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Experience and trust to handle uncertainty of biodiversity responses to innovative agricultural practices: Lessons from citizen science on farms

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1 **Experience and trust to handle uncertainty of biodiversity responses to innovative agricultural**
2 **practices: lessons from citizen science on farms.**

3
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16 **Abstract**

17

18 1. As for any innovation, integrating farmland biodiversity into agricultural practices is a
19 complex process, leading to decisions made under uncertainty, due to the difficulty of foreseeing the
20 consequences of decisions. This uncertainty comes under many different forms, depending among
21 others on the type of environmental innovation in agriculture, in a continuum from
22 Efficiency/Substitution-Based Agriculture (ESBA) to Biodiversity-Based Agriculture (BBA). To
23 handle this uncertainty, new knowledge production tools, some of which rely on citizen science on
24 farms (CSOF), are developed. They aim to support decision-making by collecting large databases but
25 also by enabling knowledge production “on the field”, directly by farmers. Yet, the ability of CSOF
26 to actually meet these challenges has little been studied. It is now necessary to understand how new
27 biodiversity knowledge production tools are designed and used.

28 2. Using a user-centred approach, we analysed a CSOF monitoring scheme, the Farmland
29 Biodiversity Observatory (FBO), wherein farmers monitored biodiversity in their fields (3558 fields,
30 from 2011 to 2023, still ongoing). As insiders in the research group, and using an exploratory
31 approach based on 32 interviews, we observed an operational limitation of the scientific knowledge
32 produced, which fails at producing technical recommendations to protect biodiversity locally. While
33 this led to a difficulty to offer prescriptive practices, some participants shifted to non-prescriptive
34 knowledge, i.e. they accepted high uncertainty and used FBO to gain knowledge and navigate through
35 this uncertainty.

36 3. As a theoretical result, we witnessed that shifting to high uncertainty due to the complexity of
37 ecological processes consists in accepting a leap into the unknown. Farmers must trust the action of
38 biodiversity, making themselves “vulnerable” with respect to the possible responses of the
39 ecosystems to a change in farming practices. We identified several factors likely to favour this trust
40 towards biodiversity.

41 4. As a practical outcome, our results show that, to work with biodiversity, farmers must move
42 from reduction and control of uncertainty to acceptance and reliance on trust towards biodiversity.
43 The ensuing management recommendation is to favour a clinical and contextual production of
44 knowledge, emerging from individual experience, over a controlled, standardised and statistical
45 production, inherited from industrialization.

46

47 **Keywords**

48

49 Citizen science on farms, Uncertainty, Trust towards biodiversity, Environmental transition of
50 agriculture, Experiential knowledge, Environmental innovation, AKIS players, Learning tool.

51

52 **1 | Introduction**

53

54 In the face of complex challenges, numerous innovative technical decisions¹ must be made under
55 conditions of uncertainty, i.e. without the benefit of reliable knowledge about the potential outcomes.
56 This is particularly true in agriculture, where farmers and advisers must develop innovative ways of
57 farming when faced with the social and environmental damages (Merino et al., 2019) of industrial
58 agriculture². Decisions under uncertainty, i.e. the way farmers select techniques from several options
59 in the context of environmental innovation, often involve farmland biodiversity, a key but complex
60 element that new farming practices struggle to incorporate. Although technical choices are expected
61 to be driven by the ability to foresee consequences, decisions regarding biodiversity can generally not
62 count on reliable forecasts of future states. Horlings & Marsden (2011) thus distinguished two forms
63 of environmental innovation in agriculture. On the one hand, "Efficiency/substitution-based
64 agriculture" (ESBA, Duru et al., 2015), in line with the dominant agro-industrial regime, is based on
65 sophisticated machines, biotechnologies and large scale engineered processes, and aims to increase
66 resource use efficiency in order to decrease the financial costs and environmental impacts of
67 agriculture (Horlings & Marsden, 2011). ESBA relies on so-called best practices, recycling, genetic
68 improvement, substitution by biological inputs and "precision-agriculture" technologies. The
69 corresponding changes in practices are usually justified as solutions to comply with environmental
70 regulations (Duru & Therond, 2015). Innovators are mainly entrepreneurs and investors (startups,
71 farmtechs) along with researchers and agricultural advisers providing top-down recommendations.
72 On the other hand, "biodiversity-based agriculture" (BBA, Duru et al., 2015), also known as
73 "ecologically intensive agriculture" (Kremen & Miles, 2012) or "eco-functional intensification"
74 (Levidow et al., 2012), aims to create a disruption with the existing industrial model, by enhancing
75 the ecosystem services provided by agrobiodiversity, from farm to landscape level. BBA seeks to

¹ We refer here to Savage's general definition of decision and its consequences (Savage, 1972): "To say that a decision is to be made is to say that one of two or more acts is to be chosen, or decided on. In deciding on an act, an account must be taken of the possible states of the world, and also of the consequences implicit in each act for each possible state of the world. A consequence is anything that may happen to the person." (p.31).

² We adapt the definition of the main characteristics of industrial organisation by Aron (1967): *significant capitalization is required to acquire modern farming techniques (chemicals, machines, biotechs...), financialization (investments need to be repaid, and need to generate sufficient profitability to acquire new plants when previous ones are obsolete), justify rationalisation and scales economies; standardisation reduces large-scale unit costs and also leads to new labour divisions with new players: scientists, experts and engineers, farmers being seen as technique applicators, and therefore not entirely free to interact with biodiversity.*

76 diversify farming systems to increase resilience and provision of ecosystem services, with the aim to
77 reduce anthropogenic inputs (see Duru, Therond, & Fares (2015) for a review around BBA and the
78 challenges to implement it). In this article we will refer broadly to the integration of biodiversity into
79 farming practices as any kind of practices that intentionally involve the action of biodiversity into the
80 decision making.

81

82 Beyond the issue of technical choices in agriculture, uncertainty broadly refers to a “situation in which
83 there is not a unique and complete understanding of the system to be managed” (Brugnach et al.,
84 2008). Three kind of uncertainties are identified in the literature: epistemic uncertainty refers to the
85 imperfection or a lack of knowledge about the system; ontological (or radical) is related to the
86 unpredictability of a complex system; and ambiguity (or ethical uncertainty) results from the
87 simultaneous presence of multiple reference frameworks (different worldviews, values,
88 interpretations, etc.) for the system (Barnaud et al., 2023; Brugnach et al., 2008; Walker et al., 2003).
89 However, Brugnach et al. (2008) suggested that uncertainty derives from the relationship between an
90 individual and the system of interest. Hence uncertainty must not be understood in isolation as a
91 property of a system, but must include human experience in its definition. Any characterization of
92 uncertainty should acknowledge the possibility of different ways to give meaning to an uncertain
93 situation and to act.

94

95 Starting from this definition of uncertainty it is important to realise that the two extremes of
96 environmental innovation of agriculture have distinct relationships with, and face different forms of,
97 uncertainty. Born out of modern agronomy, which sought to control variation in living organisms
98 through tillage, genetics and chemical inputs (Cohen, 2017), ESBA is associated with fields that are
99 highly artificialized and standardised. ESBA generally also relies on evidence-based innovations that
100 farmers just need to adopt. These innovations often follow the large-scale standardisation of industrial
101 agriculture, hence restricting biodiversity to a limited number of factors that can be modelled and
102 whose reactions (i.e. the *consequences of decisions*) can be controlled. Hence, ESBA lowers the
103 uncertainty linked to the responses of biodiversity and to the supply of ecosystem services and faces
104 more uncertainty associated with the development of new technological solutions. Moreover, while
105 controlling variation at local scale, ESBA leads to uncertainties that go beyond the farm or regional
106 scale, such as increasing climate change, reliance on input supply and agro-industrial regime
107 complexity, etc. In contrast to ESBA, BBA uses ecosystem services that rely on ecological processes
108 involving complex networks. These complex adaptive systems are composed of multiple
109 interconnected components, associated with emergent properties and non-linear processes that are

110 incompletely understood (Anand et al., 2010). Moreover, some patterns may be detectable only at
111 specific functional levels, spatial or temporal scales (Giampetro, 2002). For instance, Haan et al.
112 (2020) showed that landscape configuration effects on agricultural pest suppression depended on the
113 interaction between the grain of landscape structure and arthropod dispersal range (forcing
114 predictions to partition species by traits), but also on indirect effects revealed while examining
115 multitrophic interactions. Furthermore, long-term effects of agricultural practices on biodiversity may
116 also exhibit threshold patterns that are challenging to assess precisely. Finally, uncertainty is also
117 associated with transition from industrial agriculture to BBA, which implies drastic changes in several
118 features of agroecosystems. Ecological processes must recover before supporting e.g. soil fertility
119 and biological regulations. During the transition, ecosystem services may vary significantly,
120 threatening the farm's economic stability. Hence uncertainties (both epistemic and ontological) faced
121 by BBA and coming from biodiversity and its supplies of ecosystem services are stronger. Finally, as
122 most farmers are positioned on a gradient of perception of environmental innovation of agriculture,
123 they are likely to have different worldviews and frameworks for interpreting a given situation,
124 creating more ambiguity around it.

