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Abstract
This paper presents 4 tools for designing herbicide-sparse cropping systems. The "virtual field" model FLORSYS was built from experiments, and can be used to test cropping systems in the long term, with different pedoclimates and weed floras. It predicts many virtual 'measurements' on crops, weeds and soil, as well as indicators of weed impact on crop production and biodiversity. Two decision-support systems co-developed with future users (farmers, crop advisers...) also allow comparing cropping systems, one in terms of weed risk for a series of harmful weed species (OdERA), the other (DECIFLORSYS) with the same weed-impact indicators as FLORSYS. Finally, OPTIFLORSYS combines FLORSYS with optimization algorithms to propose cropping systems that meet the user's production and/or biodiversity objectives.

Keywords : decision support, modelling, co-design, multicriteria evaluation, integrated crop protection

1. Introduction

Arable fields with crop–weed canopies constitute a complex system, due to the diversity and multitude of the processes involved in the dynamics of plant communities, the diversity and multitude of technical factors affecting these processes, and the biological diversity of the species, which results incontrasting responses to farmers' practices. The decisions needed for managing weeds are as much strategic ("how can I adapt the cropping system to limit the risk of losing control of weed infestations?") as they are tactical ("given the weeds I see today, what weed control measures should I take to keep them under control, considering the cropping system planned for the coming years?").

Tools for support strategic decision-making are all the more essential now that herbicide use must be reduced for regulatory, environmental and health reasons. Indeed, instead of a single curative technique, which is relatively simple and effective (i.e., herbicides), a multitude of mostly preventive and partially effective techniques, with strong interactions and long-term effects, must be combined (Liebman and Gallandt 1997). These tools are all based, in one way or another, on some form of modelling of the studied system. Models are simplified, relatively abstract representations of processes or systems, aiming to describe, explain, evaluate or predict these processes or systems (Colbach 2010; Colbach 2022). They are often constructed to synthesise knowledge about how the agro-ecosystem functions. They can also be used to support decisions, and are sometimes designed specifically for this purpose.

Model-based (or *in silico*) cropping system design approaches are complementary to other methods, such expert-based design followed by field testing of prototypes (Lançon et al. 2007). *In silico* methods can be used to evaluate a very wide range of existing and alternative cropping systems, over the long term and under different soil and climate conditions (Bergez et al. 2010; Colbach et al. 2019). These alternatives can be designed, for example, in participatory workshops with farmers (Cavan et al. 2023; Queyrel et al. 2023) but also using algorithms, in particular optimisation algorithms (Bergez et al. 2010; Colbach et al. 2021).

The structure of strategic decision-support tools depends on a number of aspects: the precision of management strategies ("plough one year out of three" vs. "plough after 50 mm of post-harvest rain if infestation in the previous year is greater than that in the previous year"), the risk taken into account ("system A is better on average" vs. "system A is better with a 90% probability"), the evaluation scale (annual vs. multi-annual), the evaluation criteria (single vs. multi-criteria), etc. (Colbach 2010; Colbach 2022).

Here, we present 4 contrasting case studies that were developed or improved as part of the COPRAA project (projet-copraa.hub.inrae.fr), and analyse how they complement each other in the design of cropping systems:

- a "virtual field" model that allows testing and evaluating diverse cropping systems over the long term, with different soils, climates and weed floras, using a number of virtual "measurements" on crops, weeds and the environment (FLORSYS). This mechanistic model was based on experiments. It can be used to compare and choose strategies on the basis of agroecosystem services and disservices indicators (crop production, biodiversity, etc.) and answers the question "what happens if …";
- two decision-support tools (OdERA and DECIFLORSYS), which are quicker and more user-friendly than FLORSYS, enabling strategic options to be selected by also answering the question "what happens if ...", but built using two different approaches (expert knowledge vs. meta-modelling of a mechanistic model) and using different evaluation criteria (weed risk for a series of key species vs. indicators of agroecosystem services and disservices);
- a tool to accompany cropping system design (OPTIFLORSYS) by answering the question "what should be done to ...". This tool combines the FLORSYS virtual field with optimisation algorithms to propose cropping systems that meet the user's production and/or biodiversity objectives.

2. The mechanistic "virtual field" model FLORSYS

2.1 Model structure

FLORSYS (Colbach et al. 2019; Colbach et al. 2021; Perthame et al. 2025)[1] (florsys.hub.inrae.fr/modeles-et-oad/florsys) is a research model that simulates a virtual arable field at a daily time step over several years or decades. It assesses the performance of arable cropping systems in terms of weed control, crop production and biodiversity, for temperate regions of France (Figure 1). FLORSYS is currently parameterised for 33 arable crop species and 32 contrasting frequent annual weed species. Perennial weeds are currently being integrated (Skorupinski et al. 2025).

Input variables. As input, the user provides a detailed list of cropping operations (crops, varieties, dates, tools, densities, doses, settings, etc.), the soil characteristics of the field, its latitude and the regional weed flora pool. Daily weather files (temperature, radiation, rainfall, evapotranspiration) must be entered for several years.

The life cycle of seeds and plants. This model is the synthesis of many past studies on the functioning of weeds in arable fields. It represents, quantifies and combines the effects of all the cropping techniques on the states of the environment as well as the weeds and crops present in this virtual field. A generic life cycle is applied with a daily time step to weed and crop species, with a 3D representation (above and below-ground) of each plant in the crop–weed canopy. The model inputs affect the species stages (viable, dormant and germinated seeds, etc.) and the processes (photosynthesis, respiration, growth, phenology, etiolation…) driving the life cycle of weeds and crops. At plant maturity, the newly produced weed seeds are added to the soil seed bank and a yield is estimated for the crop.

