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1 **Design workshops for innovative cropping systems and decision-support tools:** 2 **learning from 12 case studies**

3

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12

13 **Keywords:** agroecology, C-K theory, multi-actor, creativity, participatory design, open
14 innovation

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16

17 **Highlights**

- 18 • Design workshop is a relevant approach to support disruptive innovations design
- 19 • A cross-case analysis, fed by design theory, drew lessons to manage design workshops
- 20 • Recommendations to prepare and implement a design workshop are suggested
- 21 • Diverse methods that avoid fixation effects and support creativity are identified
- 22 • The choice of the actors participating to a workshop is a key factor of success
- 23 • Ways to consider the systemic nature of agricultural innovations are proposed

24

25 **Abstract**

26

27 Addressing the issues that agriculture is currently facing requires disruptive innovations, which may
28 be stimulated through a process of innovative design, enhancing exploration in specific situations. In
29 the aim to equip this process, several researchers implemented 'design workshops'. Yet, the literature
30 poorly describes the way to organize, implement and capitalize design workshops, in the view to
31 achieve their objectives. We conducted a comprehensive cross-analysis of 12 case studies of design
32 workshops, informed both by data on the preparation, course and outputs of the workshops, and by
33 collective interactions among the workshop managers. Steered by theoretical elements from design
34 science, we identified similarities and divergences across cases, and derived methodological lessons

35 concerning preparation, implementation, and follow-up for future design workshops. Our analysis
36 provides new insights on the key steps for the management of design workshops: key elements to
37 define and share an ambitious but realistic design target were highlighted; the choice of actors
38 participating in the design workshops appeared as a crucial step in the preparation of all the workshops;
39 the initial knowledge basis shared before the exploration had a determinant role on the design process;
40 we identified the need to adapt, to a diversity of agricultural situations, the sequencing, the facilitation
41 of design workshops, and the width of exploration; means to manage, during the design process, the
42 systemic nature of most agricultural innovations were specified; and new criteria, consistent with the
43 diversity of the objectives, were proposed to assess the success of a design workshop. Finally, our
44 research has shown that design workshops promote collective creativity in agriculture, and feed open
45 innovation processes.

46

47 **1. Introduction**

48

49 Disruptive innovations are required in agriculture as farmers are expected to increase food supply, save
50 energy and natural resources, strengthen biodiversity, improve soil, air and water quality, and/or
51 decrease the use of external inputs such as pesticides and N fertilizer (Tilman and Clark, 2015; Wilson
52 and Tisdell, 2001). The domains of innovation concerned are widely diverse (Prost et al., 2017): plant
53 varieties and animal breeds; agricultural machinery; inputs, such as bio-pesticides or innovative
54 fertilizers; combinations of farming practices, such as farming, cropping or livestock systems,
55 agricultural landscapes (including crops, grasslands and semi-natural elements like hedges); and
56 decision support systems.

57 Disruptive innovation towards sustainability entails overarching transformation processes involving
58 technological, organizational, and institutional changes (Geels, 2002). Design, which is a collective
59 process that leads to devising artifacts, that do not yet exist, to attain goals, is at the core of such
60 innovation processes. To achieve the ambitious challenges mentioned above, design enhances the
61 exploration of innovative solutions, unknown until now, that fully satisfy new expectations (Le Masson
62 et al., 2010). Moreover, design in agriculture should be situated, that is, it should fit the solutions to
63 the precise characteristics of the situations of farmers' action, in terms of climate and soil conditions,
64 available means and resources, and institutional and socio-economic contexts (Vereijken, 1997; Darses
65 et al., 2004; Meynard et al., 2012).

66 This article is dedicated to the design of (i) cropping systems (sets of action rules, related to various
67 and consistent technical choices), and (ii) decision-support tools (action rules related to a specific
68 technical choice, embedded in a manual of digital tool). In these areas, as in the industrial or
69 architectural fields, innovative design cannot be confined to a single approach (Le Masson et al., 2010).
70 Meynard et al. (2012) distinguish three families of approaches. First, step-by-step design consists of
71 an *in situ* gradual change (over several years) of farming practices, based on learning loops and

72 resulting in an innovative system whose characteristics were not predictable at the outset (Meynard et
73 al., 2012; Coquil et al., 2014). Second, model-based design corresponds to a very broad exploration of
74 combinations of techniques and environments, using agronomic models to identify those meeting the
75 desired objectives. It has been used to design cropping and farming systems (Rossing et al., 1997;
76 Bergez et al., 2010), varieties (Jeuffroy et al., 2014), and decision support tools (Cox, 1996). Third,
77 participatory design of prototypes in design workshops, initially proposed in agriculture by Vereijken
78 (1997), brings together actors with a variety of skills (advisors, researchers, farmers, etc.) and
79 knowledge (scientific, expert) on a shared design project targeting challenging objectives (for example,
80 a large reduction in pesticide use, or self-sufficiency in energy). In agriculture, such workshops were
81 implemented to design cropping systems (Lançon et al., 2007; Colnenne-David and Doré, 2014; Lesur-
82 Dumoulin et al., 2018), livestock systems and buildings (Bos et al., 2009; Gouttenoire et al., 2010),
83 decision-support tools (Ravier et al., 2018), and environment-friendly agricultural landscapes (Berthet
84 et al., 2016).

85 Designing in workshops is a participatory approach adapted to situated collective design, as evidenced
86 by its use (sometimes referred to under different terms, such as workshops, meetings, collective design,
87 design workshop) in many recent studies (Binder and Brandt, 2008; Cardoso et al., 2001; Lefèvre et
88 al., 2014; Lacombe et al., 2018). Based on these studies, we propose to define a 'design workshop' as
89 an approach, in which a collective of actors explores and builds *in abstracto* disruptive solutions to
90 reach ambitious goals. However, while many scientific papers refer to the use of such an approach,
91 with similar intentions, they poorly describe how to prepare and implement the workshops, from the
92 design target definition to the achievement of the design objective. Moreover, some design workshops
93 are centred on the use of computer tools, which strongly shapes the design activity in the workshops,
94 as the prototypes are defined and characterized by the required inputs for the simulation tool used (e.g.
95 Hossard et al., 2013). Therefore, in our analysis, we will not consider such design workshops where
96 design is primarily based on the knowledge embedded in a model: we will only consider the design
97 workshops in which exploration mainly relied on the knowledge carried by all the participants.

98 Several approaches have been proposed to organize designing in workshops in the agricultural field.
99 The KCP (Knowledge, Concepts, Proposals) method, initially developed in industrial design (Agogué
100 et al., 2014), then adapted to agriculture (Berthet et al., 2015), is structured in three iterative steps: a
101 phase of sharing knowledge (K), intended to encourage dialogue between participants and stimulate
102 their creativity, a phase of concept generation (C), intended to explore innovations; and a proposal
103 phase (P) aimed at developing a roadmap for the continuation of the innovation process. Besides, Reau
104 et al. (2012) formalized a collective approach to design cropping systems: after an agreement between
105 participants on the objectives of the cropping systems to be designed, the group of actors lists the
106 individual crop techniques or crop choices that can be mobilized to reach these objectives, and imagines
107 candidate cropping systems, combining existing or new techniques and crops. These authors show the

108 interest of combining complementary skills among the participants, in particular experts with localized
109 knowledge, experts in innovative techniques, and assessment specialists. In the RIO (Dutch acronym
110 for Reflexive and Interactive Design) method, proposed to redesign animal husbandry systems (Bos et
111 al., 2009), the key starting points are the basic needs of living actors (animals, farmers, consumers). A
112 Brief of Requirements is formulated for each need. This method insists on the importance of taking
113 into account all the needs of the actors involved, instead of weighting the pros and cons of the various
114 interests, which often results in compromises that satisfy nobody.

115 Yet, none of these approaches informs the many choices regarding the preparation or implementation
116 of design workshops. The scientists who have implemented design workshops, in recent years,
117 hybridized proposals, and invented variants. However, to our knowledge, we miss an analysis and
118 synthesis of these experiences that would support new Research & Development actors wishing to
119 organize design workshops.

120 This paper aims to: (i) characterize a diversity of ways to prepare and implement design workshops in
121 agriculture, and to manage their outputs and outcomes; and (ii) discuss their advantages and limitations,
122 with a view to drawing methodological lessons and identifying areas requiring vigilance. Our work is
123 based on a cross-analysis of case studies, dedicated to the design of cropping systems or decision-
124 support tools. It aims at helping researchers and actors of the agricultural world to organize design
125 workshops. The authors are researchers who have all conducted design workshops, according to
126 various procedures.

127

128 **2. Material and methods**

129

130 We selected 12 case studies of design workshops (described in section 2.2), and we
131 conducted a comprehensive cross-analysis mobilising the C-K theoretical framework
132 (presented in section 2.1). Based on gathered homogeneous information from the case
133 studies (section 2.3), the analysis was performed according to several axes (section 2.4).