125

126 While the need for environmental innovation in agriculture requires intense knowledge production,
127 the associated uncertainty challenges the actual knowledge production system, which therefore needs
128 to be revisited. First, the type of knowledge produced, which is prescriptive and production-oriented,
129 is contested (Girard, 2014). While this knowledge supports a rationalisation and optimisation project
130 made possible by the simplification of complex agroecosystems systems into monodisciplinary
131 objects (Chevassus-au-Louis, 2006), the diversity, variety and unpredictability of the agroecosystems
132 imply accepting a certain amount of risk and suboptimal functioning (Girard, 2014). At the same
133 time, a body of research brings forward the local and informal knowledge of farmers, complementary
134 to the formal scientific knowledge (see for instance (IAASTD, 2008; Ingram, 2008; Šūmane et al.,
135 2018). Local and informal knowledge can be defined as “know-how, practices and skills, developed
136 and sustained over time on the basis of local people's experiences in their environmental and socio-
137 economic realities” (Beckford & Barker, 2007). Informal farmers' knowledge is linked to practical
138 experiences on the farm, tends to be adaptive, dynamic and holistic, considering local systems as a
139 whole and seeking locally specific solutions (Šūmane et al., 2018). Secondly, the top-down
140 knowledge production process, where researchers produce knowledge that farmers can apply after
141 transmission by advisers, is challenged. Thus the European Union's Standing Committee on
142 Agricultural Research stated a “*gradual contestation of linear approaches to knowledge transfer and*
143 *towards a more complex and network-like vision of knowledge, learning and innovation*” (p24, EU

144 SCAR, 2012). Thus knowledge networks and the players of the Agricultural Knowledge Information
145 Systems (AKIS) are also challenged. Moreddu & Poppe (2013) observed that AKIS are evolving
146 from traditional, linear models to more interactive and flexible systems that aim to enhance the
147 adoption of innovation and strengthen the competitiveness of the agri-food sector. Coquil et al. (2018)
148 showed that the increasing expressions of local particularities and farm uniqueness challenge the
149 prevalence of scientific expertise over action. A second difficulty comes from the need to make
150 choices that cannot be based completely on facts, due to the complexity to anticipate consequences
151 of reality and the emergency associated with many farming-related decisions. Thus, AKIS players
152 should no longer be mere prescribers of solutions but instead potential contributors to the
153 development of farmer experience, assisting farmers in their own discovery of their agroecosystems.
154

155 Accompanying these changes in the knowledge production process, new knowledge production tools
156 are created. An appreciable fraction of them originate from citizen science (see Ebitu et al., 2021;
157 Mourad et al., 2020; Van de Gevel et al., 2020 for literature reviews about citizen science for
158 sustainable agriculture), such as citizen science on farms (CSOF)). There is no universal definition
159 of citizen science embedding the full plurality of practices. Its specificity could be defined as “the
160 claim that *amateurs (general public)* can contribute to the production of scientific knowledge, with
161 education as an associated goal or a by-product” (Strasser et al., 2019). Regarding agriculture
162 research, CSOF involves new elements, based on new digital technologies, that were absent in former
163 participatory research in agriculture (Van de Gevel et al., 2020). They aim to help handling
164 uncertainty by collecting large databases supporting a more efficient and effective scientific
165 knowledge (see Ruck et al. (2024) for a review of approaches) but also by enabling knowledge
166 production “on the field”, directly by farmers, thus supporting learning from participants (Couvet &
167 Prevot, 2015; Minet et al., 2017; Ryan et al., 2018). Hence, this growing methodology claims to
168 reconcile formal research with informal knowledge, thanks to studies based on farmer’s observations
169 and to knowledge production directly on the farms. However, as any decision-support tools, CSOF
170 will face the uncertainty inherent in the new knowledge-action relationship and in the difficulty to
171 foresee consequences of decisions about biodiversity. Furthermore, CSOF relies both on farmers and
172 on AKIS players for data collection, analysis and interpretation. It therefore also faces the
173 transformation of both of their roles in the knowledge production process. However, in general the
174 processes of these new tools to produce knowledge and make it manageable for farmers and AKIS
175 players are still poorly understood. For instance managerial and political implications of these new
176 knowledge production tools, their rationalisation and performance criteria (i.e. the relationships
177 between knowledge and action induced) are seldom analysed in depth (Girard, 2014).

178

179 To understand the ability of CSOF to actually meet the challenges listed above, we analysed a
180 nationwide CSOF scheme, the French Farmland Biodiversity Observatory³ (FBO), wherein farmers
181 monitored biodiversity in their fields in order to better understand relationships between farmland
182 biodiversity and their practices. The originality of FBO lies in its main subject, farmland biodiversity,
183 and its participants, farmers and AKIS players. FBO aims to amplify the key role of farmers in
184 preserving and restoring farmland biodiversity and is designed to encourage and support voluntary
185 change on farms involved in the scheme. Furthermore, FBO has been supported by the French
186 ministry of Agriculture since its launch in 2011; the ministry helped to expand the scheme nationwide
187 and to reach a diversity of organisations working in agriculture, leading to a diversity of farmers
188 involved. This longevity, together with the diversity of participants, offers a wide variety of
189 contrasting situations to explore. Last but not least, FBO offers two different scales of knowledge
190 production: nationwide at the request of the Ministry, and local for farmers and advisers. Hence, we
191 specifically investigated (1) the types of knowledge produced by FBO, formal and prescriptive vs.
192 informal and experiential knowledge, and their uses (2) the changes in perception of the agronomic
193 role of biodiversity and the associated ecosystem services, and the ensuing uncertainties, fueled by
194 FBO. To this end, our methodology focused on FBO users, mainly farmers and local advisers. We
195 aimed (1) to grasp the potential and effective benefits of CSOF, through uses, expectations and
196 knowledge and (2) to capture the full diversity of uses of FBO, both intended and unintended.

³In French: Observatoire Agricole de la Biodiversité

197 **2 | Materials and methods**

198

199 **2.1 | Citizen science on farms to monitor farmland biodiversity**

200

201 FBO was launched in 2011 with two objectives: to produce massive data, enabling the study of long-
202 term temporal trends of farmland biodiversity and of their relationships with farming practices (see
203 Billaud et al., 2020; Bimonte et al., 2021; Van der Meersch et al., 2021) ; to raise awareness of local
204 stakeholders and bring new knowledge for farmers willing to lower the impacts of their practices on
205 biodiversity. FBO focuses on five taxonomic groups chosen for their interactions with agriculture :
206 earthworms (soil fertility, Lemtiri et al., 2014) ; aboveground invertebrates (pests and predators,
207 Kromp (1999) ; Symondson et al. (2002)) including a simple identification of beetles and mollusks
208 and a counting of centipedes, ants, woodlice and spiders ; solitary bees (pollination services, Potts et
209 al., 2016), bats (pest predators, Kunz et al., 2011) and butterflies (sensitive to changes in land use at
210 the landscape scale, Dover & Settele, 2009). Monitoring protocols are simple, yet standardised. Two
211 yearly training sessions are organised in different regions of France. They are mostly attended by
212 local advisers who would like to start a local network. A website⁴ gives access to various materials
213 including keys to identify individuals to either functional groups or taxonomic rank (genus or
214 sometimes species level), protocol information sheets, yearly reports, scientific results and
215 communication tools. Participants can upload their data on this website or more recently through a
216 mobile phone application. Various pieces of information on farming practices are requested upon data
217 uploading, even though only a few are mandatory. Since 2021, regular webinars on farmland
218 biodiversity have been organised (see FBO website).

219

220 While initiated by the French ministry of Agriculture and animated by the National Museum of
221 Natural History, FBO relies on local agricultural development organisations to recruit farmers, to
222 assist monitoring and to return feedback about observations to participants locally. Local
223 organisations are for instance the “chambers of agriculture” (public structures representing all
224 strategic players in agriculture), departmental hunting federations, environmental associations,
225 association for agricultural development, etc., depending on the local context. This diversity in local
226 animation produces diversity in the profiles of farmers involved in the scheme. Participation is
227 voluntary and is not rewarded financially. Each farmer chooses which taxonomic group(s) will be
228 monitored on their farm, even though the person collecting the data is not always the farmer :

⁴ <https://www.observatoire-agricole-biodiversite.fr/>

229 sometimes a trainee or an employee of the local organisation does the field work. Thus, FBO
230 participants are diverse, in terms of profession or organisation. We benefited from this diversity by
231 choosing an exploratory approach, which is comprehensive and non-representative, prior to future
232 studies to quantify or identify causal explanations. Hence, we sought to meet and understand
233 contrasting situations and uses of FBO in order to explore various aspects of FBO and of the link
234 between uncertainty and knowledge.

235

236 **2.2 | Data collection**

237

238 2.2.1 | Research position and data collection

239

240 Both the 1st and 2nd authors had a particular relationship with FBO, being part of the scientific team
241 dedicated to data analysis. The 3rd author was also familiar with the context, as a member of the
242 research team and a specialist in organisational studies, but was primarily an observer, external to the
243 operational management of FBO. The three authors think that modern agriculture needs deep changes
244 to address ecological challenges and that more space should be given to local and informal
245 knowledge. The authors recognised the uncertainty around the potential new model(s) of agriculture
246 and aimed to find insights to better understand what the latter could be. Social data and analysis came
247 from two complementary methods : i) a “participatory-research”, in which the 1st and 2nd authors
248 were knowledge producers inside FBO (Billaud et al., 2020; Van der Meersch et al., 2021), seeking
249 self-reflection and reflexivity on their data analysis methodology (i.e. find patterns and relationships
250 in the FBO database), allowing them to understand the potentials or limitations of the data ; ii) with
251 theoretical and methodological support from the 3rd author in the field of organisational studies
252 applied to the relationship between agricultural organisation and ecosystems, the 1st author conducted
253 an exploratory qualitative study inside the FBO network to grasp the ways participants appropriate
254 and enact knowledge. During this period, monthly meetings made it possible to share and challenge
255 the approach until the results were analysed.

256

257 For the qualitative study, we conducted two sets of interviews between March 2020 and February
258 2021, for a total 32 semi-structured interviews with 12 farmers, 14 local advisers and 6 advisers from
259 national institutions (see map on Figure S1). We sought to explore a wide range of agricultural
260 production systems and types of organisations. Hence farmers have different commercial outlets,
261 although standard for their systems (Table 1). All farmers owned their farm. Only two farmers (17%)
262 were women, which is less than the 25 % in France (Table 1). We conducted ten interviews with

263 farmers on their farm and two by phone due to the Covid lockdown in France. We met farmers from
 264 two FBO well-developed and long-standing networks. We aimed to meet participants committed to
 265 FBO and involved in group dynamics, i.e. “ideal” situations in terms of FBO potential effects. We
 266 interviewed farmers that have been involved in FBO monitoring for several years. The names of the
 267 first farmer(s) interviewed in each network were suggested by a prior interview with the local network
 268 adviser. Then we asked each farmer if they could suggest someone else to meet. Most adviser
 269 interviews were by phone or videoconferencing. Local advisers were mostly biodiversity or
 270 agronomy consultants working with farmers, providing knowledge on biodiversity and advice to
 271 conduct the FBO monitoring. More broadly they provide help on all farm-related biodiversity
 272 subjects. We aimed to interview advisers from a diversity of organisations in order to study a diversity
 273 of situations.