[1] For more details, see the references cited in these papers.

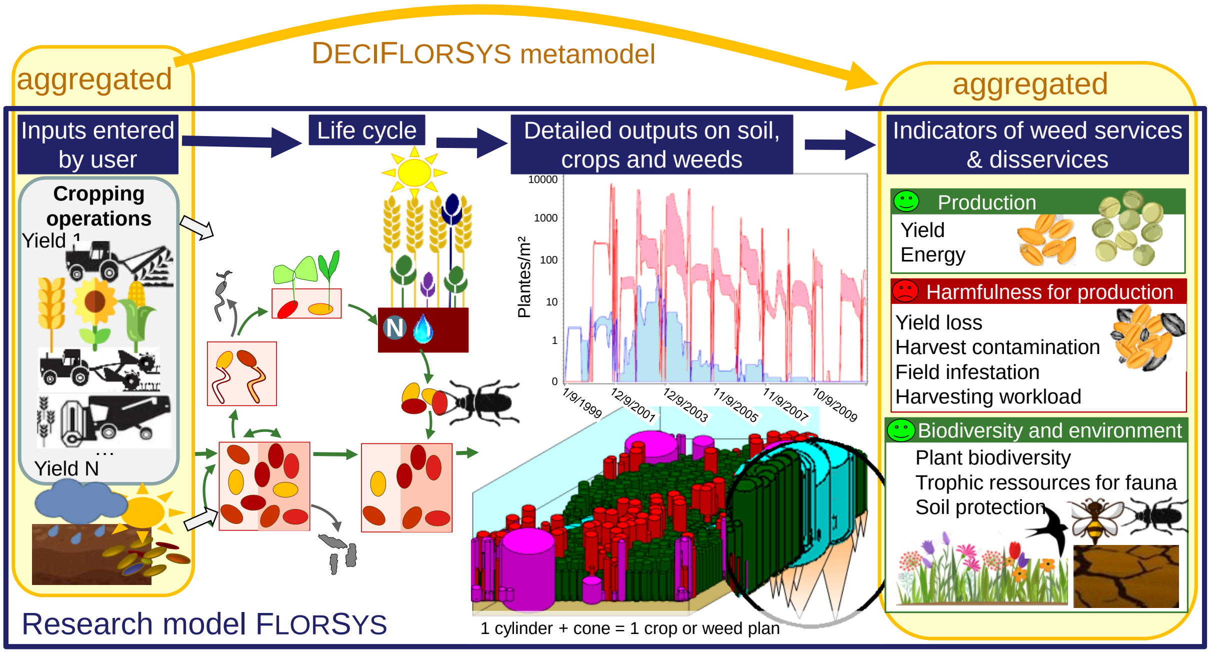

Figure 1. Presentation of (1) the FLORSYS research model (blue rectangle) which simulates the development and growth of crops and weeds based on the cropping system, weather and soil, with a mechanistic representation of biophysical processes on a day-to-day basis and in 3D individual-based (Colbach et al. 2019; Colbach et al. 2021; Perthame et al. 2025), (2) the DECIFLORSYS metamodel (yellow frames and arrows) which directly calculates the (dis)services provided by weeds from the cropping system (Colas et al. 2020) (section 4)

The processes involved in biological weed regulation. Plant–plant competition for resources primarily concerns light, but also nitrogen and water in the soil (Cournault et al. 2025). It results in crop yield losses and depends on the species (Lebreton et al. 2025) and varieties (Colbach et al. 2025). Carabid beetles predate weed seeds, which can reduce weed infestation in the field (Perthame et al. 2025)

The effects of cropping operations. The effect of each cropping technique is broken down into individual effects that interact with the states of the environment and of the seeds and plants. For example, tillage buries and excavates seeds, breaks seed dormancy and triggers germination. It also uproots and buries seedlings, killing them or reducing their growth, and reduces seed predation by carabids. This approach not only makes it possible to predict average effects (e.g., delayed sowing of winter wheat reduces the emergence of autumn grass weeds) but also their variability (e.g., delayed sowing of winter wheat is only effective in 57–64% of years, depending on the region) and can even identify the conditions for success (e.g., delaying sowing after 31 October in wet autumns) (Colbach et al. 2019).

Detailed output and evaluation indicators. All the life-cycle variables (seeds and plants at different stages and states) are available as outputs for weeds and crops, on a daily scale and in 3D. To make it easier to compare cropping systems, these variables are aggregated into indicators of weed impacts on crop production and biodiversity (Figure 1). These indicators were developed together with farmers and ecologists (Mézière et al. 2015).

2.2 Domain of validity

FLORSYS was evaluated with independent field data (i.e., which was not used to build the model) in terms of short- and long-term weed dynamics for mainland France, on a wide range of arable cropping systems. This evaluation showed that crop yields, daily weed densities and, in particular, densities averaged over several years were generally well predicted. However, in the initial version, weed seed densities at the soil surface were overestimated under continuous no-till (Colbach et al. 2006; Colbach et al. 2016). For this reason, seed predation by carabid beetles was added to the model, which indeed reduced this overestimation (Perthame et al. 2025).

