are more available than in other period. Interactions were recorded to keep track of all suggestions and comments. At the end of the workshop, participants were asked to assess their satisfaction using the DSS's prototypes. They were asked their willingness to use the DSSs on their own or with an adviser, and what improvements they would like to have. Those comments and suggestions were used to improve the DSS henceforward. By using the prototypes, farmers had access to the weed impact results of the alternative practices that they wanted to test, hence an occasion to transfer the knowledge comprised into FLORSYS. Results are forthcoming.

RESULTS

CROP ADVISORS' NEEDS AND CONSTRAINTS TO USE A DECISION SUPPORT SYSTEMS

Forty agricultural advisers from all over France (16 regions) answered the online survey. The biggest constrain for weed management is the lack of biological knowledge that is (*e.g.* the need to know the persistence of weeds in the soil or the spread emergence), then it is the existence of constraining species (like perennial plants) and then the lack of efficiency of some practices (*e.g.* mechanical weeding or the difficulty to know exactly the efficiency of tillage) (Fig. 3). Regarding the decisions that a DSS should help to take, it is mostly which practices and crop management sequences, which crop successions and which herbicides (Fig. 4). Different needs for the DSS depending on the aim of the user were identified: (1) users confronted with a problem such as herbicide resistance would like to provide only meta decision rules (*e.g.* a plough every two years) for the DSS (Fig. 3) and would like to be ready to radically change their practices (*e.g.* diversification of crop succession) (Fig. 4); (2) users ready to understand and modify their practices before reaching a dead-end would like to 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) (Fig. 4).

Figure 2: Framework of the workshop testing the future Decision Support Systems. # Ecoherbi (Rodriguez et al., 2014) is a tool suggesting different cropping systems adapted to the region and soil type to reduce herbicides.
 Trame des ateliers testant les futurs Outils d'Aide à la Décision. # Ecoherbi est un outil permettant de proposer des systèmes de culture différents adaptés à la région et au type de sol pour réduire les herbicides.