274
 275 Interviews were semi-structured, relying on a predetermined thematic framework (Notes S1, S2, S3).
 276 The order of the themes and the form of the questions were adjusted during each interview. The
 277 questions to farmers included their general vision of farming, management practices, farm future
 278 development, FBO monitoring (motivations, results and barriers) and their representation about the
 279 links between farmland biodiversity and farming activities. Adviser interviews addressed local
 280 agriculture, initiatives for biodiversity, FBO context and uses. Interviews with national animation
 281 focused on FBO history, its evolution, the management strategy, links with other organisations, etc.
 282 Finally, in all non-phone interviews, we showed graphs (Figure S2) displaying temporal trends in
 283 abundance of farmland biodiversity, produced by statistical analysis of the data collected in FBO
 284 (Billaud et al., 2020), for the interviewees to comment on them. Before recording all interviewees
 285 gave their oral consent for the use of interviews in our research, all quotes being anonymised.

286 *Table 1: Land tenure, production and farm management of interviewed farmers*

Production	Farm size (ha)	Years of farming	Farm managing	Commercial outlet
Field crops and seed multiplication	150	34	Individual	A huge diversity of crops that link to various cooperatives as customers. Can change every year.
Maize monocropping + walnut production	205 + 4	30	Individual	Cooperative
Maize monocropping	300	40	Family (with brother)	Various cooperatives depending on maize type: edible, animal feed and seeds. Can change every year.

Field crops	223	36	Family (with son)	Cooperative
Field crops + vineyards	280 + 40	8	Family (with father and uncle)	Cooperative and local wine cellar.
Crop-livestock (dairy) farming	290	20	Couple	Cooperative
Suckling farm	118	30	Individual	Local cooperative (organic)
Suckling farm	85	16	Individual	Direct sale (organic)
Vineyards	4,5	20	Individual	Wine cellar and direct sale.
Field crops	80	12	Individual	Cooperative
Crop-livestock (dairy) farming	90	35	Family (with brother)	Cooperative
Apple production	4	26	Couple	Transformation on farm. Outlet at local shops and markets.

287

288 *Table 2: National and local advisers interviewed*

Scale	Organisation	Total
National	Ministry of Agriculture	2
National	National Museum of Natural History	3
National	National Assembly of Chambers of Agriculture	1
Local	Chamber of agriculture	4
Local	Naturalist association	3
Local	Hunting federation	2
Local	Agricultural cooperative	3
Local	Wine-growers union	1
Local	Territorial community	1

289

290 2.2.1 | Meeting and documentary

291

292 We supplemented our data by taking part in various workshops and meetings related to FBO: steering
 293 committee, working groups, national network days and presentation of results (Table S1). We kept a
 294 notebook with associated records of the discussions and issues raised. These data were supplemented
 295 further by additional documents on the FBO: minutes of the steering committees, national and
 296 regional reports, newsletters, and several tools created to help advisers and farmers carrying out
 297 protocols and developing their local FBO network.

298

299 2.3 | Coding

300

301 Interviews were transcribed and coded by the 1st author using Nvivo, with frequent informal checks
302 within the research team. Coding followed a comprehensive approach, i.e. a hybrid between deductive
303 and inductive research (Dana & Dumez, 2015) involving a combination of pre-defined and emergent
304 codes. Pre-defined codes drew on theory or on personal hypotheses. These encompassed codes as
305 general farming, agricultural practices, biodiversity observation approach or use of naturalist
306 knowledge for instance (see Table S2 for more details about code background - theory or observations
307 - and code description). Emergent codes allowed enriching analyses with themes coming from the
308 data such as agronomic issues or innovation testing and adoption for instance. Codes were defined
309 by the author that led the interviews. Further discussion with other authors led to questioning and
310 reframing codes. Then the second set of interviews and presentations of pre-results helped to confirm
311 the coding process.

312 **3 | Results**

313

314 We found two main results, one related to the types of knowledge produced by FBO and their uses
315 to cope with uncertainties, and the other to the changes in relationships towards biodiversity,
316 characterised by an increasing trust towards its action, despite the associated uncertainty. First, our
317 experience and interviews showed that participants often failed in producing normative, evidence-
318 based and operational knowledge from data gathered in FBO, that would depict clear biodiversity
319 responses to their practices and help them to make decisions. However, we noted that some
320 participants shifted to another kind of knowledge, experiential, which was non-prescriptive and
321 recognised high uncertainty. We also witnessed that the implementation of the specific FBO-
322 knowledge production practices required the development of new social and technical relations. As a
323 result, FBO forms an ensemble of interconnected local social systems, each of them corresponding
324 to specific relationships with biodiversity, as well as with uncertainty associated with the
325 reintroduction of biodiversity in crop production. Secondly, farmers had two different kinds of
326 relationships towards biodiversity. For some farmers, protection of biodiversity was important, but
327 mostly for heritage reasons and much less to integrate it into their agronomic thinking. Conversely,
328 some farmers developed a feeling of trust towards the action of biodiversity, despite high uncertainty,
329 and wanted to protect it as an agronomic ally. In the following we detail these two main results.

330

331 **3.1 | Shifting from a prescriptive to an experiential knowledge**

332

333 3.1.1 | At all levels, FBO fails to produce normative, evidence-based and operational knowledge from
334 the data

335

336 FBO was designed to be a decision support tool. Locally, participants tried to apply their new
337 knowledge to improve their practices. Once biodiversity had been measured, they wanted to take a
338 step towards action thanks to the inference of direct links with farming practices, and to select
339 favourable farming techniques. To do so, farmers expected to foresee the effects of their technical
340 decisions on biodiversity. In addition, beyond observations, several networks developed a
341 prescriptive approach of FBO to locally "demonstrate" best practices: management indicators for
342 local authorities, production of "how-to guides", etc. These expectations emanated from farmers
343 seeking for general solutions [1] or more broadly from institutions, for instance funding organisations
344 [2].

345

346 « (...) I would like to see how my observations compare with those of my colleagues. At the regional,
347 but also national level. Because I want to find explanations. Last year we had an explanation with
348 the drought, which was very particular. But I'm not satisfied with that. This year it should have been
349 better. We need, that's the impression, we need to understand, to gauge ourselves and to know what
350 we can improve. » (Farmer 1) [1]⁵

351

352 « the final aim set to us by the regional council, which funds us, is to produce a small guide... To
353 produce something that outlines what is favourable for biodiversity on a farm. » (Adviser chamber of
354 agriculture 1) [2]

355

356 Nevertheless, the use of data for revealing best practices to promote farmland biodiversity while not
357 decreasing crop yields proved to be difficult. Many advisers did not feel comfortable interpreting the
358 data. At local level, observations suffered from limitations inherent to citizen science: i) coarse
359 taxonomic identification of individuals; ii) heterogeneous compliance with protocols and with
360 regularity of observations; iii) uncoordinated sampling, at the "whim" of the farmers, which did not
361 allow a strict control of environmental conditions; iv) often too few participants per network to obtain
362 proper statistical power, given the heterogeneous sampling (even if some networks managed to enrol
363 a large cohort of farmers, with up to 50 participants or more).

364

365 « Unfortunately, I had a lot of trouble because I felt that the data was not reliable enough. I sent all
366 the farmers some overall figures, but I didn't dig into it. I would have felt like I was usurping the data
367 by doing that. I had time gaps at one point, I couldn't make graphs because there was a month where
368 I didn't have information. There were too many gaps to come up with anything serious » (Adviser
369 agricultural cooperative 1) [3]

370

371 Finally, the multifactorial nature of biodiversity observation made it difficult to produce general
372 "how-to guides" from the FBO data.

373

374

375

⁵ The original French version of the verbatims can be found in the supplementary materials (Note S4)

376 « I find this complicated because it doesn't only depend on the farmer and where the nesting boxes
377 are placed. Studies of butterflies and bees are really on a landscape scale » (Adviser agricultural
378 cooperative 2). [4]

379

380 Trying to give a sense to this difficulty in interpreting data, some networks put forward their lack of
381 data and hope to find more results once they have gathered more data through the years.

382

383 « Interpretation is not always easy in fact. Even if the farmers give us the information about their
384 plot. [...] I think that over the years, with the number of years, we'll come up with something
385 interesting but with the first few years it's a bit difficult to interpret. » (Adviser territorial community)
386 [5]

387

388 These limitations were partly overcome at national level by the research team, working on synthetic
389 indicators, with the assumption that data accumulation smoothed out high local variability (see
390 Billaud et al., 2020 for details). Nevertheless, these indicators were based on simplifications that limit
391 knowledge transfer to local situations. By bringing together many variables to summarise them (for
392 instance a "field crop" category pooling crops as different as wheat, barley and maize), this approach
393 excluded the possibility of tracing causal chains. Its use was aiming to verify the statistical relevance
394 of data and methodologies. As observed in the reception of the results by farmers, the interactions
395 documented by FBO between biodiversity and agriculture, although validated by scientific peers and
396 published, were not applicable. Farmers stated that these results were interesting but that they would
397 not be able to decide on a change of practice on their basis. They could not “enact” this knowledge
398 (Daft & Weick, 1984), that is to make sense from it in a way that would help to build a representation
399 of their environment (here responses of farmland biodiversity to their practices).

400

401 « It depends to whom it is addressed. For us farmers, we need to go deeper into the analysis. We need
402 to know which factors matter, in one way or another. This being said, for the general public, I'm
403 tempted to say that it's a bit boring when you go into the details. But for the farmer, it would probably
404 be more interesting to have more accurate data. » (Farmer 2) [6]

405

406 Thus, the promise of finding solutions based on data gathered locally or nationally was not kept.
407 Participants and researchers faced an operational limitation: the complexity, variability and
408 uncertainty of ecosystems prevented farmers and scientists from producing prescriptive knowledge

409 to maintain and enhance biodiversity on the farm (Figure 1). However, as explained below, we also
410 observed another use of FBO bypassing this difficulty and shedding a different light on FBO benefits.

411

412 3.1.2 | Beyond the scientific evidence: FBO as vector of social and technical relationships about
413 biodiversity

414

415 Instead of trying to demonstrate links between farming practices and biodiversity, some local
416 networks put FBO forward for the promotion of biodiversity and to illustrate ecological and naturalist
417 knowledge such as links between habitats and species.

418

419 « *The idea behind these observations is to make these links more tangible. You see, we observe such*
420 *and such species and when we look at its ecology it's linked to such and such type of habitat. It's not*
421 *a matter of formal study or scientific demonstration. It's more a matter of demonstration and summary*
422 *characterisation of the links between habitats and species.* » (Adviser chamber of agriculture 2) [7]

423

424 Other networks did not seek to find and prove a truth, but rather to encourage innovation through
425 collective learning processes. For example, an adviser from a cooperative explained that she chose
426 where farmers conducted their monitoring in order to emphasise differences in the biodiversity
427 observed and encourage exchanges between farmers about their practices and their link with the
428 biodiversity observed through the monitoring.