2.3 Case studies of model use

Over the years, many simulation studies have been carried out to assess the multi-criteria performance of a wide range of cropping systems, focusing on specific issues (Table 1). The principle was always the same: existing cropping systems from field surveys or experimental stations as well as prospective systems proposed by experts (farmers, advisers, scientists) or algorithms were simulated over 25 to 30 years to assess the long-term effects of practices and weeds, and the simulations were repeated with 10 random climate series, with and without weeds to calculate yield loss. Statistical analyses (analyses of variance, linear regressions, RLQ analyses[2], regression and classification trees, etc.) were carried out on weed densities and simulated impact indicators.

Table 1. Case studies using FLORSYS to analyse different aspects of reducing herbicide use

Assessing the effect	Method: compare cropping system/variety scenarios		Some conclusions	Reference examples
	based on	different in terms of		
A. Identifying multi-performang crop/variety ideotypes				
Crop traits and varieties	Existing crops and varieties	Crop traits and varieties, production situation, crop diversity, management practices	Ideotypes that maximise yield potential and suppress weeds differ. A large leaf area positioned towards the top of the plants is essential	(Colbach et al. 2025)
B. Assessing farmers' cropping practices to identify herbicide-sparse solutions				
Farmers' herbicide use intensity	Farmers' past and current practices	Production situation, crop diversity, management practices	There are contrasting crop-diverse strategies that reconcile reduced herbicide use with low weed-caused yield loss	(Colbach and Cordeau 2018)
Farmers' tillage intensity			Impossible to reconcile zero herbicide and zero tillage with good weed management	(Colbach and Cordeau 2025)
C. *Ex-ante* evaluation of innovations proposed by experts				
Integrated weed management	Cropping system trial	Crop diversity, tillage intensity, mechanical weeding, herbicides (Burgundy, rotation with oilseed rape and cereals)	Crop diversification (≠ crops/varieties, alternating sowing seasons, cover crops during summr fallow) can compensate for reduced herbicide use but does not guarantee good biodiversity.	(Colbach et al. 2019)
Biological weed regulation			Weed seed predation by carabid beetles can reduce field infestation by weeds and increase yield, but the effect of crops and weather is more important.	(Perthame et al. 2025)
Wheat sowing patterns	Researchers	Cover crops during summer fallow, row spacing, sowing date and density (Burgundy, oilseed rape – winter cereals rotation)	Cover crops can increase weediness in subsequent crops if they prevent false seed bed operations; regular plant placing is essential to reduce weeds.	(Colbach et al. 2019)
Prototypes	Farmers	Crop diversity, mechanical weeding (Champagne chalk region, oilseed rape – cereals rotation)	Crop diversification reduces yield losses due to weeds; multi-annual crops are more effective than crop combinations	(Queyrel et al. 2023)
Regional crop diversity	Researchers	Spatial and tempoeral crop diversity in a field cluster (South-West, rotations with maize)	Spatial crop diversity increases the contribution of weeds to biodiversity, but also their harmfulness to production.	(Colbach et al. 2018)
Cereal–legume intercrops	Farmers & researchers	Diversity of cereal and legume species, species proportions, sowing patterns (Toulouse, highly diversified rotations)	Combinations with 2/3 cereals sown in alternate rows (or 2 rows vs 2) are the best for reconciling yields and weed control; highly competitive cereals (triticale, barley) reduce legume growth too much.	(Lebreton et al. 2025)
D. Ex-ante evaluation of innovations resulting from changes in regulations				
New maize varieties	Agricultural statistics, advisers	Crop diversity, maize varieties and associated changes in practices (South-West, maize-based rotations)	Simplified rotations and simplified tillage amplify weed impact, while cover crops during summer fallow reduce them	(Colbach et al. 2017)
Grass strips	Researchers & advisers	Crop diversity, grass strips (South-West, rotations with maize)	10% grass strips combined with monocultures provide better yields and biodiversity than diversified rotations without grass strips	(Colbach et al. 2018)

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[2] Co-inertia analysis of matrices R (cropping practices), L (weed densities) and Q (weed traits) to identify correlations between practices and traits.

The aim of these indicators is to compare cropping systems in terms of multi-performance linked to weed impact. This comparison was often coupled with a diagnosis based on crop, weed and soil state variables to understand the causes and conditions of multi-performance, an essential step for the acceptance of the model and systems by stakeholders in the field (Colbach et al. 2020; Omon et al. 2025). These analyses can also be used to establish more generic rules for guiding the redesign of cropping systems, by identifying (1) descriptors of practices that explain the performance of cropping systems (e.g., each superfical tillage reduces yield loss by 11.5% in maize-based systems in the South-West, Colbach et al. 2017), (2) weed traits selected by these practices (e.g., mouldboard ploughing selects for species with thick-coated seeds, Colbach et al. 2014), (3) weed traits explaining the impact of weeds on performance (Colbach et al. 2017).

Compared with the design of cropping systems based on expert opinion, FLORSYS makes it possible not only to propose technical solutions known to have a high impact at different levels (e.g., mouldboard ploughing), but also to define options (e.g., plough 2 years out of 5) and to evaluate actions with more limited effects (e.g., residue shredding during fallow) or based on interactions (e.g., shredding, rolling before sowing and adjusting the sowing date). This method also allows estimating the probabilities of success and failure of these options, and identifying the technical and biological determinants of cropping system performance.

3. OdERA: a weed risk assessment tool (http://www.odera-systemes.org/)

3.1 Model structure

OdERA (Pernel et al. 2022) is a tool designed to help reduce herbicide use in arable cropping systems. Through its interactivity with the user, it enables cropping systems to be redesigned to reduce weed pressure, by combining agronomic levers. The motivation for developing this tool stems from the difficulty of reducing herbicide use in farms. This difficulty is linked to (1) farmers' fears of losing onctrol of the weed infestation of their fields, as well as to (2) the need to combine several partially efficient cropping techniques, depending on the weed species to be managed, and (3) the need to reason at the scale of the cropping system.