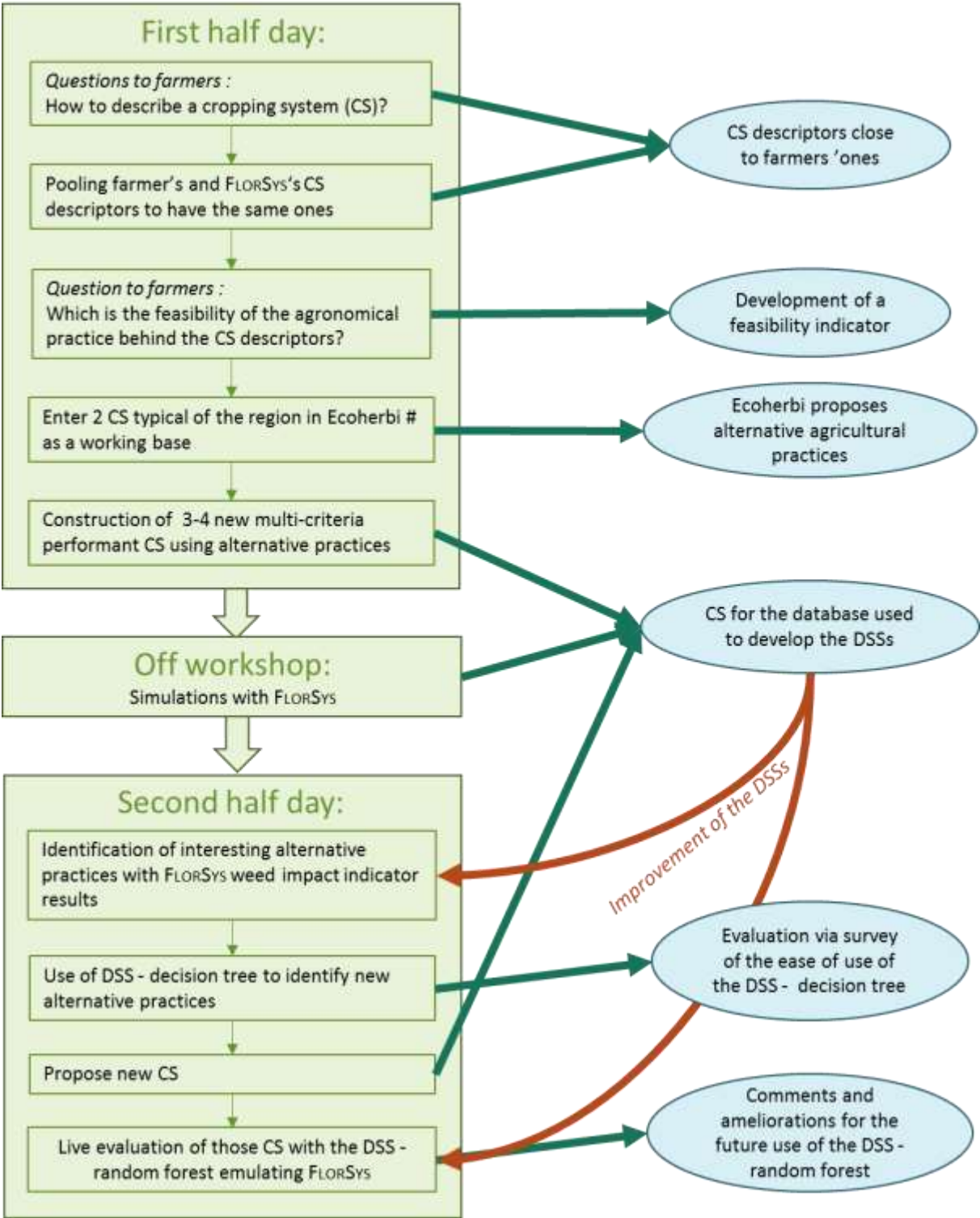
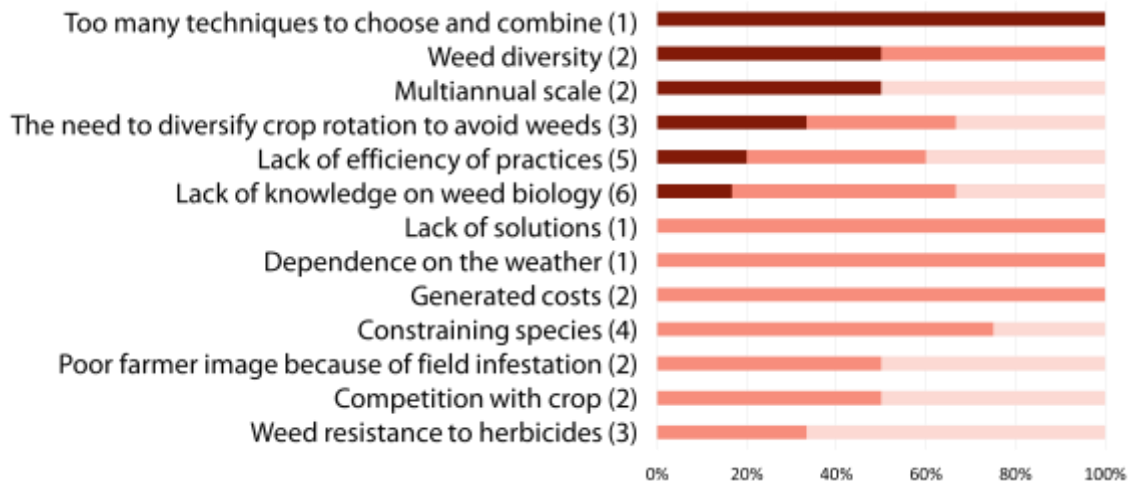


Figure 3: Percentage of answers of how much data agricultural advisers are willing to provide for a decision-support system depending on why they consider weeds difficult to manage. Dark red: detailed list of operation, light red: synthetic meta-decision rules, intermediate red: both, in brackets: number of advisers, of the 15 full answers, having mentioned the decision.