134

135 2.1. The theoretical framework to analyse the design process in the workshops

136

137 To analyse design processes in the workshops, we relied on theoretical advances from the C-K
138 framework (Concept-Knowledge, Hatchuel and Weil, 2002; 2009). According to this theory, an
139 innovative design process is a collective process starting by the formulation and share of a design
140 target, which is a “desirable unknown”: as what exists is insufficient to reach the designer’s goals,

141 something new needs to be generated (which is desirable), but the designers do not yet know what (it
142 is unknown). During the design process, the identity of the new object under design, corresponding to
143 the designer's desire, is progressively defined, i.e. its properties progressively emerge: its components,
144 the use that can be made of it, by whom, when, in what conditions, and so on. As Hatchuel and Weil
145 (op. cit.) have shown, design is an exploration process, strongly linked to the designers' knowledge
146 and learning. The C-K theory has formalized how the identification of useful knowledge both feeds
147 into, and emerges from the specification of the properties of the innovation under design. Design is
148 therefore described as a dialogue between two spaces, both of which expand throughout the design
149 process: the 'concept space' (or 'solution space'; i.e. what the designers want to make exist), and the
150 'knowledge' space (i.e. what is known by the designers, and key knowledge gaps regarding the
151 innovation under design). The C-space is structured according to various exploration paths. The K-
152 space refers to explicit knowledge, such as biophysical processes within the agroecosystem, but also
153 to tacit knowledge, to criteria regarding the assessment of the designed solutions, or even to
154 characteristics of the farmers' action situation. As the design targets are new (Le Masson et al., 2010),
155 neither the required knowledge nor even the specifications of the solution under design can be precisely
156 defined at the beginning of the design process, and they become clearer as the innovation under design
157 is taking shape. Innovative design requires not only creativity, but also the capacity to make
158 progressively evolve the fields of knowledge, and the collaboration to be mobilized, while the solutions
159 designed become clearer. Numerous studies on the creative part of design have highlighted that people
160 often explore a small number of unvaried solutions (what's called 'fixation effect', Jansson and Smith,
161 1991), and that, as a result, methods have specifically been proposed to overcome this fixation effect
162 (Agogu e et al., 2014). Jeantet (1998) has furthermore shown that designers frequently mobilize
163 intermediate objects, defined as "*objects generated or used during the course of the design process*
164 *(texts, graphs, models, mock-ups, etc.), serving as brokers, as traces and supports of the project being*
165 *pursued, and of the design action*". Moreover, involving users very early in the process helps to bring
166 out the adaptation to their own situations of (i) the design target, (ii) the characteristics of the solutions
167 to be designed, and (iii) the criteria used for the evaluation of the solutions under design (Luck, 2007;
168 Bos et al., 2012; Cerf et al., 2012).

169 This theoretical framework helped us (i) to organize data collection from the case study managers (see
170 section 2.2) and (ii) to define the axes for the cross-case analysis (see section 2.4).

171

172 2.2. Criteria used to choose the case studies

173

174 We conducted a comprehensive cross-analysis of 12 design workshops (Table 1) to identify the
175 convergences and divergences between these case studies, in order to draw methodological conclusions

176 (Yin, 2003). The 12 case studies were selected from more than 20 design workshops conducted by the
177 authors of this article, between 2008 and 2018. Four criteria were used to select the case studies:

- 178 (i) All the selected design workshops focused on the design of ways to grow annual field crops. The
179 designed solutions were either a decision-support tool (DST), or one or several cropping systems
180 (CS).
- 181 (ii) The facilitators of the design workshops were all researchers with design experience. They knew
182 the design literature, which inspired them to prepare and facilitate the workshops.
- 183 (iii) The selected case studies covered a wide range of actors involved in the design workshops, and of
184 the duration of the project (from a few weeks to three years, Table 1).
- 185 (iv) At least one of the facilitators of each design workshop agreed to provide information about it.
186 Hereinafter referred to as the "case managers", they are all co-authors of the present article.

187

188 The 12 case studies addressed a variety of issues (Table 1) related to the agroecological transition,
189 formalized either by constraints on practices, or by new ecosystem services to be promoted: pesticide-
190 free management (3 case studies), reduction of N-fertilizer inputs (2 case studies), cropping systems
191 diversification through various crops or cultivar mixtures (3 case studies), climate change mitigation
192 (3 case studies), and work organization (1 case study). In all case studies, systemic solutions were
193 designed: sometimes situated (for example, a cropping system for a specific farm), sometimes more
194 generic (Decision-Support Tools, *a priori* usable by any farmer, or generic cropping systems for a type
195 of farm in a given region). Another common feature of all workshops was the involvement of future
196 users of the designed solutions. In many cases, the outputs of the design workshops were operational
197 (Table 4): cropping systems designed to be tested in experiments (SDCI, AGROSEM, SIC), or
198 implemented by farmers (AUTO'N); DSTs designed to be developed and disseminated to support a
199 decision improving the management of cropping systems (APPI-N, CAPS). A detailed presentation of
200 the 12 case studies is provided in supplementary material.

201

202 Table 1: Characteristics of the 12 design workshops selected as case studies (CS: Cropping system; DST:
 203 Decision-Support Tool)

Project name	Designed innovations	Involved actors *	Organisation
AGROSEM	Pesticide-free seed-oriented CSs	6 experimenters, 2 R&D engineers, 3 researchers	3 meetings over 9 months
AUTO'N Guillier et al., 2020	Nitrogen-autonomous arable CSs for farmers	7 farmers and 3 experts	7 meetings (1 per farmer) over 1 year
CONSYST Ferchaud et al., 2020	Arable CSs including crops intended to feed a biorefinery	3 researchers and 4 R&D engineers	2 meetings (1 per soil type), over 6 months
LEGITIMES Pelzer et al., 2020	CSs including more legume crops within three territories	8 to 13 local actors or innovation leaders, according to territories: 1 to 2 farmers, 3 to 5 advisors, 2 to 5 researchers	3 one-day meetings (1 per territory) over 2 months
SDCI Reau et al., 2012	Pesticide-free CSs, adapted to various specific areas	5 to 10 actors per meeting (advisors, R&D engineers, researchers)	1 meeting per area, over 3 years
SIC Colnenne-David et al., 2017	Arable CSs limiting GHG (greenhouse gas) emissions	10 actors per meeting (advisors, R&D engineers, researchers)	2 meetings, over 6 months
SYSCCLIM Angevin et al., 2016	Arable CSs with low GHG emissions, within a collecting area	At each meeting: 3 researchers, 1 to 2 advisors, 1 collector, 6 farmers	2 meetings (1 per zone) over 3 months
VIVLEBIO Salembier, 2019	Innovative strategies to manage perennial weeds in Organic Farming	8 farmers, 2 advisors	1 meeting
APPLI-N Ravier et al., 2018	A DST to manage wheat N fertilization while tolerating N deficiencies	5 researchers, 3 R&D engineers, 3 advisors	2 meetings over one year
CAPS Paut et al., 2021	A DST to help choose the companion species to grow with rapeseed according to the ecosystemic services targeted	3 researchers and 7 advisors	2 meetings over 7 months
CASABIO Hazard et al., 2016	Rules to mix wheat cultivars in Organic Farming	6 to 10 actors per meeting: 8 researchers (agronomists and geneticists), 1 farmer and 5 R&D engineers	2 thematic meetings (N and weeds) over one month
DST-WORK Delecourt et al., 2019	A DST to take into account work in the change of practices	First meeting: 8 farmers, Second meeting: 5 advisors and R&D engineers	2 meetings over 3 months

204 * In addition to the one or two facilitators present in all the workshops

205

206

207 2.3. Information collected on the 12 case studies

208

209 For each of the 12 case studies, we collected information from the case managers, through (i) written
210 documents on the case studies (workshop reports, articles, PhD theses, dissertations); (ii) an oral
211 presentation of each individual case study by the case manager in front of the group of all case
212 managers; and (iii) collective interactions within this group, during 3 collective work sessions. The
213 presentations were organized in such a way as to answer a series of open-ended questions, aimed at
214 acquiring homogeneous data on the course and outputs of the design workshops, and their preparation
215 and implementation modalities (Table 2). More specifically, the questions focused on: (i) the
216 chronology of events (steps, results, choices made by the case managers, etc.); (ii) the reasons that
217 justified the choices made; and (iii) an argued assessment, by the case managers, on the course and
218 outputs of their own design workshops. These questions were chosen on the basis of the theoretical
219 framework presented above (e.g. How did you manage the formulation of the design targets? How did
220 you stimulate exploration and creativity?). Following each of the 12 oral presentations, exchanges
221 between each case manager and the whole group made it possible to complete the data collected from
222 the presentation and to start comparisons. The cross-case analysis began during the collective
223 discussions following the presentations, and was based on iterations between the analysis of each case
224 and cross-analyses, aiming to bring out and categorize convergences and divergences between cases.

225

226

227

228 Table 2. Questions to the managers of the 12 case studies, to inform an oral presentation and collective
229 interactions

General questions on the course of the design workshops and their outputs

- Why did you decide to organize this design workshop?
- According to you, what were the factors explaining the success or failure of the design workshop?
- What were outputs and outcomes of the design workshop?

Questions related to the preparation of the design workshop

- What type of innovation were you planning to design during the workshop (e.g. a cropping system, a decision-support tool)?
- How did you choose the actors to be invited to the design workshop? Who were these actors? What arguments did you use to enrol them?
- How did you manage the formulation of the design targets? What were these targets?
- How did you choose the knowledge to be shared at the beginning of the design workshop (and what consequences on the following design step did you observe)?

Questions related to the implementation of the design workshop

- How did you manage the design of systemic solutions during the workshop?
- Did the workshop last more than one day? If so, what was the temporal organization of the successive meetings? What was the design progress from one day to the next? How was the design organized on the successive days?
- What balance did you decide to strike between exploring a large number of ideas and deepening an exploration path? Why did you decide to do so?
- How did you stimulate exploration and creativity? What did you do to reduce the fixation effects among participants?
- Did you use intermediate objects during the design workshop? If so, which ones and to what purpose(s)?
- Have these intermediate objects been remobilized in other design workshops or do you think they should be specifically built *ad hoc* for each workshop?

230

231

232 2.4. Axes for the cross-case analysis

233

234 The theoretical framework presented above allowed us to identify the commonalities and differences
235 between the 12 case studies, concerning the preparation of the design workshops, their implementation,
236 and their outputs and outcomes (Table 3). The analysis is based on a collective reflection among the
237 workshop managers.

238 The preparation of the workshops was analysed according to 4 axes, which emerged from the inductive
239 cross-case analysis (e.g. the sequencing of the meetings) or have been chosen in coherence with the
240 key dimensions of the *C-K theoretical framework* described in section 2.1 (and identified in italics
241 below):

- 242 (i) Design target: we compared the nature and formulation of the design targets, corresponding to the
243 *desirable unknown*, shared among the participants. We categorized these targets according to
244 what they aimed to explore and how they were formulated.
- 245 (ii) Actors participating: we registered the reasons, given by the case managers, for choosing the *actors*
246 *invited to participate* in the design process.
- 247 (iii) Knowledge shared: we classified the nature of knowledge that has been shared at the beginning
248 of the workshop, *as an initial K-space basis*.
- 249 (iv) Sequencing of the meetings: as the “design workshop process” included several meetings in some
250 case studies, we compared their numbers, roles and frequencies.