OdERA is a tool developed based on expert knoledge, and is the result of joint development work with stakeholders in the field, coordinated by Agro-Transfert Ressources et Territoires. The tool estimates risk of weed species from the link between management practices and weed biology. For the various weed management levers (rotation, sowing date, mouldboard ploughing, stubble tillage, mechanical weeding), their effect is translated into a score for each weed species, taking into account biological parameters (emergence period and the annual seed bank decline rate). For example, the effect of crop sowing date takes into account knowledge on seasonal weed emergence flushes during the crop emergence period. The effect of ploughing takes into account the seasonal weed emergence dynamics, the annual rate of seed bank decline and the frequency of ploughing in the rotation.

For each species, the tool sums the scores corresponding to the levers applied each year to the field to calculate an annual score ranging from 0 to 100. It then calculates a weighted average of the annual scores as a function of the annual seedbank decline rate, to obtain the overall risk score of the cropping system. The risk scale, which has 5 classes, was compiled from a set of data from system trials and farmers' plots (Figure 2).

The required input data are the target weeds present in the field and a description of the cropping practices. The result is displayed as a grid of scores showing the risk for each weed and for each year (Figure **3**). The sowing date of the crop generates an initial score for a given year (positive scores) and the other levers used reduce this initial risk (negative scores). The score grid shows which practices have the greatest impact on the risk in the cropping system.

The tool is used to carry out a diagnostic of the field to assess the weed risk in the current cropping system. Following this, a teaching mode allows simulating changes in practices, based on the modelled effects of agronomic levers on weeds. Graphs show the scores awarded to each cropping operation depending on when it is carried out. The user can thus visualise the effect of the various levers and optimize their dates to reduce weed pressure. This facilitates the work of the adviser in making farmers aware of the benefits of changing their practices.

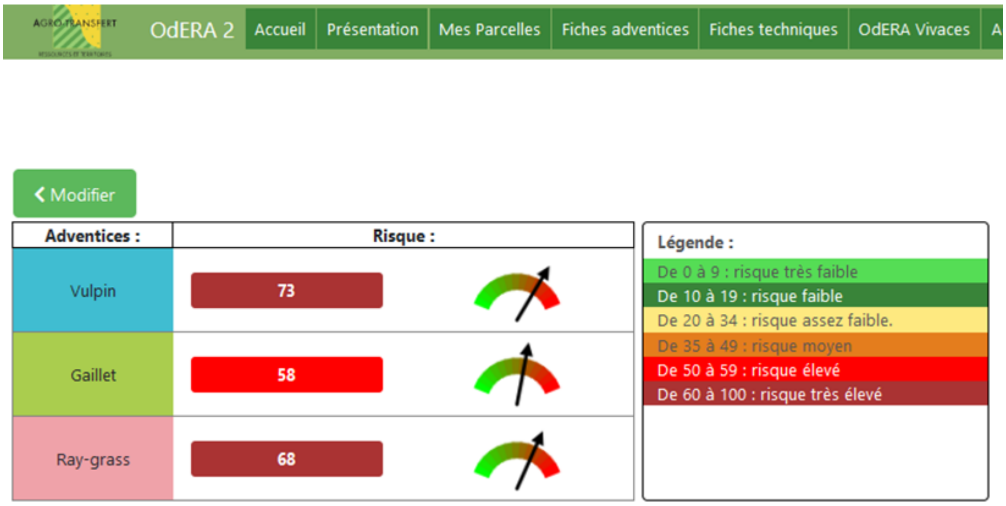

Figure 2. Screenshot from the OdERA software showing risk scores at the cropping system level for three weed species.

