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Agronomy for Sustainable Development (2021) 41: 61
https://doi.org/10.1007/s13593-021-00713-z

RESEARCH ARTICLE

A theoretical framework for tracking farmers' innovations to support farming system design

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Received: 16 November 2020 / Accepted: 1 July 2021 / Published online: 30 August 2021

Abstract

Over the last few years, an increasing number of agricultural R&D actors have sought to discover and get to know farmers' practices that they consider as innovative, unconventional, or promising. We refer to these approaches, all of which aim to support the design of farming systems, as 'farmer innovation tracking'. There is still a lack of knowledge, however, about the specificities of the approaches adopted to track innovations and how they contribute to design processes. To explore these questions, we studied 14 initiatives in France led by actors from different R&D networks. We analysed the data collected using agronomy and design science concepts. Three outcomes emerge from this work. (1) We shed light on the common features of innovation tracking. We outline five stages that structure all the approaches: formulating an innovation tracking project, unearthing innovations, learning about them, analysing them, and generating agronomic content. (2) We characterize six contributions of farmer innovation tracking to design processes: giving rise to creative anomalies, shedding light on systemic mechanisms to fuel design processes on other farms, uncovering research questions, stimulating design in orphan fields of innovation, circulating innovation concepts, and connecting farmer-designers with each other. (3) Finally, we highlight three tracking strategies: the targeted tracking of proven practices, the targeted tracking of innovations under development, and the exploratory tracking of proven practices. This article is the first to propose a theorization of the farmer innovation tracking approaches, thus enriching the agronomic foundations supporting farming system design. The purpose of our paper is not to provide a turnkey method, but to highlight concepts, mechanisms, and points of reference for actors who might wish to develop farmer innovation tracking in different contexts in the future. By revealing their contributions to design processes, this article seeks to contribute to the institutionalization of innovation tracking.

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Keywords Agroecology · Agronomy · Creative anomalies · Design theory · Generative functions · On-farm innovation · Farmers' practices · Tracking innovations

1 Introduction

Today, a growing number of initiatives involve agricultural research and development (R&D) actors seeking to discover and get to know farmers' practices which they consider innovative (Gupta et al. 2019; Verret et al. 2020), unconventional (Blanchard et al. 2017; Figure 1), deviant (Modernel et al. 2018), or promising (Elzen et al. 2017). These actors always engage in these activities with a view to supporting innovation in other farming systems. In line with Salembier et al. (2016), we refer to all these approaches as 'farmer innovation tracking'.

Such innovation tracking is emerging alongside the development of new agricultural projects, such as agroecology (Altieri 1999) which calls for designing farming systems that are more equitable, use fewer resources, and are more respectful of the environment (Hill and Mac Rae 1996; Meynard et al. 2012). From R&D actors' point of view, supporting the design of these systems on farms raises new challenges, such as venturing off the paths historically explored in research (linked to the productivist paradigm); producing knowledge by navigating the many unknowns on agroecological systems (Brugnach et al. 2008); and taking into account the diversity inherent to the situations in which farming is practised (Bell et al. 2008). In order to address these challenges, many authors argue that farmers themselves should design farming systems tailored to their own socio-technical and ecological situations (Dolinska and d'Aquino 2016; Waters-Bayer et al. 2009; Dogliotti et al. 2014; Douthwaite and Gummert 2010). Moreover, scientists as well as public policies have stressed the importance of studying and scaling out farmers' innovative practices to fuel and foster agricultural innovation systems/agricultural knowledge and innovation systems (Šūmane et al. 2018; Klerkx et al. 2010; Fieldsend et al. 2021; EIP Agri EU, 2020). Despite these scientific and political injunctions, studying and scaling out these innovations deeply challenges dominant R&D practices, by recognizing that innovation emerges on farms (thus questioning dominant top-down models of innovation, Joly 2017), as well as knowledge production standards, which are largely based on controlled experiments. Many long-standing questions have still not received significant attention, such as how to unearth and study farmers' innovative practices to boost innovation in other farming contexts.