251

252 Then, the analysis of the implementation of the design workshops was organized along 4 axes:

- 253 (i) Width of the *exploration*: we compared the variety of solutions that had been explored during the
254 workshops, in the aim to characterize and assess the *explored C-space*.
- 255 (ii) Management of systemic design: we analysed the means used during the workshops to
256 progressively build systemic solutions.
- 257 (iii) Intermediate objects: we identified the various roles of the *intermediate objects* used during the
258 workshops to foster the design process.
- 259 (iv) Modalities of facilitation: we classified the different objectives and related actions performed to
260 facilitate the design process, with a particular attention to the levers used to *reduce fixation*
261 *effects* and *stimulate creativity*.

262

263 Finally, we mapped the outputs and outcomes of the design workshops and compared them to the
 264 initial objectives of the case managers: *solutions designed, knowledge mobilized* during the workshop,
 265 test in real conditions.

266
 267

268 Table 3 : Key axes, mainly derived from C-K theoretical framework, of the cross-case study analysis
 269 of design workshops steps: preparation, implementation, and outputs

Key steps of design workshops	Key axes for the cross-case analysis	Key dimensions of the theoretical framework serving as bases (see section 2.1)
Preparation	<ul style="list-style-type: none"> • formulation of the design target • choice of the invited actors • choice of knowledge to be initially shared • sequencing of the meetings 	<ul style="list-style-type: none"> • Defining the “desirable unknown” • Collective dimension of the design • sharing a knowledge basis to initiate and stimulate the exploration process (part of the K-space) •
Implementation	<ul style="list-style-type: none"> • width of the exploration • management of the systemic nature of the solutions under design • intermediate objects used • aims and modalities of facilitation 	<ul style="list-style-type: none"> • characterizing and assessing the C-space that was built through exploration of unknown solutions • • intermediate objects intended to support the design process • overcome of fixation effect (usually observed)
Outputs and outcomes formalization	<ul style="list-style-type: none"> • formatting and sharing the solutions designed and the knowledge mobilized during the workshop, or lacking to reach the target 	<ul style="list-style-type: none"> •

270
 271
 272

273 **3. Results**

274

275 **3.1. Preparation of the design workshop**

276

277 In most cases, the preparation of the workshop required a significant investment of time over several
 278 days.

279

280 3.1.1. Formulation of the design target

281

282 All case managers defined disruptive, ambitious, forward-looking, but realistic targets, *i.e.* likely to
283 lead to innovative solutions (Table 4): for example, the removal of pesticides within conventional
284 cropping systems (SDCI, AGROSEM), or a 50% reduction of greenhouse gas emissions, compared to
285 the dominant CSs (CONSYST, SIC).

286 Different rules were used to define the targets, with a view to stimulate the participants' creativity and
287 avoid fixation effects: (i) proposing an oxymoron (e.g. "living in harmony with thistle" for
288 VIVLEBIO); (ii) defining a target that is out of step with current or recommended practices, or even
289 free of regulatory constraints (e.g. "to fertilize without defining a target yield" for APPI-N); (iii)
290 introducing a strong constraint on the inputs that can be mobilized (e.g. "no use of mineral nitrogen
291 fertilizer", for AUTO'N; or "seed production systems without pesticides", for AGROSEM); (iv)
292 prioritizing a formulation based on the expected results rather than on the means. Table 5 summarizes
293 all the methods used in our case studies to avoid fixation effects and stimulate creativity.

294 In some cases, a specific work was carried out beforehand to define the target. For example, in the case
295 of APPI-N, a diagnosis of uses of the tools formerly available to manage nitrogen fertilization was
296 carried out through interviews (Ravier et al., 2018). The frequent difficulties encountered by the users
297 of the 'dominant' tool, the balance-sheet method, concerning the choice of the target yield (which is a
298 key step of the method), led to the proposal of a disruptive target: "to fertilize without defining a target
299 yield". In the case of VIVLEBIO, the results from previous on-farm innovation tracking, showing that
300 some innovative farmers tried to value thistles in their fields, led to the proposal of a target which did
301 not entail their withdrawal. In the AUTO'N case, the target was defined before the workshop, through
302 bilateral discussions between the workshop facilitator and the farmers, focusing on an in-depth analysis
303 of their motivations in terms of nitrogen management. However, even though farmers generally
304 expressed several indicators for their expected results, it appeared, in this case study, that starting a
305 workshop with a precise and complete definition of a framework of objectives and constraints tends to
306 block the thought of participants, and seems less generative than a definition of a target centred on the
307 most challenging criteria. Similarly, defining a distant target, *i.e.* to be reached only in several years,
308 was essential to help the designers to leave aside immediate feasibility constraints that hamper
309 creativity (APPI-N, AGROSEM, CONSYST, LEGITIMES, CAPS, DST-WORK case studies).

310 Several case studies confirmed that it was essential for the target to be shared by the actors participating
311 in the design workshop, in order to foster a collective exploration. In the case of SYSCLIM, the
312 frequent warnings of some participants (the collectors) about the risk of reducing the harvested grain
313 volume ("we need to fill the silos") indicated that the target focused on reducing GHG emissions did

314 not take into account their concern about the level of production. In the case of CASABIO, the case
 315 manager identified another difficulty: the target was very broad ("to reduce weed pressure") and the
 316 lever explored (rules for wheat cultivar mixtures) was too narrow, which prevented the workshop from
 317 reaching its target. On the other hand, in several case studies (APPI-N, VIVLEBIO, SIC, DST-
 318 WORK), the case managers stressed the importance of the time devoted, at the beginning of the
 319 workshop (knowledge sharing, § 3.2.3), to the participants' appropriation of the target.

320
 321

322 Table 4: Description of the targets, and of the outputs that were targeted or not, for each case study

Project name	Target(s) formulation	Outputs that were targeted	Outputs achieved whereas not targeted
AGROSEM	Rotation, crop management and landscape infrastructure for annual seed-oriented crops (cereals, legumes, vegetables, forage crops), without pesticides.	CSs reaching the target, implemented in trials.	Learning to think 'out of the box' and to enhance systemic reasoning, for partners.
AUTO'N	One N-autonomous CS per farmer Example: Eliminate the purchase of mineral nitrogen fertiliser, while ensuring the absence of economic losses due to nitrogen deficiencies.	CSs more self-sufficient in synthetic nitrogen, implemented by farmers.	Mutual support between farmers (e.g. to implement ambitious and feasible systems, or even to cultivate a new species).
CONSYST	CSs that reduce net GHG emissions by 50%, increase the biomass produced and exported, and maintain the feeding capacity (do not degrade it by more than 20%), compared to current CSs (i) in deep silty soils, and then (ii) in shallower silty sandy soils.	CSs reaching the target.	A learning process about the possible levers to adjust flexible CSs.
LEGITIMES	CSs including a diversity of legumes and species, and limiting the risks of pests, weeds and diseases, and nitrogen losses to the environment.	High-performance CSs including legumes, and the adaptation of the management of the other crops, in each territory.	A dynamic between actors was created, which was useful in a later stage aiming at implementing territorial actions for the development of legumes.
SDCI	CSs without pesticides (in a first step), and then with few pesticides, and controlling weeds, pests and diseases.	CSs reaching the target, implemented in on-farm field experiments.	Learning for advisors to think 'out of the box' and to enhance systemic reasoning.

SIC	A CS aiming to reduce GHG emissions by 50%, and to meet several environmental objectives while being productive.	A CS that reaches the target and implemented in the SIC trial.	
SYSCLIM	Alternative CSs adapted to the local context, designed to mitigate the effects on global warming and improve their contribution to sustainable development.	Original CSs, compared to those practised by the farmers participating in the workshop.	Show to the collector that alternative CSs were possible.
VIVLEBIO	Cropping strategies to live in harmony with thistle, including CSs without alfalfa and without tillage.	A set of strategies for living with thistle; a collective willingness of participating farmers to go on working together on this target.	Research questions of interest (e.g. when does the thistle begin to wither if its density is high? Why do various thistle plants react differently to similar practices?)
APPI-N	A N-fertilization method without yield target (for the 2 nd meeting: idem + taking into account the risk of drought to maximize the efficiency of fertilizer use).	A prototype of DST reaching the targets.	The creation of new scientific knowledge (e.g. NNI path avoiding detrimental deficiencies).
CAPS	A DST helping to select species to mix with oilseed rape providing several ecosystem services and based on the causal chain "trait-function-service".	A prototype of DST, capitalizing on empirical knowledge.	
CASABIO	Rules for the mixture of wheat varieties to reduce weed pressure and/or nitrogen deficiencies in Organic Farming.		A knowledge tree to identify technical and genetic levers toward the target.
DST-WORK	A DST to help farmers: (i) to think about the introduction of a new technique before experimenting with it; (ii) to analyse the results of their experiment, and adapt their work organization.	A portfolio of 30 conceptual mock-ups for a DST meeting the target.	A large range of unplanned ways to consider work in the dynamics of change on a farm.

323

324

325 3.1.2. Choice of the actors participating in the design workshops

326

327 In most case studies (Table 1), the facilitators called upon actors with diverse expertise (e.g. advisors,
328 farmers, researchers) and from various professional structures (e.g. chambers of agriculture, research

329 institutes, technical institutes, agricultural cooperatives). Case managers justified this diversity with
330 several motives:

- 331 • Enhancing creativity through the confrontation of different points of view: e.g., in the APPI-N case
332 study, the facilitators took care to mix (i) actors developing and supporting the most used method
333 (balance-sheet method) with actors claiming an alternative way to improve fertiliser management;
334 and (ii) actors who are familiar with farmers' decision process, researchers studying nitrogen flows
335 in the agroecosystem, and engineers skilled in formalizing and disseminating technical advice (see
336 Table 1).
- 337 • Ensuring the participation of actors with general knowledge (agronomists working on bio-physical
338 processes within the agroecosystem), and actors with local knowledge on agricultural conditions
339 and farmers' work situations (e.g. engineers, advisors and farmers from the study region, in
340 CONSYST, LEGITIMES and SDCI case studies).
- 341 • Involving future users of the designed solution (e.g. farmers for CSs, and/or advisors for DSTs).
342 When the design workshop aimed to produce cropping system prototypes to be experimented, the
343 facilitators considered the experimenters' presence as essential to guarantee the acceptability of the
344 designed solution (e.g. AGROSEM and SIC case studies), even if sometimes they were too much
345 fixed on solutions they already knew.