Pourcentage de réponses sur quelles informations les futurs utilisateurs de l’outil d’aide à la décision accepteraient de fournir en fonction de ce qu’ils considèrent difficile à gérer pour les adventices. Rouge foncé : liste d’opération détaillée, rouge clair : méta-règle sythétique, rouge intermédiaire : les deux, entre parenthèse le nombre de conseillers parmi les 15 réponses complètes, ayant répondu à la proposition.



CONTRIBUTIONS OF THE GROUPS MEETINGS

Farmers’ reactions to the consultants’ responses to the online survey

For each agricultural advisers’ answers to the online survey shown farmers agreed to it. Although, farmers were more open to innovation (*e.g.* by suggesting many modifications of cultivation techniques) than the agricultural advisers thought. Farmers were also more sensitive to the weather influence. The regression tree presented as an example was difficult to understand by some farmers and they suggested a table format instead.

Farmers’ feedback to improve the decision tree – decision support system prototype

Finding a cropping system in the table consisted of consistent combination of different agricultural practices. Finding a cropping system or understanding the table was mostly difficult or really difficult (Fig 5). When judging the comprehension of the table, we had 20 % of correct answers, 45 % ± 30 % of wrong answers and 35 % ± 30 % of partially correct answers. When the regression tree was shown, its principle was immediately understood and approved by farmers we talked to. During the questionnaire time farmers were discussing together, helping each other to understand and proposing interpretations. The majority of their feedback consisted of a discussion with us, asking questions and giving us their immediate thoughts. This recommends to encourage discussions between participants for a better understanding of the prototype for the future workshops.

Figure 4: Percentage of answers of how much data agricultural advisers are willing to provide for a decision-support system depending on the decisions they would like to take with it. Dark blue: detailed list of operation, light blue: synthetic meta-decision rules, intermediate blue: both, in brackets: number of advisers, of the 15 full answers, having mentioned the decision.

Pourcentage de réponses sur quelles informations les futurs utilisateurs de l'outil d'aide à la décision accepteraient-ils de fournir en fonction des décisions qu'ils souhaiteraient prendre avec l'outil. Bleu foncé : liste d'opération détaillée, bleu clair : méta-règle sythétique, bleu intermédiaire : les deux, entre parenthèse le nombre de conseillers parmi les 15 réponses complètes, ayant répondu à la proposition.

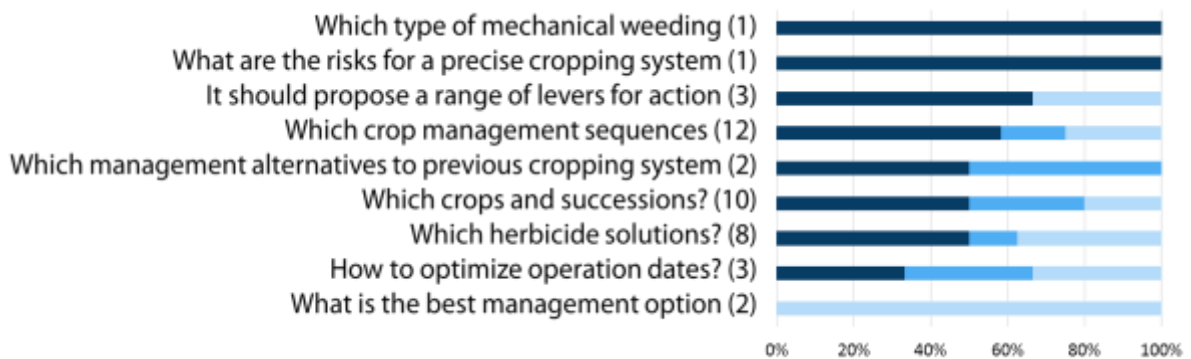
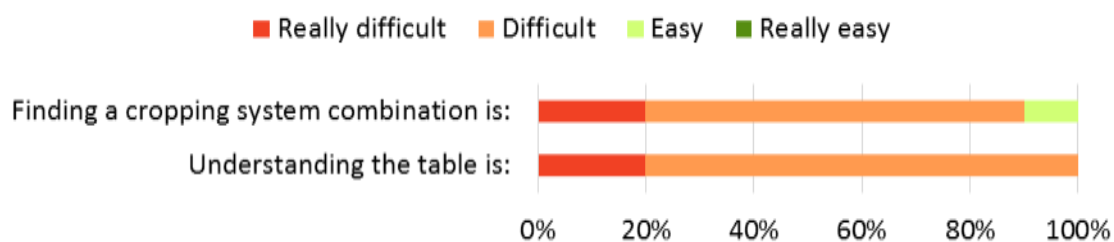