Since the emergence of the movements for *Farming System Research* (Byerlee et al. 1982) and *Comparative Agriculture* (Cochet 2015), different ways of studying farmers' practices have been formalized (Landais et al. 1988; Ruthenberg 1971; Jiggins 2012). The best known include agronomic diagnosis (e.g. Doré et al. 1997), the modelling of farmers' reasonings (e.g., Girard and Hubert 1999; Mérot et al. 2008; Zhang et al. 2019), and agrarian diagnosis (Barral et al. 2012). These approaches generally apply to the study of populations of fields or farms within a micro-region: (i) to identify problems that need to be solved and deviations from recommended practices (e.g. Zandstra 1979), (ii) to

Figure 1 "Those farmers considered crazy". Excerpt from Entraid' journal no. 310, December 2017. "Unlike those who consider that going off the beaten track is insane, in December 2017, insanity inhabits us. Like those farmers considered crazy but who are spearheading progress in farming. Thirty years ago, they were the first ones to buy a milking robot, to join forces to work together, to embark on the adventure of direct sowing… Today, it doesn't surprise anyone anymore. But at the time, it took courage, instinct and conviction to take the leap. What about today? Who are our new madmen? Those we frown upon and who, in a few years, will have redefined the norm?" (Fig. 1 courtesy of Entraid').

monitor the adoption of an innovation proposed by R&D (e.g. Chenoune et al. 2016), (iii) to highlight and analyse the diversity of existing practices in an area (e.g. Choisis et al. 2012), or (iv) to assess the dominant practices or types of farming systems in a geographical area (e.g. Andersen 2017; Steinke et al. 2017; Lacoste et al. 2018). In these works, R&D actors seek to study more frequent on-farm practices, or their diversity; unconventional, and deviant practices are encountered merely by chance.

Other authors—mostly social scientists—have explored agricultural innovation processes, as well as the outscaling and upscaling of grassroot innovations, highlighting their characteristics and development conditions. The 'learning selection model' (Douthwaite 2002; Douthwaite and Gummert 2010), for example, identifies several steps in technological innovation processes, inspired by evolutionary science. Several authors have studied innovation journeys and shown that these processes require adaptive management, so as to handle and foster reformism within institutional environments, local contexts, and the mindsets of actors and their relations with one another (Klerkx et al. 2010; Hornidge et al. 2011; Djanibekov et al. 2012; Hermans et al. 2013, 2016; Wigboldus et al. 2016; Cofré-Bravo et al. 2019). These studies provide precious results for analysing and fostering innovation processes. To the best of our knowledge, however, from an agronomic point of view, they have paid little attention to the approaches used to unearth and study grassroot innovations, as well as these approaches' impact on design processes.

Innovation tracking approaches have been mentioned in two types of scientific work. In the first body of studies, researchers have described and characterized innovations that were previously unknown to them. Studies presented in the books of Chambers et al. 1989) and Scoones and Thompson (2009) are emblematic of this body of work. Other examples include the work of Feike et al. (2010), who studied how Chinese farmers implemented multispecies intercrops; Jagoret et al. (2012), who studied agroforestry practices with cocoa trees; Barzman et al. (1996), who studied ant domestication practices for lemon growing; and Abay et al. (2008); and Tafesse et al. (2018) and Modernel et al. (2018), who studied innovations in seed and potato disease management and in animal husbandry. In all these cases, each author developed his/her own method with few references to the others. A second category of studies on innovation tracking has produced methodological recommendations. This is the case of Elzen et al. (2017), who proposed an approach for building a 'portfolio of promises' by identifying niche innovations, and Salembier et al. (2016), Blanchard et al. (2017), and Penvern et al. (2019), who have all discussed some of the desirable features of the methods they developed. For example, Salembier et al. (2016) have highlighted the importance of taking farmers' own evaluation criteria into account in the analysis of their cropping systems. These studies report a steady rise in the adoption of such approaches in research but also among development organizations (e.g. advisory services, technical institutes), and the need to 'take a step back' to take stock of this diversity and develop theoretical guidelines.

In this research, we posit that tracking farmers' innovations contribute to enriching agronomy and its methods, with a view to supporting the design of farming systems. Given the growing number of initiatives in a wide variety of R&D contexts, we endeavoured to add to the theorization of the underlying approaches and their little-known contributions to innovation. To this end, we explored the following questions: what are the common features of innovation tracking approaches, and how do they contribute to farming systems design?