429

430 « *We deliberately surveyed sites in areas where we knew that fields were in the middle of hectares of*
431 *maize, where we knew there was only maize. And other sites in more varied places, where high*
432 *biodiversity was almost known. But this made it possible to strengthen differences.* » (Adviser
433 *agricultural cooperative 3) [8]*

434

435 Generally, these advisers accepted the contingency of knowledge; they warned farmers that they
436 could not guarantee results and there was no ready-made recipe to improve farmland biodiversity and
437 see benefits on their crops thanks to ecosystem services.

438

439 « *If you create a habitat you're going to favour the species richness of some taxonomic groups. On*
440 *the other hand, I am unable to give the number of beneficial organisms that will come and what*
441 *services they will provide. Today, we don't have access to the service provided and its qualification*
442 *and quantification. So, on the whole, the farmers we work with understand, we are able to make them*

443 *understand by teaching. So on the habitat-species link and what the FBO says on an individual scale,*
444 *I think they can hear and understand that it is not easy to interpret. » (Adviser chamber of agriculture*
445 *2) [9]*

446

447 Thus, we observed that some farmers and advisers expected high uncertainty related to biodiversity
448 and produced an experiential knowledge without a will to increase in generalisation. This experiential
449 knowledge is often tacit, valuing personal experience and is built in action. It is thus related to field
450 reality and is context-dependent by nature (Krzywoszynska, 2016). Each observation equally reduced
451 some uncertainties while revealing others. Participants were aware of this and used FBO as a tool that
452 allowed them to navigate through this uncertainty.

453

454 In addition, we observed an important production of social and technical relations. For many
455 participants, FBO was used to enhance the value of their work on farms and to show their commitment
456 to biodiversity to other stakeholders.

457

458 *« For us, for the association, working with the FBO is an image of quality. Because it's national, it's*
459 *not just anyone. It's a method, a tool that we use that allows us to value ourselves » (Farmer 3) [10]*

460

461 The national coordinator also used indicators, even if they were not perfect, to legitimate biodiversity
462 observation and environmental efforts.

463

464 *« I see the benefit of [FBO] first of all to convince. We're in an ultra-cartesian world, so it's very*
465 *difficult to get away from it. A lot of us are looking for hard evidence, except that when it comes to*
466 *biodiversity it's difficult to put a figure on it. So the advantage of having a biodiversity monitoring*
467 *indicator, such as the number of carabid beetles under the wooden board, is that it can be convincing.*
468 *» (National adviser 1) [11]*

469

470 Moreover, it turned out that FBO belonged to two different cultural worlds, agriculture and natural
471 history. By promoting monitoring of biodiversity by agricultural professionals, FBO led to exchanges
472 between these two worlds, which are often in conflict. At the local level, farmers and naturalist
473 associations regularly worked together to carry out surveys (12 interviewee over 26 mentioned it).
474 These led sometimes to partnerships in other projects (for instance farmers being part of an
475 experiment aiming to promote birds of prey with perches in fields) or to the integration of FBO into
476 local naturalist surveys (for instance a biodiversity survey of a group of villages). At institutional

477 level, a national adviser told us how observations enabled him to be invited (and accepted) in meetings
478 related to the national conservation plans on butterflies and bats, despite negative preconceived ideas
479 from naturalists and staff of the Ministry of the Environment towards officials of the Ministry of
480 Agriculture (in charge of the FBO). This partnership finally led to a joint work on conservation actions
481 in agricultural ecosystems.

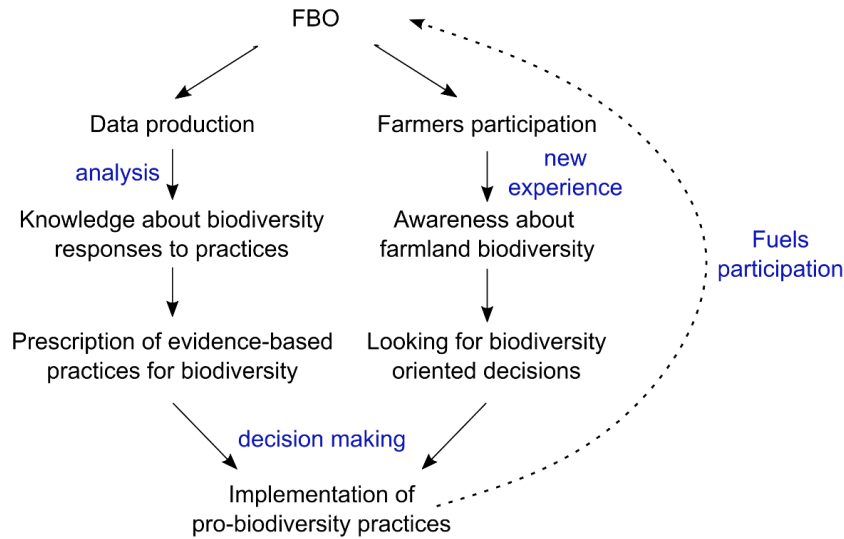
482

483 *« We went to present the OAB [...] to a steering committee for the butterfly national action plan. It*
484 *was a totally magnificent session in terms of interculture. We were up against around fifty people, all*
485 *of them naturalists. [...] And we arrived [...] to present a scheme run by the Ministry of Agriculture.*
486 *[...] They were astonished that representatives of what they saw from afar as the big bad wolves were*
487 *talking about a scheme that allowed them to take an interest in biodiversity. » (National adviser 2)*

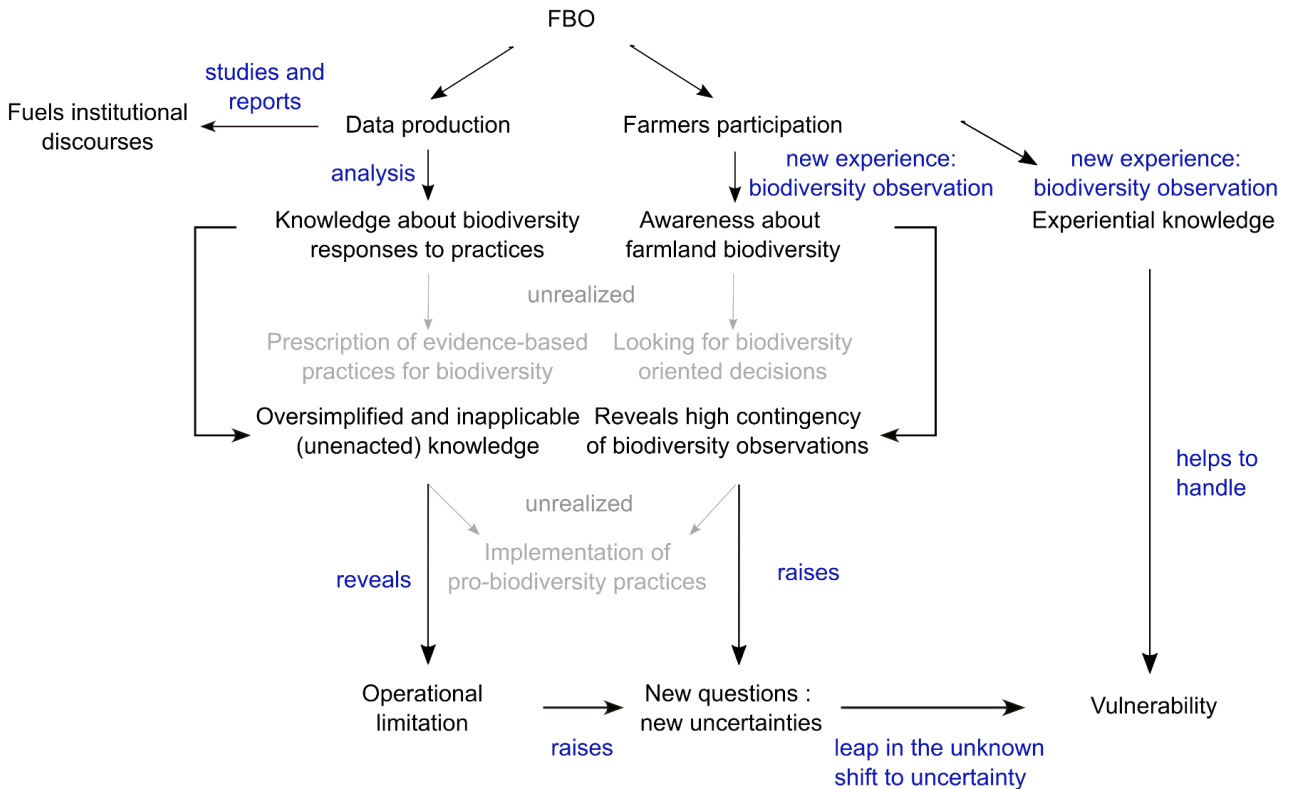
488 [12]

489

1) What FBO was designed for



2) What FBO produced



490
 491 *Figure 1. Synthesis of FBO production, compared to what it was designed for. 1) FBO theoretical*
 492 *functioning and results. While data were supposed to reveal best practices to combine the promotion*
 493 *of farmland biodiversity with sufficient crop yield, participation would have raised awareness of*
 494 *participants and motivated change of practices. Knowledge of best practices and motivation to*
 495 *change would lead to implementation of practices working with farmland biodiversity 2)*
 496 *Observations of FBO results. Failure to prescribe evidence-based practices combining the promotion*
 497 *of farmland biodiversity with sufficient crop yield. While the knowledge produced is not applicable,*

498 *the participation in biodiversity monitoring promotes an experiential knowledge linked to*
499 *observations and increases awareness about the high contingency around it. The new biodiversity*
500 *knowledge reveals new uncertainties and the vulnerability (as a quality of being easily influenced or*
501 *hurt) of a system when farmers work with farmland biodiversity. Their system depends at least in part*
502 *on a factor, farmland biodiversity action, they cannot fully control or anticipate.*

503

504 Through the farmers' participation, FBO hence allowed us not only to study knowledge production
505 under uncertainty, but also to better understand how farmers interact with biodiversity and what kind
506 of relationships they form with it and its action, in particular to handle uncertainty.