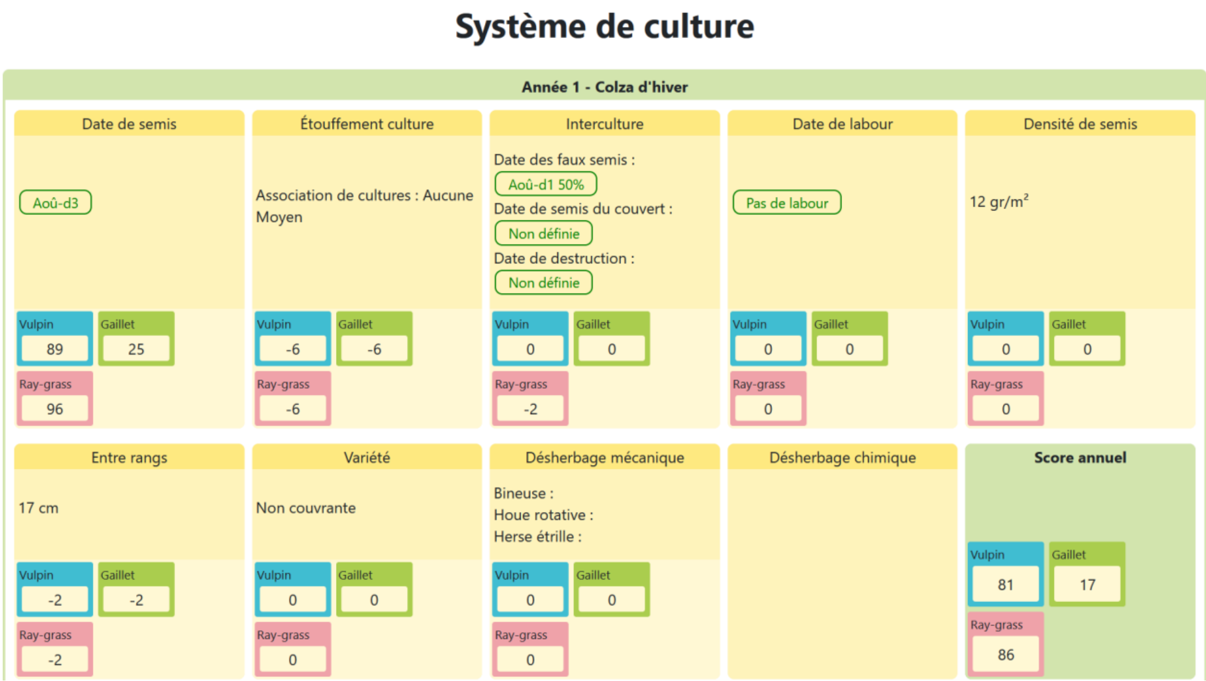

Figure 3 **:** Grid of scores showing the effect of a cropping system on the dynamics of weed species in OdERA.

OdERA was parameterised from scientific results and expert knowledge on weed biology and the effectiveness of agronomic levers in the context of French arable crops. It has been validated using field data from Hauts-de-France and Burgundy. Since its release, it has been used in various French regions.

One of the limitations of OdERA is that it does not take into account the soil and climate context; the model is based solely on standard elements of weed biology. Nor does it take account of the field's initial weed seed bank. Work is underway to link OdERA with another tool developed by Agro-Transfert RT that estimates the weed seed bank from weed flora observations. Moreover, the list of agronomic levers taken into account is not exhaustive and only includes those for which there was sufficient knowledge to model their effects. Finally, the tool does not propose alternative chemical weed control strategies adapted to the new cropping system designed using the tool: this remains the responsibility of the adviser.

3.2 Application case studies

OdERA was used, for example, as part of the "Integrated Cropping Systems with Even Less Herbicide Use" project run by Agro-Transfert RT in partnership with the Picardy Chambers of Agriculture and INRAE. The aim was to test the reduction in herbicide use on farms involved in an Integrated Production approach.

The tool was used with 9 farmers to assess the initial cropping system (2002–2006) on 4 fields per farm and to simulate alternative scenarios. These change scenarios were used to draw up an action plan to reduce the pressure of the dominant weed species in these fields. The farmers then implemented this action plan, with a few adjustments to fit the year's weather conditions. In the end, the herbicide treatment frequency indicator (TFI) was reduced by 20 to 30% depending on the system.

Figure 4 shows the changes in the OdERA risk scores for blackgrass (*Alopecurus myosuroides* Huds.) and the TFI of grass-weed herbicides used on wheat, for the studied fields, in the initial (2002-2006) and redesigned (2007-2012) cropping systems. As a result of the redesign of the cropping systems, the risk rating for blackgrass was reduced by an average of 25% over the 2007-2012 period, and the TFI for grass weed hebricides was reduced by an average of 24%.

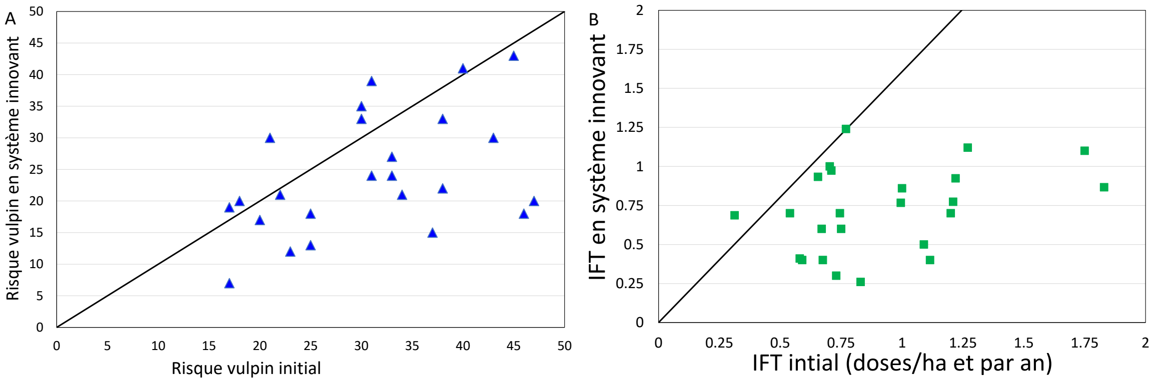

Figure 4. Changes in the risk of blackgrass (*Alopecurus myosuroides* Huds.) in fields assessed with OdERA (A) and in the average anti-grass-weed herbicide Treatement Frequency Index (TFI) in wheat over 4 years (B) on the reference field of the "Integrated cropping systems with even less herbicide use" project between 2002-2006 (initial system) and 2007-2012 (system redesigned using OdERA).

Distributed since 2011, the tool has been used by more than 2,500 people (data from the user account database), mainly crop advisers, teachers, students, researchers and farmers. The most frequent uses of the tool are by farmers working groups transitioning to lower herbicide use (DEPHY[3], GIEE[4], zones with water pollution issues), when evaluating cropping systems proposed in participatory workshops or when carrying out an agronomic diagnostic by students. While the tool can be used by individual farmers, the changes needed in the cropping system to reduce weed pressure require support from an adviser and an assessment of performance criteria other than weed pressure management.