The article outlines our conceptual framework, the method we adopted, and the cases we studied. We then present and discuss the results.

2 Conceptual framework and research method

2.1 Conceptual framework

Given the diversity of terminologies used to refer to the approaches, we studied (e.g. spotting promising, deviant, innovative practices), in line with Salembier et al. (2016), we propose to refer to all of these as 'farmer innovation tracking'. This notion emphasizes 'tracking', an active process leading to the discovery of innovations (in contrast with encountering them 'by chance'). We study innovation tracking as an investigative process driven by intentions, involving data collection and analysis and the production of outputs and outcomes.

We use the term 'innovation' to designate a novel object that is either emerging or has already been developed and implemented. This object can be a basic technique (e.g. an intercrop), equipment, or an agricultural system (e.g. cropping system, livestock system, couples of equipment, and cropping systems). We use the term 'innovation process' to refer to the process underlying the emergence and development of a novel object and its adoption in one or several farming situation(s).

We consider 'design' as a process driven by a desire to generate something that does not yet exist. This process is a particular look at an innovation process and consists of the gradual emergence of an innovation, either material or immaterial, and its integration into socio-technical environments (Papalambros 2015; Wynn and Clarkson 2018; Hatchuel et al. 2017).

The innovation tracking processes we studied were initiated and steered by R&D actors to support the design of farming systems. Salembier et al. (2018), Le Gal et al. (2011), and Martin et al. (2013) show that these actors' involvement in agricultural design processes can be threefold: (i) they can co-design these systems, in situ, with farmers (e.g. Prost et al.

2018); (ii) they can foster distributed design processes, often by generating and circulating generic agronomic content for a large number of farmers (e.g. decision-making rules, types of cropping systems prototypes, optimization tools); and (iii) they can themselves design farming systems, for instance, to test them on station.

To study the contributions of tracking to design, we draw on the concept-knowledge (CK) theory of design reasoning (Hatchuel and Weil 2003) and the work of Schön (1983) on the interconnections between design, situations, and action. As Hatchuel and Weil (2003) show, design is a process of exploration of the unknown, intimately linked to what the designers know and learn. A design process involves the formulation of a target which refers to an unknown and desirable object (Le Masson et al. 2017). In other words, what exists is insufficient for the designer, who wants something new to emerge (that is desirable), but does not yet know what that is (it is unknown). Again, according to Hatchuel and Weil (2003), the emergence of the new object relies on the definition of its identity, through the exploration and gradual characterization of its properties: its composition, and the use that can be made of it, by whom, when, in what conditions, etc. In design reasoning, the exploration and gradual definition of properties are intimately linked to the designers' representation of the objects emerging, to the choices and decisions they make in the process (e.g. choosing one option over another), and to the mobilization and acquisition of knowledge (evidence of causality, evaluation of the object's performance, new models, etc.). Furthermore, these developments arise through negotiations between the designers and other stakeholders. Thus, the design process is highly dynamic and collective and evolves through encounters with new situations over the course of the action (Schön 1983).

Studying the way tracking contributes to design therefore means investigating (1) the contributions (i.e. generative functions, Hatchuel et al. 2013) of tracking to farming system design processes (e.g. co-design, distributed design, pilots designing themselves farming systems, and contributions such as formulating new design targets, exploring and defining properties of an innovation, and gaining knowledge on this innovation, etc.), and (2) the different ways of implementing this approach that afford these contributions (e.g. data collection, data analysis).

2.2 Method

2.2.1 A multiple-case study analysis

Our objects of study are 'approaches' developed by different R&D actors to track farmers' innovations, with a view to fostering the design of other farming systems. In other words, we study the studies of others and some of their contributions to design processes. We adopt a theory-building approach (Eisenhardt and Graebner 2007) based on a multiple-case study with embedded units of analysis (Yin 2003). This method explores the convergences and divergences between cases to contribute to a common theoretical construct. We selected the cases based on the following criteria: (1) R&D actors had set up innovation tracking processes to support the design of farming systems; (2) innovation tracking related to a range of innovations (e.g. cropping systems, basic techniques, agricultural equipment. for winegrowing, field crops and market gardening, both organic and conventional); and (3) the tracking initiatives emerged in diverse institutional settings, as part of agricultural research or within development bodies (Table 1). We refer to the R&D actors who carried out the various tasks associated with innovation tracking as 'pilots'.