507

508 **3.2 | Relationships towards biodiversity: from heritage protection to trusting a mysterious ally**

509

510 Our observations highlighted two kinds of working relationships between farmers and farmland
511 biodiversity. For some farmers, the protection of biodiversity was mainly a question of not depleting
512 it for heritage reasons, but without integrating it into their agronomic thinking. Conversely, some
513 farmers developed a feeling of trust towards biodiversity's action and wanted to protect an agronomic
514 ally. Both relationships can be observed to varying degrees in the same farmers, depending on the
515 elements of biodiversity and their experience.

516

517 3.2.1 | Biodiversity as a heritage to be protected

518

519 For several farmers participating in the FBO, biodiversity issues were mainly centred on the limitation
520 of their impacts for heritage reasons. They therefore wanted to understand what was in their fields in
521 order to "do their job well".

522

523 *« When I arrived in the village I was not the son of a winegrower, nothing, I arrived in a place that*
524 *was rather nice, so in a way, I benefit from what others have done before, so it's up to me to give back*
525 *and to make sure that we don't destroy the environment in which we are, and on the contrary, if we*
526 *can improve it, let's improve it.» (Farmer 5) [13]*

527

528 Moreover, environmental issues challenge their farmer ethos and FBO provided them a means to act.
529 For some farmers, their participation in FBO allows them to challenge and even to experience
530 narratives about farmland biodiversity loss, by being an actor of the monitoring.

531

532 « We already had this approach of observing things, around crop biodiversity and so on. So when I
533 was told that, I said to myself, here we are, today I'm told that there are no more insects, I'm not
534 convinced. But I really want to see what is happening in my field with the FBO. (Farmer 6) [14]

535

536 For other farmers, contributing to FBO was less a way to challenge a narrative than a means to
537 understand their impact, by measuring it.

538

539 « And we realised, well we knew it before, but at least now we measured it, to say to ourselves, is
540 everything we have done so far, is it rather positive or rather negative? On principle, I couldn't be a
541 farmer if it meant doing something negative. » (Farmer 4) [15]

542

543 These farmers expressed their environmental sensitivity and their desire to incorporate possible
544 impacts on biodiversity into their thinking. Their main concern was to not undermine biodiversity
545 and the environment, to meet a current demand in society. Accordingly, we felt that their vision of
546 the link between biodiversity and agriculture remained fairly coarse. They knew, or had the intuition,
547 that biodiversity loss would also be detrimental to the functioning of their fields, as well as to their
548 economic activity, but without going into the details of this link.

549

550 Even though we noticed elements of discourse from scientific ecology, revealing the acquisition of
551 new skills, this knowledge was mostly about biodiversity outside of the fields. For example, a farmer
552 explained how he learned to leave room for biodiversity around his fields by working on habitats:

553

554 « Today I leave grass under the pylon and the habitat, sometimes we have - not anymore because in
555 conservation agriculture we no longer have this problem - but at the time when we ploughed, we used
556 to bring out stones regularly, we piled them up, under the pylons for example, a pile of stones. From
557 time to time in winter, I would have had someone come and remove the stones, to clean under the
558 pylon, because a pile of stones would have been considered a nest for vermin, and conversely this
559 pile of stones can be a reservoir of biodiversity. So this will be a conservation of a habitat. A dead
560 tree at one time would have been cut down to keep it clean, but today I'm going to leave it and I'm
561 going to see it as a reservoir of biodiversity. A bramble is the same thing, I'm going to control it
562 anyway because I don't want to be overtaken by it and have it get in the way of my field, but I'm going
563 to contain it in certain places where it doesn't bother me, but this bramble can be a reservoir of
564 biodiversity. » (Farmer 8) [16]

565

566 Thus, although these farmers were very interested in biodiversity and wanted to change their practices
567 (generally around the field) to promote it, we did not get the impression that they were working *with*
568 biodiversity. Biodiversity remained a heritage element to be protected, and they recognised that it
569 certainly plays an important role, but this role still appeared to be poorly integrated into agronomic
570 considerations.

571

572 3.2.2 | Biodiversity as an uncertain support, but a support nonetheless, and a mysterious ally that must
573 be trusted

574

575 Other farmers described a slightly different relationship with biodiversity that was no longer just a
576 heritage to be preserved but an ally to work with. They mobilised naturalist knowledge to observe
577 and identify elements of biodiversity and recognised their important role in their agronomic practices.
578 Naturalistic observations then played an important role in the decision to spray chemical inputs. :

579

580 « Yes, like that, when you start to see ladybirds in the field, you say to yourself 'they're here'. You
581 can't necessarily see the larvae but if there are ladybirds, there are certainly larvae. That's how I see
582 it. I could see three or four ladybirds on a faba bean plant, or when I see them in my canopies,
583 sometimes on sunny days in spring, before I have planted a new crop, I'd say "look, there are
584 ladybirds already". It's reassuring, you don't have to worry too much. » (Farmer 9) [17]

585

586 This involved a feeling of confidence towards the action of biodiversity they observed:

587

588 “Above all, you have to let them do their things. Because if you reset everything, you will have to
589 start all over again.” (Farmer 9) [18]

590

591 We presented in introduction and showed in the first part of the results that working with biodiversity
592 services implied to manage an inherent uncertainty. Biodiversity is thus a “mysterious ally” for
593 farmers, in the sense that its actions can not always be anticipated and therefore there is no other
594 option but to trust it. We identified several factors favouring this trust (Figure 2). First, this confidence
595 seemed to go hand in hand with the acquisition of naturalist knowledge, the ability to identify species
596 [19], to know their ecological traits [20], dynamics, etc.

597

598 « I didn't know much about carabid beetles before, I had heard of them, and even less about rove
599 beetles. There are rove beetles, there are many species. Some even destroy a few wireworms.

600 *Everything will take care of itself, and that's what's interesting about it. It's a balance, it must not be*
601 *broken. »(Farmer 9) [19]*

602

603 *« I think the trigger was this : the discovery of conservation agriculture. At the beginning I was*
604 *fascinated by earthworms. I think they're pretty ugly animals, but the work they do is enormous. Then*
605 *there are insects. And also birds, the ability to eat aphids: two pairs of chickadees can wipe out all*
606 *the aphids on a hectare, it's crazy! You think you can do without insecticides. I have never used any. »*
607 *(Farmer 10) [20]*

608

609 Secondly, this scientific knowledge interacted with experiential knowledge, such as observations on
610 the field or agronomic changes and experiments. This latter type of knowledge is essential to test
611 farmers' trust towards biodiversity services. Farmers thus have their own ways to rationalise
612 biodiversity observations and integrate them into their decisions. For instance, a farmer explained
613 how he rationalised his reduction of slug pellets by measuring the slug pressure and linking it to each
614 crop sensitivity:

615

616 *« Slugs are managed either blindly, we see a slug or we don't see one, but we see a trace and we*
617 *apply chemicals. I'd say that maybe 80 or 90% of people do this. I put little squares of wet felt and I*
618 *count my slugs. I have the slug pressure per square metre. If the crop is more or less sensitive, on a*
619 *rapeseed, if you find a slug per square metre, you have to be very careful. On a wheat crop, if I have*
620 *30 slugs per square metre, it doesn't bother me that much. I've even seen as many as 50 slugs per*
621 *square metre and I didn't necessarily have any problems. So I do my counts and then I look at my*
622 *crop and how it's developing. If the weather is good and the crop develops quickly, there will be a*
623 *little damage but it's not a problem. If the weather is colder and the crop grows more slowly, then I*
624 *have to keep an eye on it. It's monitoring but it's exciting. You don't use the products when they are*
625 *not needed. That's what it's all about, because I'd say that 50% of the spraying, I say it a bit like that,*
626 *but there are largely 50% of the spraying that could be avoided. » (Farmer 9) [21]*

627

628 This trust is dynamic, always challenged by new experiences, either consistent with ecological
629 (scientific and experiential) knowledge or raising new uncertainties. In the same slug management
630 example, the farmer explained their current questioning regarding biodiversity action.

631

632 *« There are slugs but we no longer need to use slug pellets, all we need are carabid beetles and rove*
633 *beetles that manage the populations. And we have a lot of ladybirds in spring to deal with aphid*

634 *problems. But in autumn we always have aphids on the cereals and the ladybirds are not always*
635 *there. [...] With a little training, I realised that there are fewer crop auxiliaries on the soil surface in*
636 *the autumn. For example, if we sow on October 15, the aphids will be treated in the first ten days of*
637 *November, and there are already far fewer active auxiliaries. » (Farmer 9) [22]*

638

639 Moreover this trust also relied on a general belief that agriculture should learn how to work with
640 biodiversity and promote its services. This belief is not isolated but rather fueled by scientific and
641 experiential knowledge. Reciprocally, it fueled a motivation and an urge to learn more about
642 biodiversity.

643

644 *« I wish I had discovered this 30 years earlier, because in fact, this kind of agriculture is brilliant.*
645 *It's really great and we can see we are improving a lot of things and that biodiversity is coming back,*
646 *despite our negative effects due to production. [...] It's exciting actually. I've regained a taste for it*
647 *all » (Farmer 8) [23]*

648

649 Finally, this new knowledge and trust about biodiversity led to reframing interpretation of agronomic
650 situations, often giving a greater prominence to biodiversity action and reducing the role of chemical
651 inputs.

652

653 *« Why do we have such a plant problem? We realised that these plants have an indicator character*
654 *and that in reality it's a problem of soil compaction, a problem of hydromorphy, a problem of this*
655 *and that, and that ultimately we have to work on rotations, on soil life, we need to work on dose*
656 *modulation of certain fertilisers, the elimination of certain molecules or dose modulation. There are*
657 *many parameters to take into account, but first and foremost we need to deal with the cause and not*
658 *the consequence. » (Farmer 7) [24]*

659

660 Thus acquisition of ecological knowledge and its fine-tuned integration into activity and experience
661 appears to be a way of replacing (or reducing) the place of chemical inputs. The biodiversity-trusting
662 farmers generally explained that crop yield is not increased by their new farming practices, but neither
663 does it drop significantly when certain practices are stopped, which increases the economic margin.
664 Finally, this replacement of practices of agricultural modernisation led to a reversal of the farmers'
665 risk aversion. Whereas risk aversion was traditionally used to explain a fear of losing yield by
666 stopping some practices associated with modern farming, such as mineral fertilisation or pesticide

667 use, biodiversity-trusting farmers were afraid of weakening their ally, of destroying the biological
668 communities by using useless chemistry, even if it meant some yield loss.