[3] https://ecophytopic.fr/dephy/quest-ce-que-le-reseau-dephy

[4] economic and environmental interest group (https://agriculture.gouv.fr/quest-ce-quun-groupement-dinteret-economique-et-environnemental-giee)

4. DeciFlorSys: a tool synthesising FlorSys knowledge for decision-support purposes

4.1 Accounting for user needs: reconciling ease of use with the complexity of the agro-ecosystem

The OdERA decision-support tool (section 3) is ergonomic and easy to use, particularly in participatory workshops with stakeholders. It is based on expert knowledge of the effect of the various cropping-system components on field infestation by specific weed species. However, despite the experts' extensive knowledge of this issue, it is difficult for them to assess the long-term effects and interactions among several techniques or between techniques and the soil and climate, particularly in a context of climate change.

In contrast, the FlorSys research model accurately predicts these interactions and long-term effects (section 2). However, FlorSys is unsuitable for live use in participatory workshops because (1) the model has no human-machine interface, (2) it requires numerous input variables that are often difficult to fill in, and (3) its complexity makes simulations very slow.

The DeciFlorSys decision support tool (florsys.hub.inrae.fr/modeles-et-oad/deciflorsys) is a compromise between ease of use and the complexity of the agroecosystem. To achieve this, FlorSys was transformed ('metamodelled') into a simpler tool that mimics the functioning of the research model (Figure 1). This transformation was based on sensitivity analyses and data mining (classification and regression trees, random forests), and was carried out together with advisers and farmers as well as students and researchers to ensure that the new decision support tool meets their needs and constraints (Colas et al. 2020).

4.2 A model structure co-developed with users

The structure of the tool and its graphical interface continue to evolve in response to feedback from users (Lefeuvre et al. 2023; Lefeuvre and et al. 2024). In the current DeciFlorSys version, the users:

1. Position their field on a map of mainland France to define its pedolimate (with the option of refining its soil characteristics),
2. Describe their existing cropping system in detail (like FlorSys) (Figure **5**) and identify its major technical determinants (Figure 6). The multi-performance in terms of services and disservices is then estimated in a few seconds using a random-forest calculator based on rotation-scale meta-decision rules (Figure 1) similar to the technical determinants of weed (dis)services identified using FlorSys simulations (e.g., proportion of spring crops in the rotation, frequency of shallow tillage, section **Erreur ! Source du renvoi introuvable.**.),
3. Modify this system as many times as they like, according to the multi-performance calculations that accompany these modifications (Figure 7).

To understand the results of step 2 and guide step 3, the user has access to advice grids ranking cropping techniques according to their impact on weed-related (dis)services, along with the causes of these impacts.

The previous version of the tool also included a decision tree to answer the question "which combinations of practices to achieve objective X?", depending on the performance indicators that the user wanted to maximise and the pedoclimate. This aspect proved to be unsuitable during tests of DeciFlorSys in different usage situations (Lefeuvre et al. 2023; Lefeuvre and et al. 2024).