2.2.2 Description of the cases

The 14 cases studied have diverse characteristics (Table 1).

The tracking of case 1 took place over a 6-month period, in 2015, led by INRAE researchers in Occitanie (South of France). The project was initiated to explore the way in which market gardeners developed protected vegetable intercrop systems to manage plant health while minimizing the use of pesticides. As protected vegetable intercropping is little known on a scientific level, the pilots' objective was to learn from on-farm practices in order to design original vegetable cropping systems which they could test on station.

Case 2, also studied by INRAE, was part of a project which sought to study the conditions for legume development in farming systems, with a view to reducing the use of inputs (nitrogen and pesticides). Within this project, intercropping species emerged as a particularly interesting technique to avoid the problems associated with legumes in pure culture (e.g. lack of competitiveness with weeds, risks of lodging) and to leverage niche complementarity between species. Multispecies intercrops were tracked to learn from farmers' practices and to enrich scientific knowledge, which had until then focused on a small number of intercrops (e.g. pea-wheat, pea-barley).

The tracking of cases 3 and 8 was initiated as part of a project (2013–2017) led by Agro-Transfert Ressources-et-Territoires (AGT-RT) and its local partners (e.g. advisory services) to contribute to the development of organic farming in the Hauts-de-France region (North of France). Based on a regional diagnosis, the project focused on organic nitrogen management and weed control in arable crops. Two kinds of innovation tracking were carried out in the project. The first (case 3) aimed to identify and study cropping systems which addressed these challenges, within a preexisting farmer collective. The other (case 8) consisted in identifying and evaluating on-farm intercrops with protein crops, an original (but little-known) option to manage nitrogen and weeds in organic farming.

Case 4 was steered by engineers from Terres Inovia (French technical institute of the vegetable oil and protein sector) and was launched in 2005 in the Berry region

Table 1 Elements used to characterize and distinguish between the 14 cases studied. In the second column, "S" signals a scientific approach (e.g. academic field), and "D" a development approach (e.g. advisory field). In the column presenting the geographical area (GA) where the innovation tracking took place (column 5), 1R stands for a region, 3R for three regions, and N for nationwide. The acronyms of the pilot organizations are the following: INRAE—Institut national de recherche pour l'agriculture, l'alimentation et l'environnement (National Institute of Research for Agriculture, Food and Environment), AGT-RT—Agro-transfert ressources et territoires (Resources and Territorial Agro-Transfer), CA—Chambres d'agriculture (Chambers of Agriculture), BFC—Bourgogne-Franche-Comté region, IFV—Institut français de la vigne et du vin (French Institute of Vineyards and Wine), and ITAB—Institut de l'agriculture et l'alimentation biologiques (Organic Farming and Food Institute). In the sixth column, C refers to centralized organisations, and D to distributed organisations.