346 In contrast, in a few other case studies, the design workshops brought together only actors sharing the
347 same profession (only farmers for AUTO'N, SYSCLIM, and DST-WORK 1st meeting; only advisors
348 for the DST-WORK 2nd meeting). The aims were (i) to foster peer-to-peer sharing of similar concerns,
349 (ii) to avoid fixation effects linked to farmers' dependency on the 'good agricultural practices'
350 recommended by their advisors, and (iii) to ease structure the discussions. Besides, some case
351 managers observed that a large exploration was easier to achieve when the main users of the solution
352 to be designed were not involved, as they considered insurmountable their daily-experienced
353 constraints. Thus, in the case of AUTO'N, the 'central' farmer, for whom the cropping system was
354 designed, did not participate in the exploratory phase. He only presented the situation of his farm at
355 the beginning of the meeting, and, at the end of the meeting, he discussed and further developed the
356 solutions proposed by the other farmers.

357

358 In all cases, the case managers stressed that they selected people who were motivated to change their
359 agricultural practices, and were *a priori* open to new solutions, to avoid participants which could act
360 as 'floaters' or 'blockers'. For example, in DST-WORK, based on prior interviews, the facilitators
361 decided not to invite an actor who seemed set on his own solution. The prior inter-knowledge of the
362 actors was taken into account in several workshops. For APPI-N, actors belonging to the same

363 organization and with hierarchical relations between them were accepted, as they had freedom of
364 speech allowing fruitful discussions. By contrast, in DST-WORK, the participants in the first
365 workshop were a group of farmers with their advisor. The presence of the advisor seems to have
366 hindered the farmers' contribution to the discussions, as they were afraid of proposing solutions that
367 were inconsistent with the recommendations previously given by their advisor.

368 Finally, in some design workshops, a particular role was assigned to some participants. For example,
369 in the CONSYST case study, a researcher was in charge, during the workshop, of calculating indicators
370 such as food production or GHG emissions, in order to assess, in real time, the options explored, and
371 give preference to those that seemed most promising or, on the contrary, eliminate others.

372

373 3.1.3. Choice of the knowledge to be shared

374

375 In all the design workshops studied, a knowledge-sharing phase preceded the collective exploration
376 phase. It required significant preparation from the workshop facilitators, and sometimes gave rise to
377 specific prior research. The nature of the shared knowledge varied according to the targeted aim:

- 378 • Share a same vocabulary, or even become familiar with the design issue. Thus, in the LEGITIMES
379 case study, the benefits and limitations of legumes were presented, varying according to species
380 and modes of insertion in cropping systems (as a pure crop, intercropped with another crop, as a
381 cover crop, etc.).
- 382 • Share a diagnosis of the current situation. In the LEGITIMES and SDCI case studies, the current
383 most prevalent cropping systems in the territories under study were described, including their limits
384 in terms of agronomic and environmental impacts, taken as a starting point for design. In the
385 AUTO'N case study, the 'central' farmer presented his farm, his unsatisfactory results, or his new
386 targets. In the DST-WORK and APPI-N case studies, the results of diagnoses of uses, conducted
387 as a specific prior research (Ravier et al., 2016; Delecourt et al., 2019), were presented at the
388 beginning of the workshop with the aim to go beyond fixation effects (see Table 5). For APPI-N,
389 these results showed that a key principle of the balance-sheet method, i.e. estimating the crop
390 requirements by a target yield, was a barrier for the users. Sharing this diagnosis allowed the
391 participants to adhere to the proposed ambitious design target (a N-fertilization method without
392 yield target).
- 393 • Share a common representation of the processes involved in the agroecosystem functioning. In the
394 CAPS case study, the "Traits-Functions-Services" conceptual framework (Violle et al., 2007) was
395 presented. Similarly, in the VIVLEBIO case study, a literature review (Favrelière et al., 2020) was
396 synthesized to present the studied crop techniques able to control thistle, in relation to its biological

397 characteristics. In the SYSCLIM case study, the biophysical processes involved in GHG emissions
398 were presented.

- 399 • Enhance creativity: disruptive examples were sometimes presented to stimulate creativity (see
400 Table 5). For example, in the VIVLEBIO case study, the results of an on-farm innovation tracking,
401 highlighting innovative practices implemented by farmers to control thistle, completed the
402 literature review mentioned above (Salembier, 2019). In the AGROSEM case study, the results of
403 previously tested pesticide-free systems in arable farming, describing the technical options
404 implemented and their effectiveness to control pests, were presented.

405 When the design workshop was composed of several meetings, the presentation, at the beginning of
406 the second meeting, of the assessment of the prototypes designed at the first one (CONSYST and
407 APPI-N case studies), or of the knowledge generated since the previous meeting (Nitrogen Nutrition
408 Index path avoiding detrimental deficiencies, in the case of APPI-N), were crucial for the design
409 progress.

410 In some case studies (LEGITIMES, CAPS, CASABIO), the presentation of technical options allowing
411 the chosen target to be reached may have limited the participants' creativity by 'fixing' them on already
412 existing solutions. For example, in LEGITIMES, during the first two meetings, the advantages of
413 legume-based mixtures were presented in detail, and this technique was then largely mobilized by the
414 participants in the CSs designed. During the third meeting, this focus was mitigated, as the knowledge
415 sharing phase was positioned after a phase of individual reflection and proposals. This limitation was
416 less frequently encountered when the shared knowledge focused on agroecosystem biophysical
417 processes, and only mentioned technical levers as options influencing these processes (AUTO'N and
418 SIC case studies).

419

420 3.1.4. Sequencing of the meetings

421

422 In most case studies, design workshop processes included several meetings (Table 1), and the
423 facilitators had to organize their articulation, upstream or *in itinere*, considering the results of the
424 previous meetings. Across all case studies, three types of sequencing were identified:

- 425 • A successive exploration of situations: in the CONSYST and SYSCLIM case studies, two meetings
426 were organized with the same target, on two different soil types. Similarly, in the LEGITIMES
427 case study, locally-adapted cropping systems were successively designed for 3 territories,
428 characterized by different pedo-climatic and socio-economic contexts (better adapted legume
429 species, outlets, presence of livestock, etc.), while keeping a common design target. Lastly, in the
430 AUTO'N case study, 7 meetings were organized to design cropping systems for 7 farmers.

- 431 • A progression in the target: in the SDCI case study, the first target proposed was very ambitious
432 (e.g. manage pests without pesticides) to encourage participants to propose very disruptive
433 technical options; then, in the following meeting, a less ambitious target was formulated (e.g.
434 manage pests by reducing pesticide use by 50%) to propose more realistic cropping systems
435 intended to be tested in trials. Consistently with the target evolution, the assessment criteria
436 changed: economic criteria, which are decisive for realistic systems, were not put forward at the
437 beginning of the exploration of disruptive systems, but appeared at the end.
- 438 • A progression in the designed solutions: in the AGROSEM case study, the facilitators planned a
439 series of meetings to deal with objects of increasing complexity. The first meeting was dedicated
440 to the design of herbicide-free crop management for a seed-oriented carrot, while the second
441 meeting combined the design of the crop rotation and of the zero-pesticide management of the other
442 crops. The third meeting was mainly dedicated to landscape infrastructures. The choice, in the first
443 meeting, of designing a rather simple object (withdrawal of only herbicides from only one crop)
444 aimed to teach the participants to be less fixed on known solutions, and to make them adhere to the
445 design workshop principles.

446 Sometimes there was a long interval between two meetings, allowing the realization of specific
447 activities necessary for the organization of the following meetings: e.g. multi-criteria assessment of
448 cropping systems designed, in the CONSYST case study; parameterization of the Nitrogen Nutrition
449 Index (NNI) threshold path, in the APPI-N case study; literature analysis to inform a database of
450 species traits, in the CAPS tool. However, some case managers mentioned that too much delay between
451 two meetings (such as in SDCI case study) had affected the overall dynamics of the design workshop.

452

453 **3.2. *Implementation of the design workshop***

454

455 3.2.1. Broad exploration or deepening of some paths

456

457 The design workshops organized the exploration phase to favour, depending on the case study, either
458 a wide range of solutions (CASABIO, LEGITIMES, DST-WORK, VIVLEBIO, SYSCLIM, and SIC
459 case studies), or the deepening of a small number of solutions (CAPS, APPI-N, AUTO’N, SDCI, and
460 CONSYST case studies).

461 Concerning DSTs, the choice between diversity and refinement depended on the time available, and
462 on the targeted outputs. Thus, in the case of APPI-N, conducted during a PhD thesis, the objective to
463 have an operational prototype of the tool by a set date led to focus on the deepening of one of the paths
464 opened during the first design meeting. This deepening made it possible to generate the necessary

465 knowledge, to create the prototype, and to test it in on-farm conditions, during a PhD of 3 years (Ravier
466 et al., 2018). By contrast, in DST-WORK case study, as the problem was new and had received little
467 attention in plant production research (Delecourt et al., 2019), a broad exploration was given priority.
468 The same type of contrast was observed for the design of cropping systems. When the targeted output
469 of a workshop was new practices to be implemented by a participant, either farmer or experimenter
470 (AGROSEM, AUTO'N, SDCI case studies), the diversity of the paths explored was restricted, and
471 preference was given to finding rapidly implementable solutions. Conversely, in a framework less
472 constrained by time, or with no intent for rapid implementation, the exploration was broader (SIC,
473 VIVLEBIO, LEGITIMES, SYSCLIM case studies). In some design workshops, both objectives (broad
474 exploration and deepening of some paths) were targeted, and achieved by organizing a
475 complementarity between successive meetings within the same project (e.g. in LEGITIMES, the
476 feasibility of some designed CSs was discussed with the actors during a second meeting, and changes
477 were proposed to make them more "feasible"; see Pelzer et al., 2020).