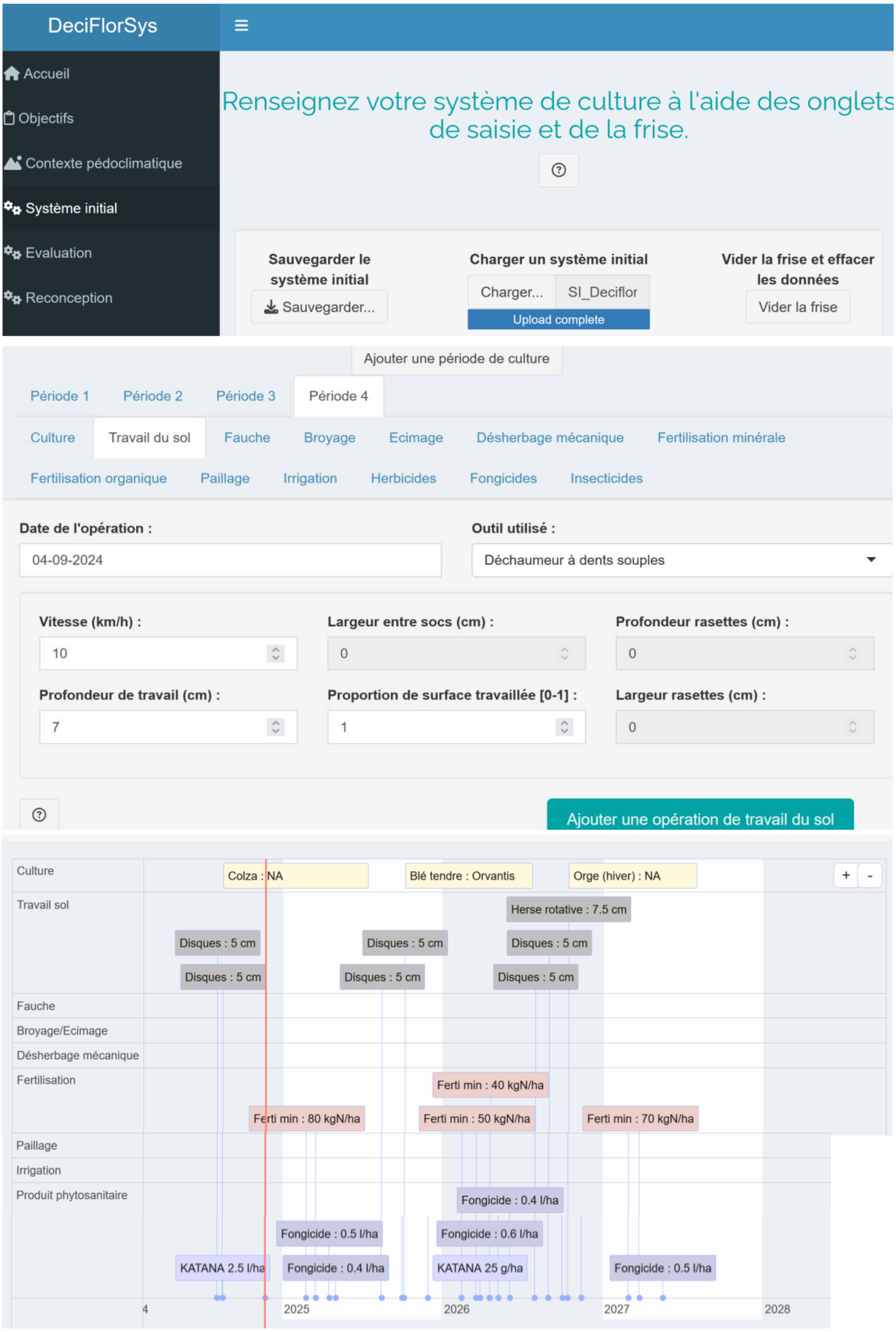

Figure 5. Screenshot of the DeciFlorSys software assessing the impact of weeds on crop production and biodiversity based on a detailed description of an existing or prospective cropping system. Tab for entering a cropping system and displaying it in the form of a timeline.

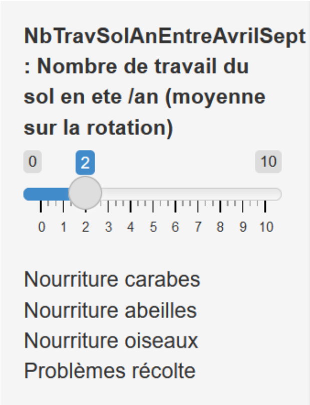

Figure 6. One of the synthetic descriptors of the initial cropping system, its position in the range of systems used to build DECIFLORSYS, and the performance indicators that depend on it. Extract from the "Evaluation" tab.

	initial	modifie
Nourriture carabes	0.332	0.411
Nourriture abeilles	0.357	0.279
Nourriture oiseaux	0.191	0.250
Richesse spécifique adventices	0.384	0.436
Equitabilité de la flore	0.410	0.420
Perte rendement	0.733	0.706
Pollution récolte	0.328	0.320
Salissement champ	0.158	0.144
Problèmes récolte	0.338	0.324

Figure 7. Multicriteria comparison of the initial cropping system and an alternative system in the 'Redesign' tab of DECIFLORSYS. The indicators represent scores ranging from 0 to 1 (worst and best performance observed in the cropping system database used to build the tool).

4.3 What role does the tool play in the co-design of cropping systems?

During the COPRAA project, DECIFLORSYS was used with several groups of farmers to co-design herbicide-saving scarce cropping system (Cavan et al. 2025; Omon et al. 2025; Queyrel et al. 2025). Thanks to its prediction speed of prediction, DECIFLORSYS it can speed up the design-evaluation loop for cropping systems, which helps to change local practices. The tool also has a more general pedagogical educational role, for coordinating farmers groups of farmers and transferring the knowledge initially synthesised in the FLORSYS tool, when analysing the effects of changes in cropping techniques and the advice tables included in the tool.

However, although DECIFLORSYS can rank cropping systems in terms of weed impacts just as well as FLORSYS, this tool can neither diagnose the causes of system performance nor accurately assess interactions with the pedoclimate (Colas et al. 2020) . In fact, DECIFLORSYS directly predicts (dis)service indicators without using variables illustrating the biophysical processes responsible for the effects of cropping techniques (Figure 1). This can be a problem for techniques that interact strongly with environmental states, such as the tillage dates and soil moisture. In this case, it is necessary to return to FLORSYS to quantify this variability and to identify the conditions for successful practices, thus demonstrating the complementary nature of the two tools (Cavan et al. 2025; Omon et al. 2025; Queyrel et al. 2025).

5. OPTIFLORSYS: proposing rather than evaluating cropping systems

The previous tools evaluate existing cropping systems or prototype systems designed by different stakeholders rather than proposing or designing such systems (Colbach 2010). The latest tool presented here, OPTIFLORSYS (Maillot et al. 2025), represents a paradigm shift in that it proposes cropping systems by answering the question "what should be done to ...". OPTIFLORSYS is the result of coupling FLORSYS with optimisation algorithms, in this case genetic or firefly algorithms (Chetty and Adewumi, 2013; West, 2019). These algorithms improve an initial cropping system entered by the user step by step to simultaneously optimise weed impact indicators chosen by the user (e.g., yield loss, herbicide treatment index), by modifying cropping system components indicated as modifiable by the user (e.g., crops in the rotation, sowing and harvesting dates, nitrogen fertilisation, etc.).

OPTIFLORSYS is still at the prototype stage. It includes a human-machine interface co-developed with future users (researchers, advisers, farmers, students), following the same principle as for DECIFLORSYS (section 4). OPTIFLORSYS is described in detail by Maillot et al (2025), with examples of applications.