669

670 *“The idea is to avoid spraying. We'll keep an eye on things and we'll realise that the auxiliaries are*
671 *there and will regulate the situation. And I'd like to say that we're almost prepared to lose a bit of*
672 *yield but we want to keep this biodiversity. As soon as we apply an insecticide, we'll start all over*
673 *again, and that's what we don't want.” (Farmer 8) [25]*

674

675 This new relationship represented a qualitative leap forward in the way biodiversity was integrated
676 into agronomic decision-making. It also showed how some farmers cope with ecological uncertainty,
677 developing a specific trust towards biodiversity services. Finally, FBO participation seemed to be
678 part of this process of working with uncertainty, offering space for naturalistic observations and for
679 building ecological knowledge.

680 4 | Discussion

681

682 In this study we investigated how a CSOF scheme helped to understand biodiversity responses to
683 agricultural practices and to integrate this knowledge into new practices, despite the uncertainties
684 associated with biodiversity and its services. We observed an operational limitation of the scientific
685 knowledge produced, creating as many new uncertainties and questions as it solved. This led to a
686 difficulty to offer prescriptive pro-biodiversity practices guiding decision-making. However, we also
687 observed how some farmers developed a trust towards biodiversity action, accepting a leap into the
688 unknown, because no solution could be based on a reliable assessment of the consequences. This trust
689 helped them to cope with a high uncertainty and was fueled by “trials and errors” and relied on an
690 eclectic mix of scientific knowledge on the ecology of species, measurement techniques and
691 observations in the field, as well as personal experience. In the following we first discuss the lessons
692 learnt from this study on farming under uncertainty and how a CSOF program can help. We discuss
693 the operational limitation of large scale statistical ecological knowledge for local management. We
694 then explain how FBO shifted from a prescriptive to a learning tool thanks to the peculiar nature of
695 farmland biodiversity observation, seen as a boundary object accepting flexible interpretations.
696 Thereafter we discuss how the trust towards biodiversity action allows farmers to act under
697 uncertainty and end by promoting knowledge built from clinical evidence. Secondly we examine how
698 relevant FBO (as an example of citizen science scheme) is as a knowledge tool to understand
699 biodiversity responses to practices. We specifically examine FBO through the lenses of (1)
700 appropriation by participants and (2) knowledge production.

701

702 **4.1 | How to work under uncertainty: operational limitation of formal statistical knowledge,** 703 **biodiversity observation as a boundary object, need for trust to act and suggestion to shift to** 704 **clinical evidence**

705

706 4.1.1 Operational limitation of CSOF to deduce general formal knowledge that would lead to new
707 practices

708

709 Our observations show the limitations of knowledge from CSOF to deduce normative technical
710 recommendations that would set standard practices to develop farming practices working with
711 farmland biodiversity. Both from the research and from the local advisers perspective, the knowledge
712 produced from in-field observations could not come up with “one size-fits-all” best practices for
713 farmland biodiversity, despite the willingness of most FBO participants and coordinators to change

714 farming practices. On the one hand, researchers succeeded in producing formal scientific knowledge
715 based on statistics and considering large categories of crops (Billaud et al., 2020). These results led
716 to interest and discussion from other scientists and institutional actors, such as national advisers or
717 officials from the Ministry of Agriculture. However, when presented to farmers and advisers this
718 knowledge based on synthetic indicators appeared too broad to be applied and trigger new practices.
719 On the other hand, local farmers and advisers did not have enough accurate data to face the
720 multifactorial nature of biodiversity observation and to produce formal knowledge based on their
721 regional particularities.

722

723 These results are broadly consistent with known limitations associated with the use of statistical
724 models to inform agroecosystem management. As pointed out by (Duru, Therond, Martin, et al.,
725 2015), statistical models often allow the design of conceptual models or the definition of proxies that
726 are useful to learn about ecological groups of species. However, they are generally not conceived to
727 transfer such knowledge into practice; besides, the amount of data available is often not large enough
728 to incorporate the full complexity of local contexts into the analysis. This does not imply that
729 statistical studies are useless, but it does point out the limitations for action associated with this mode
730 of knowledge production, which is nonetheless often used with citizen science schemes, which
731 provide large amounts of data. We think such statistical studies require more contextualisation, but
732 also more data to cope with local specificities, to provide knowledge that can be put into practice.

733

734 4.1.2 Farmland biodiversity observation, a boundary object allowing CSOF participants to shift to a
735 learning tool supporting exchanges between farmers and AKIS players and the exploration of each
736 farming system informal and situated knowledge

737

738 Recognising these difficulties, some farmers and advisers therefore accepted uncertainty and merely
739 tried to illustrate the links between biodiversity, practices and habitats, without any claim to find a
740 “one best way”, but rather to support understanding of each farming system separately. This shift
741 from a prescriptive tool to a learning tool supporting the exploration of the farm environment is based
742 on the particular status given to biodiversity observation.

743

744 As a CSOF, FBO was meant to be easily used by participants, thereby facilitating interactions with
745 farmland biodiversity via simple monitoring protocols adaptable to local situations. This helped
746 farmers and advisers to take a first step in observing, and learning about, farmland biodiversity.
747 Moreover, FBO’s strong focus on monitoring placed biodiversity observation at the centre of

748 agronomic thinking. Farmland biodiversity observation therefore became a boundary object (Star &
749 Griesemer, 1989), adaptable to different viewpoints, but with the different interpretations still
750 structured enough to be recognised by other players and to be a source of discussion and negotiation.
751 Bearing an 'interpretative flexibility' (Star & Griesemer, 1989), biodiversity observation takes on
752 different qualities depending on the context and actors, showing its 'multiplicity' and its evolution
753 according to the appropriations. For example, from local to national levels, farmland biodiversity
754 observation can be: an irreducible experience for the farmer, providing information on their field and
755 a source of naturalist learning; data that are more or less contextualised depending on the networks,
756 a support for comparisons, a source of questions and frustrations; a vector of legitimacy for
757 agricultural players, also generating discussions, negotiations and cooperation with the naturalist
758 sector; or, finally, one piece of data among many, simplified to conform to the database that will be
759 used for statistics.

760

761 Thus biodiversity observation contributes to knowledge management, at the boundary between
762 groups, through two activities of translation and transformation (Carlile, 2004). Translation on the
763 one hand, involves exchanges of views in indeterminate situations, possibly leading to compromises
764 and visions acceptable to all. Examples of translation occur during the interpretation of observations,
765 whether locally in the discussions between farmers and advisers to understand the observations, or
766 nationally to discuss the statistical analyses. The seminar organised to present the national trends was
767 an opportunity for some of the participants, farmers and local advisers, to grasp the inherent
768 imprecision of data. This recognition contributed to their subsequent switch from a use of FBO to
769 find best practices, to a consideration of FBO as a useful tool for local animation on biodiversity
770 issues. On the other hand, biodiversity observation also involves transformative activity, playing the
771 role of "social mediator", a source of negotiation of interests and discussion of identities, as observed
772 in the links between the agricultural and naturalist sectors. Naturalistic observation became a source
773 of joint work and exchanges. At national level, the compilation of these observations into a database
774 shows the efforts of the agricultural sector in the eyes of naturalists and enables acceptance and
775 collaboration on national public conservation actions.

776

777 4.1.3 Developing a trust towards biodiversity action to work under uncertainty

778

779 Following the definition of trust⁶ by Mayer et al. (1995), we chose this concept to describe the
780 relationship of some farmers towards biodiversity because the latter remains a *mysterious ally*. Any
781 social change is accompanied by a questioning of standards and norms resulting in a loss of references
782 (Durkheim, 1897). Farmers face two related sources of such anomie: organisational (Hodson, 1999)
783 — the failure of industrial approach to prescribe solutions — and environmental (Brown, 2022) —
784 the impending environmental disasters that will impact agriculture, experienced here as a leap into
785 the unknown. The farmers we met admit that they still did not understand everything, and that
786 grasping the dynamics of biodiversity in their fields required neverending investigation. Moreover,
787 results from FBO showed the impossibility to monitor the action of biodiversity entirely. Thus,
788 shifting to “farming with biodiversity” consists in accepting a leap into the unknown, thus making
789 oneself “vulnerable” with respect to the possible “responses” of the ecosystems to a change in farming
790 practices. Despite this situation of change and the uncertainty inherent in working with biodiversity,
791 the trust developed by these farmers gave them a way to comprehend a situation, reducing the
792 uncertainty linked to the ambiguity of interpretation. From our observations, combined with earlier
793 studies, we can introduce a conceptual framework to improve our understanding of how trust towards
794 farmland biodiversity, or in other words “biodiversity trustworthiness”, is assessed by farmers,
795 depending on four identified factors (Fig.2): i) formal scientific knowledge about the ecology and
796 natural history of species, ii) experiential knowledge leading to new practices, iii) belief that
797 agriculture can rely mostly on farmland biodiversity services iv) and gradual changes that allow a
798 limited exposure to uncertainty and a gradual build-up of the trust.