478

479 3.2.2. Ways to design systemic solutions

480

481 In all workshops, the designed solutions were systemic (Table 1). For example, in the AGROSEM
482 case study, reducing pest pressure on wheat, and thus pesticide use, is reached through managing
483 interactions between variety, sowing density, nitrogen fertilization and sowing date, as proposed by
484 Loyce et al. (2008). Similarly, in the APPI-N case study, the targeted increase in fertilizer use
485 efficiency depends on the interaction between the use of a NNI threshold path – which helps to
486 determine deficiencies that will not be detrimental to yield –, and a weather criterion for choosing the
487 application date, i.e. before rainfall to facilitate the diffusion of the fertilizer into the soil. In the
488 AUTO'N case study, designing self-sufficient CSs required nitrogen to be managed by combining
489 proposals for three timeframes: (i) the short timeframe aimed at sufficient nitrogen nutrition throughout
490 the crop cycle; (ii) the intermediate timeframe of the crop sequence, a key to manage nitrate losses;
491 and (iii) the long timeframe for organic nitrogen storage in the soil.

492 In most workshops dedicated to CSs design (SDCI, CONSYST, AUTO'N, VIVLEBIO case studies),
493 the exploration was organized in two successive phases: the first one aimed at designing the crop
494 sequence, and the second one concerned the management of each crop. However, during the second
495 phase, the participants often had to reconsider the choice of crop sequences, to value the interactions
496 between crop management and crop sequence in the view to reach the design target. Therefore,
497 facilitators of some design workshops chose to split the cropping system to be designed into sub-
498 systems, which were believed to be 'easier to handle' during the exploration process. They then

499 organized an information feedback loop between these successively designed sub-systems throughout
500 the exploration phase. This was the case of AGROSEM, in which facilitators organized a feedback
501 loop between the design of the crop sequence and the management system of each crop (see section
502 3.1.4). In the LEGITIMES case study, an individual reflection phase aimed at proposing short crop
503 sequence patterns (involving 2 to 3 crops) including at least one legume crop, mainly focusing the
504 collective exploration phase on the combination of these 'bricks'. Conversely, in the CASABIO case
505 study, the separate exploration, in successive and independent meetings, of the management of
506 nitrogen and weeds (that farmers considered to be independent), made it impossible to design rules for
507 choosing variety mixtures allowing control of these two major limiting factors in Organic Farming
508

509 3.2.3. Intermediate objects used during the design workshops

510

511 In all design workshops, different intermediate objects were used for three purposes: to stimulate
512 creativity and/or reduce fixation effects; to build the emergence of systemic effects; and to assess the
513 selected options.

514 Firstly, various intermediate objects enhanced the exploration of new options, helping to overpass
515 fixation effects (see Table 5). In several case studies (e.g. SIC, VIVLEBIO, AUTO'N), the presentation
516 to the participants of an exploration tree summarizing the ideas resulting either from a first phase of
517 exploration, or from previous work by the facilitators, made it possible to refine the exploration and
518 guide it towards new paths. In the APPI-N case study, the presentation of a "martyr" prototype of the
519 Decision-Support Tool highlighted several original required characteristics, and allowed participants
520 to challenge its particularities and to propose alternatives.

521 A second type of intermediate object was proposed to support a systemic design by sharing the
522 visualization of interactions. In the CASABIO case study, a tree synthesizing the available knowledge
523 on strategies and practices to achieve the objectives (weed control or crop nitrogen nutrition) was
524 presented and served as a support for discussion on the levers to be combined. In the AGROSEM,
525 CONSYST, and SDCI case studies, a diagram showing the chronology of the individual technical
526 actions resulting from a previous meeting supported the consideration of temporal concordances in the
527 designed cropping systems. In the AUTO'N case study, a dedicated board game was also used, serving
528 to manipulate the various components of the cropping system (crop sequence, synthetic and organic
529 fertilization actions, catch crops), and to continuously visualize their interactions, in order to build a
530 consistent cropping system.

531 Finally, a third type of intermediate object was used in some workshops to assess the explored options.
532 Thus, during the meetings of the CONSYST case study, a calculator of assessment indicators was used

533 to perform a simple and quick evaluation of the proposed options, in order to sort them and to deepen
534 the exploration of the most interesting ones.

535

536 3.2.4. Aims and modalities of the workshop facilitation

537

538 In all case studies, the facilitation had several objectives. The first one was to manage the systemic
539 nature of the solution under design, a necessity for reaching ambitious performance. In all design
540 workshops, the facilitator encouraged the participants to combine the proposed concepts coherently,
541 thereby putting the systemic characteristics of the designed innovation at the centre of the design
542 process.

543 The second aim was to stimulate and facilitate collective discussions during the exploration phase. In
544 all case studies, the facilitator encouraged benevolence and trust between participants, and the creation
545 of a group dynamics. For several design workshops, a major objective of the first meeting was to make
546 participants want to come back, as design could not be ended in a single one (e.g. VIVLEBIO,
547 AGROSEM, AUTO’N, APPI-N, and LEGITIMES case studies).

548 The third aim was to limit the participants’ fixation effects, and to stimulate their creativity (Table 5).
549 Several facilitators mobilised tricks during the exchanges to get participants to think differently from
550 usual, and be creative: (i) stating a property for the innovative system, which is contrary to that usually
551 known (e.g. a crop that is always well supplied with N vs. a crop that tolerates nitrogen deficiencies,
552 in the APPI-N case study); (ii) working from a known solution, by formulating the properties that
553 characterize this solution, and exploring variants of these properties (VIVLEBIO and CASABIO case
554 studies); (iii) temporarily removing constraints: in the SDCI and SIC case studies, while the aim was
555 to design profitable pesticide-free cropping systems, removing the profitability constraint made it
556 possible to explore less remunerative species to lengthen the crop sequence, and then, in a second
557 stage, to recover good profitability thanks to the cost savings they allowed on the crop sequence; (iv)
558 encouraging the participants to clarify the underlying knowledge for each proposed option (in most
559 case studies): this clarification often led to a new idea, which then became a new solution, thus
560 contributing to enrich the exploration.

561 The facilitation also aimed to help participants situate themselves in the solutions space under
562 construction. As the discussions between participants were often very quick, it was generally not
563 possible to write down the main ideas and the underlying knowledge, so as not to break the dynamics
564 of the interaction. Nevertheless, in some design workshops (AGROSEM, APPI-N, and VIVLEBIO
565 case studies), the facilitator sometimes temporarily stopped the discussion to help the participants to
566 take a step back from the ongoing design process: the facilitator summarized the discussion by

567 identifying that a new property of a solution, or a new evaluation criterion, had just been proposed.
568 Sometimes, he/she redefined an option by specifying the concept and the underlying knowledge, or
569 pointed out that the proposal opened a new exploration path.

570 The facilitators mentioned the tricks they used to deal with an heterogeneous collective of designers:
571 (i) using a time for individual reflection ('sticky notes sequence') to force every participant to make
572 proposals, which encouraged everyone to speak afterwards and avoid 'floaters'; (ii) never allowing the
573 floor to be monopolized by a single participant; (iii) never allowing certain solutions to be imposed
574 (for example, those that had already been tested or implemented by some participants), or to be
575 discarded without debate, but always stimulating the exploration of new solutions. In some design
576 workshops involving farmers, advisors and researchers, the facilitator had to deal with a lack of
577 exploration. This stemmed from the fact that many farmers adopted a posture inherited from the classic
578 top-down model of R&D in agriculture, where they waited for researchers or advisors to propose
579 options that they can then apply (e.g. SYSCLIM and DST-work case studies).

580

581

582 Table 5: Summary of the methods used in the case studies to avoid fixation effects and stimulate
 583 creativity, with mention of the corresponding paragraphs of the Results section, the concerned case
 584 studies, and some references citing the methods.

	General principles to avoid fixation	Section	Case studies	References citing this principle
Preparation of the design workshop	Adopt a disruptive and ambitious target (oxymoron, loosening constraints, prioritizing a formulation based more on the expected results than on the means)	3.1.1	AGROSEM, AUTO'N, CONSYST, SDCI, SIC, SYSCLIM, VIVLEBIO, APPI-N	Agogu� et al., 2014; Hatchuel and Klasing Chen, 2017, Brun, 2019
	Choose diverse and open-minded participants	3.1.2	CONSYST, LEGITIMES, SDCI, APPI-N, CAPS	Reau et al., 2012; Ravier et al., 2018; Voure'h et al., 2018
	Share disruptive knowledge (i.e. innovative examples, generated by on-farm innovation tracking or diagnosis of uses)	3.1.3	AGROSEM, LEGITIMES, VIVLEBIO, APPI-N, DST-WORK,	Agogu� et al, 2011; Ravier et al., 2018; Salembier et al., 2021
Implementation of the design workshop	Use intermediate objects (previously made exploration tree; disruptive prototype, etc.)	3.2.3	AUTO'N, CONSYST, LEGITIMES, SDCI, SIC, SYSCLIM, VIVLEBIO, APPI-N, CASABIO, DST-WORK	Reau et al., 2012; Gillier et al, 2010
	Facilitate the exploration of new properties: stating a property contrary to that usually known; formulating the properties that characterize a known solution; temporarily playing with the constraints.	3.2.4	AGROSEM, LEGITIMES, SDCI, VIVLEBIO, APPI-N, CASABIO	Agogu� et al., 2014; Brun, 2019
	Stimulate creativity, by making explicit, for each proposed option, the underlying knowledge, and encourage new explorations based on this knowledge.	3.2.4	AGROSEM, AUTO'N, CONSYST, LEGITIMES VIVLEBIO, APPI-N, CAPS, CASABIO, DST-WORK	Hatchuel et al., 2011; Agogu� et al., 2014; Brun, 2019
	Entrust the design targeting a central farmer to his peers	3.2.4	AUTO'N	Guillier et al., 2020

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 588

589 **3.3. *Outputs and outcomes of the design workshop***

590

591 On the whole, the design workshops achieved their targets (Table 4). Moreover, in most case studies,
592 the facilitators mentioned results that had not been targeted at the outset: the workshops made it
593 possible to convince and mobilize actors who were initially reluctant to commit to changing their
594 agricultural practices (VIVLEBIO, SYSCLIM, LEGITIMES, DST-WORK case studies); they
595 promoted the learning of new technical levers, unknown to some participants (all case studies); for
596 some participants, they contributed to learning new ways of reasoning the management of their
597 cropping systems; they were useful in prioritizing the knowledge to be produced to pursue the design
598 or in producing new knowledge (all case studies).