Table 3. Summary of the characteristics and complementarities of the 4 weed management support tools for stakeholders

	FLORSYS	OdERA	DECIFLORSYS	OPTIFLORSYS
Objectives	Understand the determinants of multi-performant cropping systems and accompany the design of multi-performance systems	Comparison of cropping systems in terms of risks of weed infestation→ design systems with low weed pressure	Compare cropping systems in terms of crop production and biodiversity→ accompany the design of multi-performant systems	Propose multi-performant cropping systems based on the user's objectives
Authors	Researchers	Engineers, researchers, advisers and farmers		
Construction method	Experimental results	Expert knowledge	Data mining of thousands of FLORSYS simulations	FLORSYS coupled with optimisation algorithms
Structure	Mechanistic simulation model of biophysical functioning, combining deterministic and stochastic relationships	Empirical model of weed risks as a function of cropping practices	Statistical model of production and biodiversity indicators as a function of cropping practices	
Evaluation	Comparison with field observations	Comparison with field observations	Comparison with FLORSYS simulations	Like FLORSYS
Spatial scale	Field, field cluster	Field		
TIme step	Day	10-day period	Multiannual: scores ofcropping system	Like FLORSYS
Time scale	Multiannual	Multiannual		
Inputs	Exhaustive list of cropping operations, daily climate, soil, initial weed flora	Main cropping practices that influence weeds	Similar (but less detailed) to FORSYS	Crop production and/or biodiversity targets
Outputs	Indicators of weed impact on crop production and biodiversity	Weed risk, effect of different agronomic levers	Indicators of weed impact on crop production and biodiversity	Proposals of cropping systems that meet targets
Human machine interface	no	Co-designed with users		
Biophysical limits	Few species are well parameterized for water and nitrogen competition	Soil and climate effects are ignored	The FLORSYS version used for the initial simulations	Like FLORSYS
Ergonomic limits	Slowness, complexity of inputs, lack of human-machine interface	No multi-criteria approach to evaluation	No diagnosis of the causes of performance	Slow, complex outputs
Domain of validity	Arable crops, temperate French mainland (and neighbour countries)	Arable crops, France	Like FLORSYS (except for mixed and minor crops	Like FLORSYS
Users	Researchers and technical institutes	Advisers, teachers, students and farmers	Advisers, farmers, teachers, researchers	Researchers, advisers & farmers in the future
Use with farmers	Occasional	Frequently used for advice		Tool development

6. Complementarity of the 4 tools

Table 3 summarises the essential characteristics of the 4 tools presented above, and identifies their complementarities

- The major advantage of FLORSYS is that it takes into account the interactions among cropping techniques, and between techniques and soil and climate. This enables it not only to predict average effects but also probabilities and conditions of success or risks of failure. This is particularly important given that farmers are often more interested in reducing the risk of failure or the inter-annual variability of crop production than in increasing production or average income (Ridier et al. 2013). As FLORSYS was designed based on the physical and biological processes involved, it can take into account a very wide range of cropping techniques, with a level of precision that can prove decisive in terms of sustainable weed flora management.
- The advantage of OdERA is that it is fast and easy to use. It can be used as a decision-support tool for farmers in order to objectivise the adviser's discourse on the effect of different agronomic levers on weed flora. Different scenarios can be run to compare different strategies, which results in a very useful educational value for supporting farmers.
- DECIFLORSYS is a compromise between the two approaches, reconciling the diversity of FLORSYS outputs with the speed and user-friendliness of a tool like OdERA, but at the cost of FLORSYS's diagnostic capabilities.
- OPTIFLORSYS represents a paradigm shift by proposing cropping systems that meet objectives, instead of assessing the multi-performance of systems like the first 3 tools, at the cost of being even slower than FLORSYS. On the other hand, it attempts to reconcile the complexity of FLORSYS with the ergonomics of a tool like DECIFLORSYS.

7. Conlusion

The complexity of the 'arable field – weeds' system makes it a prime candidate for a mechanistic modelling approach. Much progress has been made over the last decade in modelling the effects of agricultural practices on weeds, even though the initial parameterisation of the models was hampered by a lack of expertise in the biology and ecology of weed species and the diversity of processes involved. The structure of such models makes it possible to include new knowledge, such as recently the predation of weed seeds by carabid beetles (Perthame et al. 2025), plant–plant competition for water (Cournault et al. 2025) or the vegetative multiplication of perennial weeds (Skorupinski et al. 2025).

Using models to guide decisions in the field in an operational way requires adaptations that call on specific skills in ergonomics, IT and even artificial intelligence. There are many decision-support tools available today for advisers and farmers. The feedback we get is that, in the end, these tools are used very little. To increase the chances of the tools being used, it is essential to involve users continuously in the design, development and improvement of the tool. The cases of OdERA and DECIFLORSYS have shown that the context or priorities of users can change between the specifications being drawn up and the tool being released. Sometimes it is when users have a near-final version of the tool that they discover new uses for it. Interactions with users have also shown that different tools are needed for different uses and users, even for strategic weed management alone. The 4 tools presented here cover such a wide range, from the analysis of biophysical processes to the co-design of innovative systems.

This is therefore a wide-open, multi-disciplinary field that needs to be explored in greater depth, especially as there is a great need for tools in the field, even if they are not always explicitly formalised. Finally, these tools need to be coupled with other assessment tools to move from a multi-criteria assessment of the impacts of weed flora to a multi-criteria assessment of the three pillars of the sustainability of cropping systems, without having to input the same cropping system several times.

Ethics

The authors declare that the experiments were carried out in compliance with the applicable national regulations.

Declaration on the availability of data and models

The data supporting the results presented in this article are available on request from the author of the article.

Declaration on Generative Artificial Intelligence and Artificial Intelligence Assisted Technologies in the Drafting Process.

The authors used artificial intelligence technology (DeepLPro) in the translation of the article from French to English.

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NC, TM and JP wrote the first version, and all the authors reviewed and completed it.

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