N°	S/D	Pilot structure	Duration	GA	Orga. tasks	Desirable unknowns	Documents/websites consulted
1	**S**	INRAE Alénya	6 months (2015)	1R	C	Intercropping species in protected vegetable growing to reduce the use of pesticides	Master's thesis (Dupré 2015), project documents, minutes of meetings
2	**S**	INRAE Grignon	6 months (2015)	3R	C	Intercropping species with legumes to reduce the use of inputs	Article, Master's thesis, project brochure (Lamé et al. 2015; Jeuffroy et al. 2018), https://www6.inrae.fr/legitimes
3	**S + D**	AGT-RT	2013–2017	1R	C	Innovations to manage weeds and nitrogen in organic farming	Articles (Favrelière and Ronceux 2016; Ronceux and Favrelière 2016), http://www.agro-transfert-rt.org/projets/agri-bio/
4	**D**	Terres Inovia	Long term	1R	C	Innovative management systems for robust rapeseed in the Berry region (expressing their best yield potential with low inputs)	Technical Guide (Cadoux and Sauzet 2016) https://www.terresinovia.fr/-/benefices-et-conduite-du-colza-associe-a-des-legumineuses
5	**D**	CA Grand Est	2013–2020	1R	C	Innovative cropping systems to reduce synthetic nitrogen fertilization in the East of France	Articles (Cros 2017); https://grandest.chambre-agriculture.fr/productions-agricoles/references-agronomiques/projet-auton/
6	**D**	CA BFC and Brittany	Long-term	1R	D	Innovative farming or crop management systems in Bourgogne-Franche-Comté and Brittany	Written testimonies (Abgrall et al. 2016), project documents, CA BFC website; http://www.innovaction-agriculture.fr/
7	**D**	Solagro consultancy	Long-term	N	D	Agroecological farming systems in France	Written and video testimonies; https://osez-agroecologie.org/qui-sommes-nous
8	**S + D**	AGT-RT	6 months (2016)	1R	C	Intercropping species with protein crops in organic farming, in the Hauts de France region	Article (Favrelière and Ronceux 2016), project documents, minutes of meetings; http://www.agro-transfert-rt.org/projets/agri-bio/
9	**D**	CA Finistère	Long-term	1R	D	Agroecological farming or crop management systems in Brittany	Written testimonies (Abgrall et al. 2016); http://www.bretagne.synagri.com/synagri/les-agri-novateurs
10	**D**	Atelier Paysan	Long-term	N	D	Self-built farming equipment for organic and small-scale farming	Written testimonies, online platform; videos, https://www.latelierpaysan.org/
11	**D**	IFV	2013–2017	3R	D	Innovative farming or crop management systems in organic winegrowing in three regions	Written testimonies (Petit 2018), project documents, minutes of meetings; https://www.vignevin.com/bio/pratiques-innovantes/
12	**S + D**	AGT-RT	6 months (2017)	3R	C	Innovative methods to manage rumex, sow-thistle, and thistle in organic farming for the Hauts de France region	Master's thesis (Rodot 2018), project documents, minutes of meetings; http://www.agro-transfert-rt.org/projets/vivlebio/
13	**D**	ITAB	6 months (2017-18)	N	C	Innovative methods to manage rumex and thistle in organic farming in France	Master's thesis (Vancleenputte 2019) http://www.itab.asso.fr/programmes/CAPABLE.php
14	**D**	Atelier Paysan	2014–2017	1R	C	Equipment to reduce work time and maintain soil fertility with vegetable systems in the Finistère region	Project document, minutes of meetings, https://www.latelierpaysan.org/

(Central France), at the initiative of local farmers who wanted to change their oilseed rape management practices in order to overcome technical hurdles (lower yields, increasing difficulty to manage weeds and pests). Based on an agronomic diagnosis of their practices, the engineers and the farmers collectively explored, implemented, and analysed innovations in oilseed rape management tailored to each farm.

Case 5 (2015-2019), which focused on reducing the use of synthetic nitrogen in field crops, was led by the Chamber of Agriculture and involved research organizations and consultancies in the Champagne Crayeuse region (North-East of France). In calcareous soils with low mineralization, which are slow to warm in the spring, farmers use large quantities of mineral nitrogen, which is financially costly and energy-intensive and leads to water and air pollution. Working with several farmers eager to innovate in their farming systems, the pilots explored innovative cropping systems to reduce the use of mineral nitrogen.

Case 6 was initiated in 2008, within the network of the Chambers of Agriculture (farming advisory bodies) of the Brittany region (Western France) and then extended to all regions under the name 'InnovAction'. Through farm open days, this tracking focused on identifying and sharing testimonies about farmer innovations uncovered by local farming advisers. Innovations (crop management systems, equipment, collective organisation, etc.) were presented on the basis of 'farmers talking to farmers about their innovations'. We studied this tracking in the regions of Bourgogne-Franche-Comté (Eastern France) and Brittany (Western France).

Case 7 was initiated in 2010 by the consultancy Solagro. Through an online platform and farm visits, this long-term project called 'Osaé' (OSez l'AgroEcologie) shared innovative cropping and farming systems developed by farmers who had changed their practices to transition towards agroecology.

Case 9 focused on the Agri'Novateurs network, which was created in 2013 by the Chamber of Agriculture of the Finistère region (Brittany) to locally share farmers' innovative cropping and farming systems, to provide a space for dialogue between these farmers and a breeding ground for research questions to explore.