599

600 Events subsequent to the design workshops differed from one case to another. In most case studies,
601 after the design workshops, the participants formatted and shared the prototypes designed, and/or the
602 knowledge introduced during the workshop. Indeed, during the workshops, the short duration of the
603 discussions, and the lack of time to formalize the exploratory paths, had rarely allowed for a precise
604 description and formalization of the designed solutions. The case managers thus organized to report to
605 all participants on the richness of the content, in terms both of designed solutions, and of shared
606 knowledge. In the workshops organized to design a cropping system for a ‘central’ farmer, the precise
607 description of the designed system was finalized during a further meeting between the workshop
608 facilitator and the farmer concerned.

609 Finally, in most case studies, an *in situ* test of the designed CS prototypes was implemented, either in
610 an experimental station (SIC and AGROSEM case studies), or directly in the farmers' fields (AUTO'N
611 case study). The DSTs (APPI-N, and CAPS case studies) were tested by their users, under real
612 conditions of use, with the aim of both adapting the tool to various situations of use, and encouraging
613 the users to learn from a new tool becoming available.

614

615 **4. Discussion**

616

617 Design workshops are a key approach to support innovative design in agriculture. In the 12 cases we
618 studied, as already shown in the industrial (Elmqvist and Segrestin, 2009) and agricultural (Berthet et
619 al., 2015) fields, such an approach has shown its effectiveness to initiate a dynamic of change, to open
620 up the range of innovations explored, and to propose new solutions that meet ambitious objectives.
621 We propose here to discuss methodological lessons for the organization and implementation of future

622 workshops (4.1.), and issues related to the implementation of design workshops within innovation
623 processes in agriculture (4.2.).

624

625 **4.1. Methodological lessons to organize design workshops**

626

627 The results of this study substantiate and enrich the literature on methods to organize design
628 workshops. Main lessons concern preparation, implementation, and follow-up of the design workshops
629 (Table 6).

630

631 We highlight key elements to be considered, in the context of agriculture, to formulate a design target
632 that is both ambitious and realistic. We observed that starting a workshop with the precise and complete
633 definition of a framework of objectives and constraints, as previously proposed in prototyping
634 workshops in agronomy (Vereijken, 1997; Lançon et al., 2007), tends to keep participants in their
635 known field, and seems less generative than the partial definition of a design target, formulated by an
636 undecidable (neither true nor false) proposal (i.e. a desirable unknown). Bos et al. (2009) likewise
637 proposed that each of the actors involved in the design process define their "*brief of requirements*", to
638 integrate their expectations as a whole, instead of building a consensus, weighting the pros and cons
639 of their different interests. Such a plurality of expectations seems to be more favorable than trade-offs
640 for the adhesion of the collective of actors, as shown by Ravier et al. (2015), and for a broad
641 exploration. The role of constraints in exploration is ambivalent (Hatchuel and Klasing Chen, 2017):
642 taking them into account may either contribute to fixation effects (e.g. stickiness to the problematic
643 situation) or, on the contrary, constitute affordance to stimulate exploration. Based on the experience
644 acquired from the 12 case studies, it seems that the constraints that participants experience on a daily
645 basis fix their points of view, while unusual constraints help to encourage the exploration of disruptive
646 proposals.

647

648 The choice of actors participating in the design workshops, rarely addressed in the literature on the
649 subject (see, for example, Vereijken, 1997; Lançon et al., 2007; Elmquist and Segrestin, 2009), was
650 identified as a crucial step in the preparation of the workshops in the 12 case studies. Whereas the
651 presence of participants with the same job may facilitate the discussions, encouraging a diversity of
652 points of view and knowledge has proved to stimulate exploration (Vourc'h et al., 2018). Moreover,
653 in the design workshops that we analysed, a primary place was given to the future users of the designed
654 solutions, as proposed by Bos et al. (2009) and Cerf et al. (2012). They were generally involved in the
655 three following stages: the definition of the design target, the exploration of solutions, and the

656 definition of the evaluation criteria of the designed object. In all cases, as a basis on which to argue
657 the choice of participants, it seemed essential to clearly identify their role, their position in relation to
658 the 'dominant' sociotechnical regime and possible lock-ins (Rip and Kemp, 1998), and their ability to
659 listen to others and interact on their proposals. Bos et al. (2009) insist on the importance of inviting to
660 the design process all the actors concerned by the problem to be solved: for example, for livestock
661 buildings, "*users, stakeholders, employees, and other participating beings like animals*". We show that
662 involving pioneering actors who have already imagined and implemented innovative practices can
663 help the collective to better share not only the challenge and the target, but also the feasibility of
664 innovative solutions, and can therefore help to motivate actors who were *a priori* reluctant. The
665 particular attention paid by the facilitators to the choice of participants in the design workshops is
666 therefore, if not specific to agricultural issues, at least particularly difficult, as numerous actors can
667 legitimately take part in design, from farmers to advisors, agribusiness firms, consumers, NGOs, local
668 authorities, etc (Prost et al., 2017). Knowing the functioning of agricultural innovation networks
669 (Davies et al., 2018; Kilelu et al., 2011; Klerkx et al., 2012), and the key role of innovation brokers
670 (Klerkx and Aarts, 2013) or network managers (Berthet and Hickey, 2018) can be a valuable resource
671 for selecting the participants of a design workshop.

672

673 The main methods used in our case studies to overpass fixation effects and stimulate creativity had
674 already been described in previous papers, as shown in Table 5. The contribution of this article is to
675 wrap up all these ways, and to illustrate them by examples from the agronomic field. For instance, like
676 the KCP workshops (Elmqvist and Segrestin, 2009), our case studies show the importance of sharing,
677 within the collective of participants, a common desirable unknown that is ambitious, prospective – but
678 realistic – and stimulating, and the usefulness of an initial phase of sharing disruptive knowledge to
679 start the exploration.

680

681 The sequencing of the design workshops appeared to be closely linked to the choice of the target, the
682 diversity of actors chosen to participate, and the time available, so as to maintain a balance between
683 the broad exploratory and the in-depth phases. Facilitating a design workshop cannot be decreed:
684 efficient facilitators are flexible, have interpersonal skills, are open to original - sometimes
685 destabilizing - proposals, and know how to manage their own fixations, and to take up to proposals
686 that allow the discussion to continue. Therefore, beyond the principles formulated here, which have
687 emerged from the experiences of the facilitators, it seems beneficial to promote learning - through
688 practice - of the know-how for design workshop facilitation, for example by setting up pairs of
689 facilitators, involving an experienced one and a trainee.

690

691 An important feature of the objects designed in agronomy is their systemic nature, including the
692 interactions between environmental and socio-technical conditions, and technical actions (Sebillotte,
693 1974; Rossing et al., 2021). In the design workshops studied, the sequencing of the meetings, and the
694 splitting of complex objects into sub-systems, appeared as a means of organizing design efficiently,
695 without losing sight of the whole system. This splitting of complex objects into subsystems can be
696 compared to the division of a design process into successive design sequences, in which the design
697 efforts (e.g. production of knowledge, exploration of properties) are successively focused on parts,
698 easier to manipulate, of the global solution under design, leading to exploration within differentiated,
699 and more restricted design spaces (Hatchuel et al., 2006). There is no *a priori* rule for a ‘good split’,
700 even if a breakdown by biophysical process (water supply, nitrogen supply, weed control, etc.) is
701 usually not optimal because these processes strongly interact within an agroecosystem. But the
702 systemic coherence of the object finally designed is achieved only if the facilitator has been able to
703 organize constant dialogue between the successively designed partial solutions. Intermediate objects,
704 especially those contributing to the visualization of the solution under design, appeared to be effective
705 means of managing interactions during the design process (Jeantet, 1998). Vinck (2009) and Klerkx et
706 al. (2012) argue that these intermediate (or boundary) objects contribute to the representation and
707 translation of the knowledge, practices and activities of heterogeneous actors. They give access to a
708 part of the distributed socio-cognitive processes of the design activity, and participate in the
709 construction of shared knowledge between actors. They contribute to shifting the actors' points of view,
710 thus challenging them, and constitute traces of the emergence of the solution, and of the progressive
711 construction of the problem and its solution.

712

713 Our results confirm that workshop facilitation is crucial to their success. It first consists in managing
714 the progress stages of collective design thinking. It also aims to encourage participants, as Hatchuel
715 and Weil (2009) pointed out in their C-K design theory, to avoid fixation effects and to make explicit
716 the knowledge on which their ideas are based. The ongoing formalization of this reasoning (most often
717 oral in the design workshops, but sometimes with the help of intermediate objects) facilitates the
718 continuation of the design process, and the positioning of participants within the virtual design space.
719 However, some participants, unfamiliar with conceptualization, may find it difficult to verbally
720 express, in a room, their explorations and assessment of the designed solutions. Therefore, other
721 approaches for participatory design, based on building innovations on the course of action, in platforms
722 or in situ, such as Binder and Brandt's design:lab (2008), step-by-step design (Meynard et al., 2012),
723 or Farmer Field Schools (Bakker et al., 2021), are better suited than design in workshops.