799
800 We mainly observed how these factors interact in strategic explanations of this trust, with farmers
801 evaluating the trustworthiness of farmland biodiversity, i.e “its capacity and commitment to fulfil the
802 goals and desire of the farmer” (adapted from Robbins, 2016). As suggested by Duru et al. (2015),
803 farmers used their formal knowledge on the functional ecology of species (for instance large carabids
804 as mostly slug predators) to integrate some mechanisms and hypotheses about farmland biodiversity
805 actions and explain why it can be trusted. However this trust is not theoretical only: farmers put it to
806 the test with trial and error and observations. Farmers also developed their own “situated” rationality
807 to give sense to their biodiversity observations, despite inherent uncertainty. For instance a farmer
808 explained how he counted slug pressure using squares of wet felt to decide if he needs to apply
809 chemicals [19]. By trial and error he gradually set up his own way to manage slugs, combining a trust

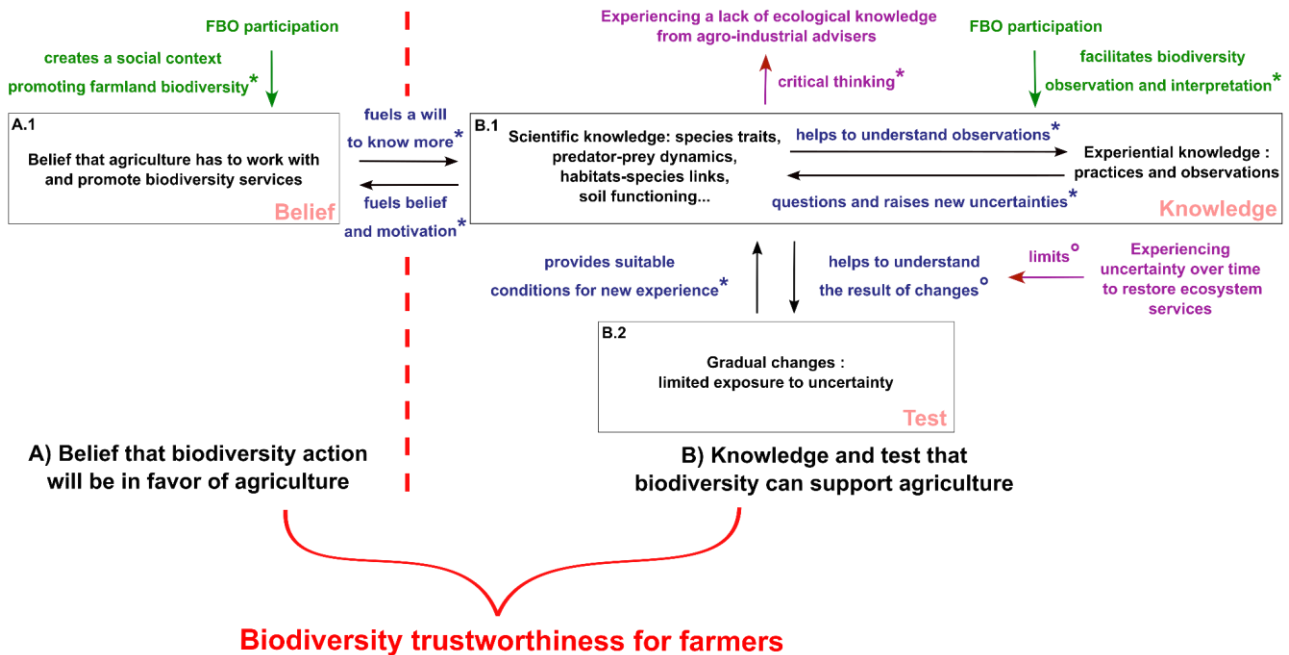
⁶ “Trust refers to “the willingness of a party to be vulnerable to the actions of another party based on the expectation that the other will perform a particular action important to the trustor, irrespective of the ability to monitor or control that other party”

810 towards their predators, which he can identify, and a rational approach based on monitoring to decide
811 whether chemicals are needed. This combined contribution of both scientific and experiential
812 knowledge on farmland biodiversity to changing behaviours is consistent with the results of Toffolini
813 et al. (2017), who showed how farmers mobilised and used basic ecological knowledge 'in situation',
814 to build interpretations of in-field observations, producing their own rationality. Furthermore these
815 farmers believed that farmland biodiversity can really provide beneficial services to their crop and
816 help them produce high yields while reducing their chemical inputs. This belief is fueled by
817 knowledge on wild species (for instance how many pests a given predator can eat per day) and
818 enhances the biodiversity's trustworthiness. Indeed in a way, this belief allows farmers to trust the
819 “commitment” of biodiversity to help.

820

821 These results remain preliminary but the notion of trust towards biodiversity, which is barely explored
822 to our knowledge, could open up new perspectives for studying agroecological transitions and
823 deserves further attention. Further work could dwell on existing literature in several fields. First, trust
824 is a widely used notion to explain changing practices in innovation and adoption of new technologies
825 (Bahmanziari et al., 2003; Li et al., 2008). Second, the literature related to experiences of nature
826 (Clayton et al., 2017; Miller, 2005) or to farmers' mental models (Bardenhagen et al., 2020; Teixeira
827 et al., 2018; Vuillot et al., 2016) may also be enlightening to understand how trust could be linked to
828 farmers's representation of biodiversity. Finally, as shown by Gardezi & Stock (2021) in precision
829 agriculture, trust has an important cultural component, driven by the moral values of a given culture
830 and social context. For instance, while the farmers we met were FBO participants and already at
831 different degrees in the process of improving their practices towards biodiversity, a farmer mentioned
832 how a cooperative adviser could influence the decision to apply chemicals; he felt his fear that
833 applying chemicals could damage biodiversity in his fields was not shared by most advisers. Hence
834 it seems important to investigate the social construction of trust towards farmland biodiversity, for
835 instance through the expansion of agroecology from individual farms to a broad socio-political
836 movement (Dumont et al., 2021; Wezel et al., 2009).

837



838

839 *Figure 2: Conceptual framework for how farmers assess the “trustworthiness” of farmland*
 840 *biodiversity, i.e “its capacity and commitment to fulfil the goals and desire of the farmer” (Robbins,*
 841 *2016). A) Belief that biodiversity action will be beneficial for agriculture. This belief is fueled by*
 842 *knowledge about biodiversity and motivates farmers to learn more about it. B) Knowledge and tests*
 843 *to assess the capacity of biodiversity to help agriculture. B1 Scientific and experiential knowledge*
 844 *interact to provide situated knowledge. B2 The situated knowledge is tested through gradual changes*
 845 *that help reduce uncertainty. Green arrows show how FBO helps to develop trust towards*
 846 *biodiversity. Purple arrows show limitations observed during the study. Arrows are either directly*
 847 *supported by our observations (*) or come from other published studies (°).*

848

849 4.1.4 Advocating clinical judgement of the farmers to work in an uncertain environment.

850

851 In the face of current ecological issues and the need to develop practical knowledge adapted to the
 852 contingency of the living world, it is important to work on the operational capacities of farmers, as
 853 close to the fields as possible. Modern agronomic sciences seek to be prescriptive, and are therefore
 854 based mainly on experiments, statistics and modelling, which often require simplification in order to
 855 be able to observe co-variations between a limited numbers of factors. However, such simplification
 856 considerably undermines the capacity to understand real situations and thus to provide relevant,
 857 locally-adapted prescriptions.

858

859 Given the unknowns of biodiversity in agricultural settings, our results argue in favour of approaches
860 based on clinical observations and the accumulation of specific cases. These approaches would be
861 similar to clinical judgement in medical practice, which stands back from evidence-based practices
862 (Tonelli, 2006) to give more space to professional experience and judgement. Clinical thinking
863 accepts that, given the high uncertainty related to human health, there is no single appropriate
864 “method”, in the sense of a clear series of steps or exact protocols to follow, to identify a relevant
865 treatment. Instead, clinical thinking seeks more for a deeper understanding of species contexts, than
866 for a general and conceptual explanation. To this end, clinical thinking relies on exploration to
867 integrate different perspectives (see Mugerauer (2021) for a deep epistemic explanation), one of
868 which can be formal scientific knowledge that supplements, but does not replace, professional
869 judgement (Pandey & Garg, 2022).

870

871 Although formal scientific knowledge is only one of many bricks in the decision process, clinical
872 thinking is not a step backwards. According to our data and literature, clinical observations by farmers
873 are in fact extremely technical and rely on their professional experience (Šūmane et al., 2018;
874 Toffolini et al., 2017). Moreover, each case study also provides robust scientific evidence and is
875 promoted by some ecologists as part of a framework to improve application of ecology (Driscoll &
876 Lindenmayer, 2012; Shrader-Frechette & McCoy, 1993). We think that clinical thinking can provide
877 an epistemic background to initiatives supporting farmers' informal knowledge, as well as their
878 capacity to explore their environment (Coquil et al., 2018) and to be directly involved in solving their
879 local issues (see for instance the new vision of EU's agri-environment schemes, which seeks to get
880 farmers more involved, Cullen et al., 2018; Moran et al., 2021).

881

882 Regarding FBO, switching to clinical evidence would mean to promote a better exploration of their
883 local environment by farmers, to allow them to find local solutions that could inspire other groups
884 afterwards. While FBO simple protocols allowed to engage a lot of farmers, the programme could
885 rely on the local networks and the relationship created with naturalist associations and researchers to
886 develop local experiments on practices integrating farmland biodiversity. The results of these
887 experiments could then be shared thanks to the national scale of FBO.

888

889 **4.2 | Prospects and challenges for a citizen science producing knowledge on farmland**
890 **biodiversity**

891

892 4.2.1 CSOF: a knowledge producing tool halfway between a rigid data-driven structure and an easy
893 appropriation

894

895 Our results showed that elicitation of experiential knowledge, as well as integration of scientific and
896 local knowledge, depend on whether FBO is locally appropriated (DeSanctis & Poole, 1994).
897 Appropriation, i.e. the way users “take possession” of a technology (Carroll, 2004), is a reciprocal
898 process: users' practices are shaped by technology but simultaneously they reshape its features and
899 find unanticipated purposes and uses.

900

901 FBO was steered by the will to produce statistical trends at the national scale and evidence-based
902 knowledge to guide the decision of farmers and control uncertainty. Therefore, most participants
903 initially focused their use of FBO on producing a formal knowledge, which was top-down and based
904 on statistics that cannot be used for a given management situation because they were based on
905 synthetic indicators. Because FBO has been conceived to produce a national database about farmland
906 biodiversity, its spatial resolution is not fully relevant to enhance local knowledge and help adaptive
907 management of the farm system. The scale at which FBO should be applied was not clearly defined
908 (as advised by Martin (2015) to allow research approaches to contribute to the development of
909 farmers' adaptive capacity and the exploration of their environment), leading to frustration of local
910 participants hoping to demonstrate benefits of new farming practices on their territory with data that
911 were in fact more suitable for national scale analysis. Moreover FBO aims at gathering standardised
912 data, as is often the case in structured citizen science schemes (Bonney et al., 2009; Couvet et al.,
913 2008; Legrand & Chlous, 2016), which may deter participants from including their own experiential
914 knowledge and from adapting protocols for local situations. Hence, parts of FBO features (rules and
915 resources offered) and spirit (general intent, goals and underlying values) (DeSanctis & Poole, 1994)
916 are designed for a statistical scientific knowledge that would control uncertainty with evidence-based
917 practices. We saw in the results that these features influenced some participants that tried to have the
918 same statistical approach to be able to recommend best farming practices for biodiversity. We detailed
919 how most of the local networks fail to produce this recommendation because of statistical limitations.
920 Thus, designing FBO to gather standardised data in order to produce large scale knowledge challenges
921 the development of an experiential knowledge, leading more participants to look for statistical
922 knowledge difficult to produce.