Cases 10 and 14 revolved around two forms of tracking implemented by the cooperative Atelier Paysan, which endeavours to stimulate the design of farming equipment for organic and small-scale farming. Case 10 consisted in identifying and describing equipment designed and used on farms and sharing them with other farmers. Case 14 focused on supporting farmers in the design of farm equipment tailored to vegetable systems in organic farming in Brittany.

Case 11 (2013–2017), led by the Institut Français de la Vigne et du Vin (IFV), involved pilots from research and advisory services. This project emerged from a twofold observation: little R&D work had focused on organic winegrowing, and the technical advice available was ill-suited to the wide range of farming situations in organic viticulture (sloping land, narrow vineyards, etc.). In order to 'give ideas' to winegrowers wishing to convert to organic farming, the project aimed to identify, analyse, and share farmers' innovations (technique, cropping or farming systems) in organic winegrowing in three terroirs: Burgundy (East), Provence (South-East), and Bordeaux (South-West).

Case 12, like cases 3 and 8, was steered by AGT-RT and consisted in a tracking process for managing rumex, thistle, and sow-thistle in organic farming, across three regions. This tracking process was initiated to support the design of organic cropping systems for arable crops, in response to the scarcity of knowledge on different options to manage these perennial weeds.

Case 13 was led by the Institut de l'agriculture et l'alimentation biologiques (ITAB, Institute of Organic Farming and Food) and involved different research and advisory service partners. A tracking project was initiated across the whole of France to explore different methods, in organic farming, to manage thistle and rumex, two weeds identified as problematic by many organic farmers in France.

2.2.3 Data collection and analysis

The data collection took place between January 2017 and February 2018. A total of 23 semi-structured interviews were carried out with the pilots of each initiative, each lasting two to 6 h (between one and three interviews per case, with additional interviews at the data analysis stage when necessary). Each interview was recorded and transcribed in full. The purpose of the interviews was for the pilots to explain which tracking processes they had deployed, for what reasons, in what situations, and what this had helped to generate. We also asked the pilots to share their thoughts on what they called 'innovations', in other words, what they deemed innovative, extraordinary, unconventional, deviant, etc., and we sought to grasp the reasons why they were interested in these particular practices. The following categories of questions were addressed during these discussions: how did the initiative emerge and in what context (individuals involved, institutions concerned, funding, timeline, etc.)? What did the pilot consider as an 'innovation'? How did the tracking process unfold? How did they identify and analyse the innovations (basic techniques, cropping/farming systems, etc.)? Who was involved and how? What did they learn, what surprises did they encounter, and how did they respond? What were the outputs-outcomes of the process? Some interviews were supplemented with observations of events (10 events such as meetings to discuss results, farm open days, presentations at symposiums). For each case, we systematically collected documents presenting the initiatives, their progress, and their objectives (slideshows, documents submitted in response to calls for projects, websites, minutes of meetings, articles, PhD theses, Bachelor's or Master's theses), as well as the written material (fact sheets, testimony booklets, articles) and videos that had been produced. We stopped the data collection once we started obtaining the same information several times (data saturation). In February 2018, we presented a cross-cutting analysis of the cases to the pilots over one day. The discussions and feedback were recorded to be taken into account in the second stage of the analysis.

The analysis of the cases began during the interviews, the observations, and the study of the written documents. It was based on successive iterations of analyses specific to each case and cross-cutting analyses, to shed light on and categorize convergences and divergences between cases, following the multi-thematic coding approach (Dumez 2013). The analysis was organized into three stages:

(1) We first retrospectively analyse each tracking process. The study of each case, and its comparison with the other cases, revealed common features of the investigation process. After exploring the intentions of the pilots when they embarked on their respective tracking projects, we endeavoured to identify the key stages of reasoning that structured the different tracking initiatives and their conditions of development. For each of these stages (e.g. unearthing innovations), we categorized the variations in their implementation (e.g. unearthing innovations using snowball sampling, exploring existing databases or social networks, etc.). We also categorized the agronomic content generated and formalized during the process according to its properties (e.g. nature of the agronomic content, medium of circulation).