724

725 We show that the assessment of a design workshop, to shed light on its performance, is twofold. First,
726 it concerns the design process from their organizers' points of view. In that aim, Le Masson et al.
727 (2010) proposed four criteria for evaluating an innovative design process (V2OR evaluation method):
728 Variety of solutions; creation of new Values; Originality of the solutions designed and the knowledge
729 produced; Robustness of the solutions with respect to a change of context. Concerning "variety", we
730 have shown that the balance between a diversified and an in-depth exploration of solutions can be very
731 variable, and depends both on the time available and on the operational nature of the targeted outputs.
732 Besides, reducing the range of concepts explored did not limit their disruptiveness (see, for example,
733 Ravier et al., 2018). Second, assessment can also be performed from the participants' points of view:
734 for instance, their learnings (e.g. appropriation of disruptive technical ideas, discovery of new ways of
735 acting, knowledge on agronomic processes), new will to "start a concrete change in their practice" or
736 to experiment an innovative idea. This article analysed the design workshop process from the case
737 managers' points of view, and further studies could enrich this analysis focusing on the participants'
738 perspective.

739

740 The methodological lessons drawn from the study are summarized in Table 6, with the intent of making
741 them operational in the form of recommendations and points of vigilance for future design workshop
742 organizers.

743

744 Table 6: Methodological lessons, and points to watch out in the preparation, implementation and
745 follow-up of design workshops

Steps		Lessons	Warning points
Preparation	Formulation of the design target	The target clarifies the design objective; it is usually formulated to be ambitious, challenging and prospective.	It is essential that all participants share the proposed target.
	Choice of the participants	The choice of participants is decisive for the success of the workshop. Favour open-minded participants with diversified knowledge.	Hierarchical relationships between participants, or top-down postures inherited from the linear R&D model, are generally not conducive to the exploration of novel solutions.

	Choice of knowledge to be initially shared	The challenge of initial knowledge sharing is twofold: to share the same vocabulary, and a common knowledge base between participants, intended to stimulate exploration.	The objective of knowledge sharing must be clear to participants. Trying to exhaustively inventory the existing solutions to meet the target may increase fixation effects.
	Sequencing of the meetings	The design workshop can be made up of several meetings, making it possible to successively explore different contexts, or to offer a time for knowledge production between two meetings.	Meetings too far apart in time can demotivate, with the risk of losing participants in the process.
Implementation	Broad exploration vs deepening of some paths	The exploration phase aims to identify a diversity of solutions, disruptive compared to what already exists, or to refine a small number of ideas to produce an operational prototype in a short lapse of time.	The balance between diversity of ideas and refinement of some of them is managed according to the objective of the design workshop and is decided during the preparation phase.
	Design of systemic objects	Splitting complex objects into subsystems is a way of simplifying design without losing sight of the systemic aspect.	The systemic coherence of the finally designed object is achieved only if the facilitator organizes constant dialogue between the successively designed subsystems.
	Intermediate objects	Intermediate objects are facilitation tools that help to organize discussions, enhance direct interactions between participants, enable everyone to get involved, capitalize on, combine and assess ideas, and make it easier to grasp the systemic dimension of the artefact.	The mobilization of intermediate objects is thought out during the preparation of the design workshops.
	Facilitation	Facilitation consists in challenging the participants, guiding them in exploring and/or deepening the ideas suggested, and maintaining the collective dynamics with benevolence.	The success of a design workshop largely depends on its facilitation. The design workshop can begin by sharing rules for the collective work: listening, benevolence, openness, respect.
	The design workshop follow-up	Capitalizing on what has been produced and on the knowledge gaps identified makes it possible to value and continue the work beyond the design workshop, and to possibly reconsider the choices, in the event of unsatisfactory evaluation of the prototype.	The prototype can be finalised in a smaller committee, after the design workshop, before testing it with various potential users. It is essential to inform all the participants of the outputs and outcomes of the design workshop.

747

748 **4.2. *Design workshops within innovation processes in agriculture***

749

750 Design workshops are an approach used to foster innovation processes. We propose to discuss here
751 three issues related to their use in agronomy and agriculture.

752

753 Design workshops are only one approach, among many others, used during innovation processes in
754 agriculture. Our results show the importance of considering the relations between these different
755 approaches to manage their interactions. First, during the preparation of design workshops, an
756 agronomic diagnosis (Doré et al., 1997) and a diagnosis of uses (Cerf et al., 2012) could be used to
757 define the exploration targets, as well as the initial evaluation criteria of the process, by specifying the
758 components of the system to be modified, the desired performances, and the concepts used to initiate
759 the exploration. Second, as shown by Salembier et al. (2021) and Verret et al. (2020), the farmer
760 innovation tracking approach could help to formulate ambitious targets and stimulate exploration, and
761 to open up the field of exploration with realistic concepts, thus fostering confidence in the desirable
762 unknown, sometimes considered by the participants of a design workshop to be risky or inaccessible.
763 Third, the assessment of the solutions derived from the workshops could contribute to inform the
764 exploration dynamics, as shown in some case studies and by Martin (2015). The confrontation of the
765 virtual solution with the real growing conditions (e.g. within on-farm experiments) makes it possible
766 to evaluate the achievement of the design target, and the feasibility of implementation, and thus to
767 enhance learning about how to stimulate a later design phase (Meynard et al., 2012). These examples
768 stress the importance of developing research on the complementarities between design workshops and
769 other approaches in agronomy, and on conditions for their successful articulations to foster innovation
770 processes, and especially open innovation processes (Chesbrough and Bogers, 2014).

771

772 To support innovation processes, some issues require that agricultural techniques be managed at the
773 landscape level, and to consider other scales and actors than those involved in the management of
774 cropping systems or decision-support tools. Thus, controlling the spread of a disease or a pest in a
775 landscape, by organizing mosaics of cropping systems (Skelsey et al., 2010), managing cropping
776 systems within a water catchment area to improve water quality (Chantre et al., 2016), or introducing
777 a diversifying crop in the cropping systems of a territory (Leclère et al., 2018; Hufnagel et al., 2020)
778 require not only the design of cropping systems, but also of their spatial organization, their link to the
779 actors of the territory, and their coupling with other innovations, whether technical or organizational
780 (Meynard et al., 2017). Design workshops to rethink territories have already been organized with such

781 objectives (Berthet et al., 2016; Della Rossa et al., 2022; Pelzer et al., 2020). Such a design can benefit
782 from a prior analysis of the obstacles to the development of certain innovations, linked to the system
783 of actors involved: a diagnosis of the sociotechnical system can be mobilized in this sense (Meynard
784 et al., 2018; Della Rossa et al., 2022). An analysis similar to the one presented in this paper, conducted
785 on workshops organized to design territories, would make it possible to identify the particularities and
786 common elements of such workshops.

787

788 In all design workshops analysed, a wide diversity of knowledge was mobilized: knowledge from the
789 experience of certain actors *vs.* scientific knowledge; knowledge on the issues or processes at work in
790 agroecosystems *vs.* knowledge on the production context; and generic knowledge *vs.* knowledge on
791 singular situations. This confirms the need to combine a wide variety of complementary types of
792 knowledge for innovative design in agriculture (Doré et al., 2011; Ernesto Méndez et al., 2013;
793 Geertsema et al., 2016). Innovation processes in agriculture thus increasingly respond to open
794 innovation logics (Chesbrough and Bogers, 2014; Prost et al., 2017), where the knowledge mobilized
795 for the design of agroecological solutions is widely distributed among stakeholders, and the design
796 process involves a diversity of actors, belonging to different firms. As shown in the design workshops
797 studied, the objects to be designed in agriculture are subject to strong uncertainties, linked to the
798 unpredictability of biological processes, faced with the variability of the environmental factors
799 influencing them (Brugnach et al., 2008; Prost et al., 2017), and to gaps in the knowledge necessary
800 for their design, particularly concerning the biological regulations within the agroecosystem. One of
801 the roles of the design workshops is thus to point out knowledge gaps that need to be filled as a priority
802 (e.g. between workshop meetings), over those that, while generating uncertainty, do not block the
803 design process (Leclère et al., 2018; Toffolini et al., 2020).

804

805 **5. Conclusion**

806

807 Based on a collective cross-analysis of 12 case studies of workshops managed to design new cropping
808 systems or decision-support tools, and on the principles of the C-K theory of innovative design, we
809 derived methodological lessons on the collective design of systemic objects in agriculture. The analysis
810 shows convergences with design workshops carried out and analysed by other authors in other fields,
811 as well as particularities linked to the specific features of design in agriculture: the importance of the
812 choice of participants; the management of the systemic nature of the designed objects; or the
813 mobilization of intermediate objects intended both for the shaping of the new product and the
814 organization of the coordination between its designers. Finally, we confirm that conducting a design

815 workshop cannot be improvised: it is based on a rigorous preparation and a know-how of facilitation,
816 which cannot be reduced to few "tricks".
817 However, this cross-cutting analysis of the management of design workshops dedicated to agriculture
818 remains focused on the design of cropping systems and decision-support tools. It would be interesting
819 to enrich the approach through the analysis of workshops dedicated to the design of farming systems,
820 landscapes or coupled innovations aimed at supporting the transition of food systems. It would then
821 be necessary to enrich or revise certain organizational principles, as well as the management of
822 complementarities with other methods, such as those helping to define design targets and participants,
823 or organizing the confrontation of designed prototypes with reality. Research on workshop-based
824 design, which makes it possible to manage the diversity of the different actors' expectations and
825 constraints, is only in its infancy. Finally, our research has shown that design workshops promote
826 collective design in agriculture, and feed open innovation processes.

827
828

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837

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1075 Supplementary material: a detailed presentation of the 12 case studies

1076
1077 1. AGROSEM: Designing pesticide-free seed-oriented CSs, for their experimental
1078 assessment (2018)

1079 The project AGROSEM, initiated by the FNAMS (national federation of seed multiplier farmers),
1080 aimed at producing healthy and pure seeds without pesticides. The objects designed were CSs including
1081 a crop sequence of 5 to 6 crops, all intended for seed production, and their crop management system,
1082 as well as the protocols to experiment with them for 8 years on 3 sites. The design workshop was held
1083 over 3 days, gradually complexifying the targets by going back and forth between crop management
1084 and crop sequences. During the workshop, a decisional diagram representing the crop sequences with
1085 the key interventions was used as a support for facilitation to visualize the interactions between
1086 technical choices, and was spontaneously remobilized by the experimenters to build the protocols
1087 during the third meeting. The designed CSs are currently being tested in experimental field conditions.