Figure 5: Ratings (from the 10 filled questionnaires) that farmers from the group meeting gave to the understanding of the table proposed as a possible output for the future Decision Support System.

Evaluations issues des 10 questionnaires remplis données par les agriculteurs d'un GRCETA pour la compréhension d'un tableau proposé comme possible sortie du futur Outil d'Aide à la Decision.



DISCUSSION

Exchanges with future users are essential to develop a Decision Support System (DSS) from a complex mechanist model (Cerf et al., 2012). The online survey for agricultural adviser brought out the need for two types of DSS: (1) a synthetic one, with meta decision rules for a radical change in cropping system when faced with a dead-end (due to herbicide resistance, high weed infestation...); (2) a detailed one, with detailed list of crops and operations about the cropping system, to adjust practices before reaching a dead end. It is possible that the use of one of the two types of DSS depend on agricultural adviser profile, that is the precise content of their activity: precise and individual advice for one particular situation, or group advice that need to fit most of production situations. Identifying the different profiles and needs for a DSS of agricultural advisers helped us to propose different tools more adapted to the various needs.

The meetings with farmers gave us useful advices, for the Picardie region it was their general need for the tool and for GRCETA farmers it was the presentation of DSS outputs. However, those comments were not based on the manipulation of the tools, probably limiting their implication in the use of the DSS. Workshops with in situ use of the tool is to better encover the limits and possibilities of the prototypes. Moreover, workshops help farmers to distance themselves from their current situation and to explore new ideas thanks to the group dynamic (Lefèvre et al., 2014). Putting the tool through the broad possible use of future users allows to develop the plasticity needed for the different usages that users have (Cerf et al., 2012). Even within a tool, plasticity is required, for example, the 'tree' form is easier to understand for most of the future users, but it is not the solution for everyone. This is why the DSS might have to propose the two representations, regression tree and table, to accommodate the great majority.

However, not all the suggestion of future users are possible to follow, the DSS mechanisms derived from FLORSYS are also impacting the structure of the DSS. The sensitivity analysis performed on FLORSYS is giving essentials inputs for weed impact on crops. If those inputs are essential for the efficiency of the tool, they are a requirement for the DSS, even if they are difficult to inform by the users. For example, the seed bank composition is important for FLORSYS simulations, but is something really difficult to access. The idea to facilitate the work by keeping a good efficiency is to have a regional presetting, with the flora region (Colbach et al., in revision).

Apart from the DSS development, exchanges with farmers and agricultural advisers is helpful for FLORSYS. New cropping systems were simulated with FLORSYS, new practices were added helping FLORSYS to keep in touch with farmers innovations.

CONCLUSION

It is known that developing a Decision Support System from a complex mechanistic model need many interactions with the future users. Here is an example of how we integrated users and what it brought to the development of the tool. Knowing users' needs and objectives for the future DSS, we identified two different types of prototypes, a synthetic one and a detailed one. The workshops helped us to put to the test the prototypes and to bring out the decision support system. The back and forth between users and developers is the solution to satisfy both parties, *i.e.* agricultural advisers and farmers, and researchers.

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