923

924 Conversely, some advisers and farmers focused their observation on understanding local situations.
925 They used FBO protocols as tools to collect new information (on biodiversity) in their systems and

926 to develop their own experiential knowledge about farmland biodiversity. They showed that FBO
927 was user-friendly and adaptable to local situations, with participation on a voluntary basis and
928 modifiable protocols thus also offering flexibility to participants. Hence, influenced in its
929 development by different general goals (large-scale data gathering and development of farmers'
930 experience), FBO has a hybrid participatory nature, between crowdsourcing and the community-
931 based approaches of citizen science (Legrand & Chlous, 2016). While this hybrid nature entails a
932 great recruitment capacity, we also saw that it could lead to ambiguities in its appropriations,
933 impacting the relevance of the knowledge produced.

934

935 4.2.2 Potential highjacking: different relationships to participation embedded into different ways to
936 envision knowledge production.

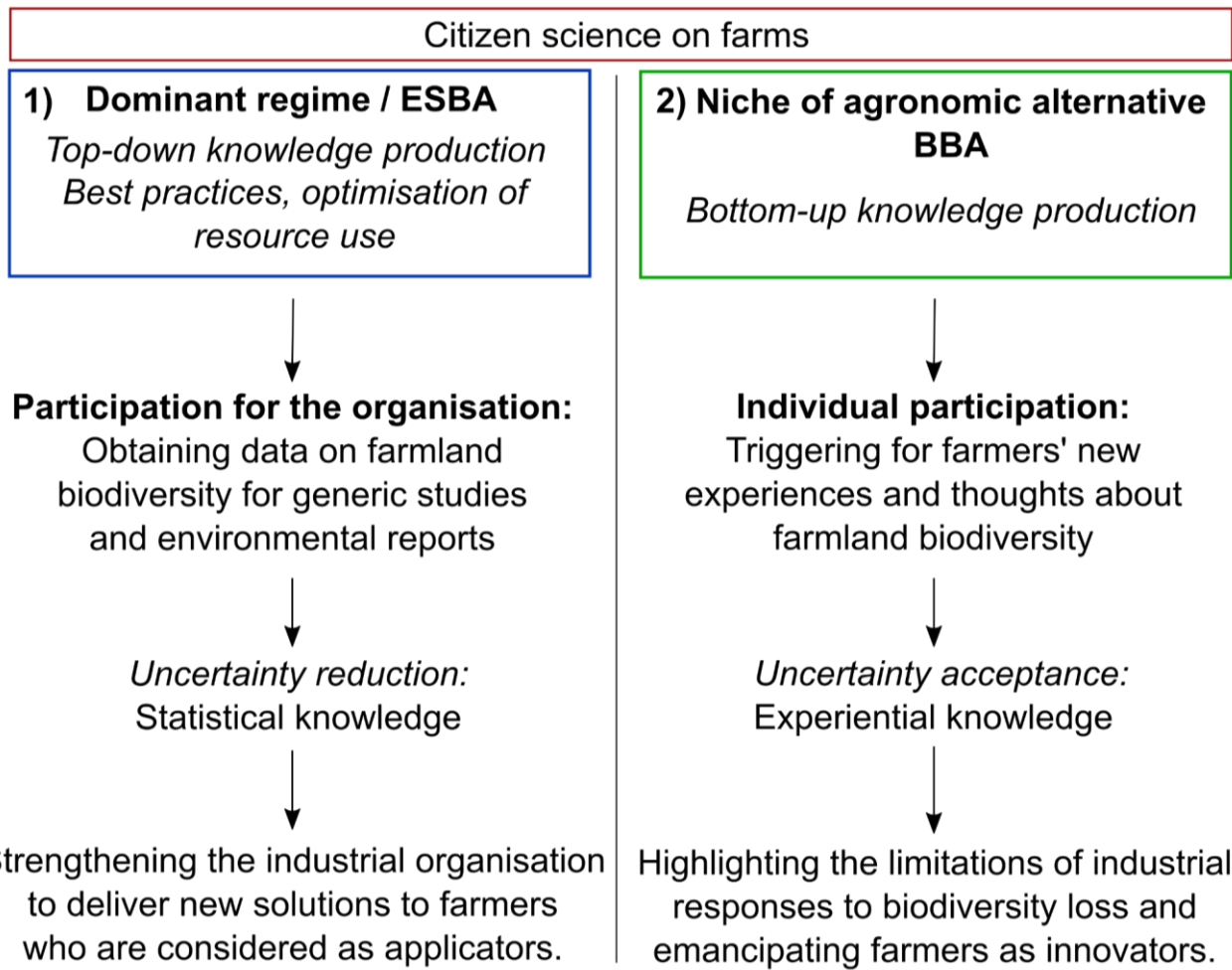
937

938 From a multi-level perspective (Geels, 2002), agronomic knowledge production may be seen at the
939 centre of interactions between a current dominant regime, characterised by a top-down framework
940 from industrial approaches, scientific expertise and institutes, to farmers. This dominant regime leads
941 to ESBA, and the development of niches in which agronomic alternatives such as BBA are being
942 built mainly from local and experiential knowledge (Barbier & Elzen, 2012; Ingram, 2015, 2018).
943 The FBO participatory nature is subject to the same interactions. The position of FBO is intermediate
944 between these two modes of knowledge production: the initial objective of accumulating data for
945 scientific research and conducting national monitoring of farmland biodiversity is part of a top-down
946 vision of knowledge production, with the idea that better generic knowledge and national assessments
947 driven by public action will lead to changes in practices. The participatory approach has been
948 incorporated afterwards, to overcome the lack of data on farmland biodiversity. In a previous work
949 (Billaud et al., 2020), we followed this rationalist approach, seeking to draw general lessons from the
950 database collected. In this study, we confronted this general knowledge with practitioners, both local
951 advisers and farmers, and showed their operational limitations.

952

953 Our results revealed two dynamics inside FBO, which have contrasting relationships with uncertainty,
954 but also which encapsulate two different approaches to participation. The use of FBO standardised
955 protocols by local networks, agri-food sector and national institutions to produce farmland
956 biodiversity indicators and evidence-based decision prioritises the requirements of organisations
957 (Ministry of agriculture, cooperative, etc.), considering farmers as mere “applicators” of their advice.
958 Conversely, networks focusing on FBO as a tool for farmers to explore little-known elements of their
959 farms are much more oriented towards the participants' feelings and requirements. They prioritise

960 data collection and exploration of agroecosystems to produce local and experiential knowledge. These
 961 observations are consistent with the literature on the dynamics of innovations, which highlights the
 962 possibility of deviating from innovations. Faced with a new tool such as CSOF, one should keep a
 963 critical eye on discourses and practices (Figure 3) and start questioning the real impacts of each
 964 approach.
 965



966
 967 *Figure 3 : The two dynamics of knowledge production observed in FBO can be associated with a*
 968 *social level of innovation (regime and niche) linked to particular approaches of citizen participation*
 969 *and uncertainty reduction. 1) Top-down knowledge production is typical of our actual industrial*
 970 *regime leading to ESBA and a participation geared towards the production of large-scale data for*
 971 *studies based on statistics. ESBA, “efficiency/substitution-based agriculture” (Duru et al., 2015), is*
 972 *a form of environmental innovation of agriculture, in line with the dominant agro-industrial regime*
 973 *and based on sophisticated machines, biotechnologies, engineered processes, and a top-down*
 974 *knowledge production. 2) Bottom-up knowledge production developed in BBA is a niche of the*
 975 *industrial regime. It looks for developing farmers' own experience about farmland biodiversity. BBA,*

976 *"biodiversity-based agriculture" (Duru et al., 2015), is a form of environmental innovation of*
977 *agriculture that aims to create a disruption with the existing industrial model, by enhancing the*
978 *ecosystem services provided by agrobiodiversity. BBA seeks to diversify farming systems to increase*
979 *resilience and provision of ecosystem services, with the aim to reduce anthropogenic inputs.*

980

981 **Conclusion**

982

983 In this paper we produced a reflexive analysis of a new knowledge production tool in agriculture,
984 citizen science on farm, exploring how the resulting knowledge helps to cope with uncertainty due to
985 environmental innovation in agriculture. We advocate that such reflexive approaches are necessary
986 in citizen science to go beyond its claims of renewing knowledge production and to provide a deeper
987 understanding of its impacts. Our study showed all the complexity inside a citizen science programme
988 from its ambiguities leading to potential frustrations to the various appropriations by participants
989 leading to a production of different kinds of knowledge.

990

991 Regarding agronomic knowledge production we revealed the operational limitation of the search for
992 generic solutions that will be prescribed to farmers and the limited applicability of formal statistical
993 knowledge based on a large database and synthetic indicators. Thus accepting uncertainty seems
994 essential for farmers to work with biodiversity. This acceptance has a cost for farmers however: it
995 implies their constant exploration of agroecosystems, which fuels experience and trust towards
996 biodiversity action. Hence, shifting from uncertainty reduction to uncertainty acceptance is a true leap
997 for farmers that must be supported by society. Moreover, bottom-up and local knowledge to accept
998 the uncertainty of biodiversity responses involves an emancipation from industrial approaches. New
999 knowledge production tools such as CSOF must therefore focus on supporting farmers in their
1000 exploration of new interactions with biodiversity in their landscape, including lower production risks,
1001 promoting an experiential knowledge far from generalisation but close to the ground. We also showed
1002 in this study how these tools are influenced by institutional contexts, mostly leading to top-down
1003 knowledge production. These findings clearly call for more in-depth analysis of these new tools and
1004 their rationalisation (Girard, 2014).

1005

1006 **Author contributions**

1007

1008 OB led the writing of the interview protocol, conducted the interviews, coded the interviews. EP, EM
1009 and OB conceived the ideas and designed methodology, contributed to situating the work in relevant

1010 literature and led the writing of the manuscript. All authors contributed critically to the drafts and
1011 gave final approval for publication.

1012

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1014

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1019 **Conflict of Interest**

1020

1021 The other authors declare that the research was conducted in the absence of any commercial or
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1023

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