1088

1089 2. AUTO’N: Designing arable nitrogen-autonomous CSs, with and for farmers (2016-
1090 2017)

1091 The aim of the AUTO’N project was to design N-autonomous CSs with a group of 7 farmers in the
1092 north of France. Seven meetings were organized, each one around the specific target of a 'central'
1093 farmer, corresponding to the results he expected and his specific agricultural situation (Guillier et al.,
1094 2020). Expectations regarding nitrogen varied among the 7 farmers: ensuring sufficient N nutrition for
1095 crops, increasing C and N storage in the soil to mitigate global warming, or lowering N losses into the
1096 environment to contribute to improving water and air quality. During each meeting, the farmer
1097 explained his expected results and constraints, after which his peers built solutions (several SCs) to
1098 address them. A board game ('Mission Ecophyt'eau') was used to facilitate exchanges and trace
1099 proposals, and assessment tools were employed to validate the *a priori* capacity of the proposed
1100 solutions to obtain the results expected by the 'central' farmer. Then, on the basis of the proposals, the
1101 'central' farmer chose those he wished to test on a part of his farm.

1102

1103 3. CONSYST: Designing arable CSs including crops to feed a biorefinery (2017-2018)

1104 The CONSYST project aimed at co-designing CSs including crops for a biorefinery in the north of
1105 France. Two one-day meetings were organized to design the CSs for two major soil types within the
1106 territory. The target was defined during a preparatory meeting between the project managers. Three
1107 strategies to reach the target emerged from the first day: increasing the number of crops per year; crop
1108 specialization (biomass *vs.* food production); and diversification in biomass uses. The CSs designed
1109 for each soil type were then assessed with the STICS crop model (Ferchaud et al., 2020) and with a

1110 Life Cycle Assessment (LCA) tool. During the design workshop, a calculator (specifically created for
1111 this workshop) and knowledge sheets facilitated the exploration, and enabled choices to be made
1112 among the alternatives proposed by the participants.

1113

1114 4. LEGITIMES: Designing CSs including more legume crops within three territories 1115 (2015)

1116 The LEGITIMES project aimed at studying and co-building the conditions for inserting more legume
1117 crops into the cropping systems of three French territories: Pays-de-Loire, Midi-Pyrénées and
1118 Burgundy. A one-day meeting per region was organized to design CSs including legume crops,
1119 generally starting from existing CSs. Three to six CSs were designed per region (15 CSs in total), in
1120 Organic Farming and conventional agriculture, for cereal growers and farmers in mixed crop-livestock
1121 farming. A multi-criteria assessment of the designed and existing CSs allowed the case managers to
1122 identify the most promising ones to be disseminated, or to use some of them to design territorial
1123 scenarios for the development of legume crops (Pelzer et al., 2020).

1124

1125 5. SDCI: Designing pesticide-free CSs, for their experimental assessment (2006-2012)

1126 In 2006, with the aim of promoting a more sustainable agriculture, a group of actors from R&D in
1127 agriculture (from the mixed technology network "Innovative Cropping Systems") wished to design
1128 and experiment innovative cropping systems (Reau et al., 2012). Several meetings, bringing together
1129 researchers, engineers and advisors, were organized to design these CS based on the diagnosis and
1130 improvement of the current ones. The objects designed were pesticide-free CSs, adapted to a region.
1131 The objectives were softened over the course of the meetings to prepare and allow for their
1132 experimentation. The exploration was based on functional diagrams of the expected services, and
1133 tables of practices contributing to these services. These CSs were then experimented within several
1134 dozens of fields.

1135

1136 6. SIC: Designing arable CSs limiting GHG emissions, for their experimental assessment (2014-2015)

1137 A previous experimental study of CSs designed by experts for very ambitious objectives (simultaneous
1138 reduction of GHG emissions and pesticide use) showed that these tested CSs did not achieve the
1139 expected results (Colnenne-David et al., 2017). To increase the chances of achieving these ambitious
1140 objectives, a two half-day design workshop was organized, bringing together researchers with different
1141 skills and agricultural advisors. The design workshop began with a tour of the field dedicated to the
1142 testing of the first prototypes and a presentation of their results. Then, divided into two groups (with
1143 or without soil tillage), the participants designed several new CS prototypes. As the *ex ante* assessment

1144 of their performance was unsatisfactory, a new design meeting attended by field researchers and
1145 agronomists led to new CSs prototypes. Their *ex ante* assessment was more satisfactory, thus leading
1146 to the selection of the most promising CSs prototypes, on which the long-term experimentation have
1147 been running since 2015.

1148

1149 7. SYSCLIM: Designing arable CSs with low GHG emissions, within a collecting area
1150 (2013-2015)

1151 The objective of the SYSCLIM project was to design, with a cooperative in eastern France, alternative
1152 CSs achieving lower GHG emissions, and adapted to the local agricultural context (Angevin et al.,
1153 2016). As the territory was characterized by two contrasting pedoclimatic zones, a design meeting per
1154 zone was organized, each lasting one day. The farmers' concerns regarding their current CSs were used
1155 as a starting point to develop evaluation criteria and proposals for alternative crop techniques. The two
1156 meetings produced two different results: very positive feedback on the CSs designed, in one, but a lack
1157 of adherence to the approach in the other. The CSs designed were evaluated using a multi-criteria tool,
1158 and were then presented to different scientific and technical audiences.

1159

1160 8. VIVLEBIO: Designing innovative strategies to manage perennial weeds (thistle) in
1161 Organic Farming (2018)

1162 The objective of the VIVLEBIO project, led by the R&D Agrotransfert-Ressources-et-Territoires
1163 organization (in northern France), was to help farmers to design multi-annual strategies for the
1164 management of thistle in Organic Farming (OF). The purpose of the workshop described here was to
1165 design a set of strategies to "live with thistle in OF". This proposal was derived from on-farm
1166 innovation tracking (Salembier, 2019) which had shown that some farmers consider thistle as a
1167 provider of services and not only as a pest. The aim was to explore systemic combinations of crop
1168 techniques, that should be further refined in specific situations. This was done based on individual
1169 proposals written on sticky notes. The design workshop helped to define original strategies for the
1170 management of these perennial weeds in OF, and to stimulate the interest of participating farmers to
1171 get involved in the project (through their commitment to experimentation, or to be engaged in writing
1172 a knowledge sharing blog).

1173

1174 9. APPI-N: Designing a Decision Support Tool (DST) to manage wheat N fertilization
1175 while tolerating N deficiencies (2014-2015)

1176 The objective of this workshop was to design a nitrogen fertilization method for winter wheat that
1177 would address the issues identified by the users of the balance-sheet method, widely recommended and

1178 used until now in France (Ravier et al., 2018). The designed object is a DST, based on the monitoring
1179 of the N nutrition index (i.e. a NNI trajectory) of the crop to be fertilized, in order to decide the date
1180 and dose of N fertilization. The first meeting, lasting one day, started with a presentation of the analysed
1181 difficulties of using the balance-sheet method. Sharing these issues helped to orient the exploration
1182 towards a method without a yield target and without measuring soil mineral nitrogen content (two key
1183 variables for the balance-sheet method), with the agreement of the participants on this new design
1184 target. A second day, one year later, started with the presentation of a first prototype of the DST under
1185 design, which allowed the participants to refine its properties. Currently, farmers are cooperating in
1186 testing and enriching an operational prototype of the DST.

1187

1188 10. CAPS: Designing a DST to help choosing the companion species to grow with
1189 rapeseed, according to the ecosystemic services targeted (2015-2016)

1190 The objective was to design a tool to help in selecting companion species to be associated with oilseed
1191 rape, taking into account farmers' expectations and their agricultural situation, and mobilizing the trait-
1192 function-service conceptual framework (Violle et al., 2007). The design was carried out over two
1193 successive collective meetings: during the first one, the target of the design and the approach mobilized
1194 were defined, while the second started with discussions on the structure of the tool and the knowledge
1195 to be included in it. Using a generic table presenting the links between traits, functions and services,
1196 built up from the bibliography, the facilitators organized a knowledge exploration to complete the table.
1197 The CAPS tool is now operational and available online ([https://www6.versailles-
1198 grignon.inrae.fr/agronomie/Productions/Outils-et-modeles/Caps-Colza-associe](https://www6.versailles-grignon.inrae.fr/agronomie/Productions/Outils-et-modeles/Caps-Colza-associe)).

1199

1200 11. CASABIO: Designing rules to mix wheat cultivars in Organic Farming (2018)

1201 The role of wheat variety mixtures in reducing diseases is well-known (Finckh et al., 2000). The
1202 CASABIO project aimed to design rules for composing wheat variety mixtures, based on agronomic
1203 and genetic levers, to manage not only diseases but also weeds and nitrogen nutrition in Organic
1204 Farming. Two thematic meetings, respectively focused on weeds and nitrogen management, were
1205 organized, each exploring agronomic and genetic strategies and levers. They were based on two
1206 knowledge exploration trees, previously built by the facilitators and then enriched during the meetings.
1207 The design workshop thus produced a synthesis of knowledge finalized by the design of variety
1208 mixtures, but which will need to be reworked to come up with generic rules for variety mixtures.

1209

1210 12. DST-WORK: Designing a DST to take into account work in the change of practices
1211 (2017)

1212 This project was based on the finding that there is a lack of tools to help farmers to take into account
1213 the work (in terms of time and organization) involved in changing practices towards a more sustainable
1214 agriculture. The objective was therefore to design tools to support farmers before or during the testing
1215 of new techniques. Two one-day meetings were organized, the first with farmers and the second with
1216 specialized advisors. After sharing the results of a diagnosis on existing tools and farmers' needs
1217 (Delecourt et al., 2019), a broad exploration led to the design of a tool kit covering numerous
1218 dimensions of their work. At the end of the workshops, 30 complementary concepts of DST were
1219 proposed. These concepts are now to be transformed into operational prototypes, which will be tested
1220 in real conditions.

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