(2) Based on our conceptual framework rooted in design science, we then sought to shed light on the tracking processes' contributions to the design of farming systems (i.e. their generative functions, Hatchuel et al. 2013). To this end, we first identified the type of design process to which the pilots were seeking to contribute when they implemented the tracking (e.g. co-design of a local farming system, design of farming systems by farmers scattered across the country, design of cropping systems to be tested on station). Through a retrospective analysis, we then highlighted how the tracking process and its results contributed to design activities (e.g. did it provide ideas to define the properties of an innovative farming system? Did it provide different options that could be used to envisage alternatives? Did it build new relations between designers seeking to collaborate? Etc.).

(3) Based on the results of the previous analyses, we built a typology (Dumez 2013) of innovation tracking strategies. First, for each case, we highlighted interconnections between the different stages of the tracking process (e.g. did different initial incentives to start the tracking affect the results produced?) and with the contributions to farming system design. We then looked for convergences and divergences between the cases, and to build strategy types, we grouped together the cases where the pilots had similar intentions across different situations, as well as similar implementation approaches and contributions to design processes.

3 Results

3.1 Common features of the innovation tracking approaches

The analysis of the 14 cases revealed five key stages—always iterative—that structured all the tracking processes (Figure 2). We detail these by tracing how each of the stages unfolded, as observed in the different case studies.

3.1.1 Defining an innovation tracking project: what are the pilots looking for?

The innovation tracking processes were initiated for a variety of purposes, and in different R&D contexts.

In some of the cases, tracking was initiated at the request of farmers who were experiencing problems that they were struggling to solve on their farms (e.g. weed management problems identified during a regional diagnosis in case 3). Sometimes, they were initiated when R&D actors identified an innovation concept with which they were not familiar (e.g. because it was very uncommon, or little expertise was available) but which they wanted to see developed in practice (e.g. multispecies intercrops, case 8). They thus undertook tracking to produce scientific knowledge and technical references to fuel farming system design in a region, or across France. These tracking processes were initiated by a few actors (two to eight), who chose to explore targeted innovations, related to specific on-farm techniques (e.g. species mixtures, case 1) or methods to manage a component of the environment (e.g. thistle in organic farming, case 13). As few stakeholders were involved, what they considered 'innovative' was defined according to their common frames of reference (e.g. the scientific literature; current on-farm practices in a territory).

In other cases, tracking was initiated to stimulate innovation in a geographical area: in response to a political injunction (e.g. to develop agroecology in a region, case 9), for developing a new service to farmers (e.g. to develop an initiative to get farmers to share their experiences with each other, case 6), and/or in support of on-farm design processes (e.g. to support the design of self-built equipment for organic and small-scale farming, case 10). These processes involved a variety of actors in the tracking's implementation (from 10 to several dozen partners, including advisors, supply-chain actors, etc.). With this type of initiative, the tracking was exploratory. In other words, unlike in the previous cases, the specific innovations to track were not pre-defined. The pilots wanted different stakeholders, with different frames of reference, to be involved in the tracking process and to pool what they considered innovative. In several cases, what constituted an innovation was defined only as different from dominant practices in the area, and in others, it was defined with reference to general principles (e.g. agroecological principles, case 7). As a result, the innovations identified were often subject to debate within the collectives. For example, in case 11, Guyot-Poussard pruning was not known and was deemed novel in Provence to manage certain diseases in vineyard, whereas it was known and more developed in the Bordeaux and Burgundy wine regions (Table 2). And, as the results of the tracking were to be national in scope, the stakeholders considered that this pruning method could be deemed innovative. In some of the cases, the pilots also wanted the tracking process to contribute to connecting farmers engaged in innovation processes (e.g. the tracking in case 10 aimed to build a nationwide network of farmers designing farming equipment).

Whether targeted or exploratory, we observed that the pilots always looked for innovations that were unknown to them and that they considered desirable for the future of farming (Table 2). In the different cases, the innovations studied related to basic techniques, crop management sequences, crop or livestock systems, farming equipment, or organizations.

We observed that, in most cases (1, 2, 6, 7, 9, 10, 11, 12, 13), the pilots collected and assessed innovations 'after their implementation on farm' (retrospective analysis of proven practices). In other cases (3, 4, 5, 8, 14), tracking was implemented over the course of the farmers' innovation processes (i.e. analysis of the innovations under development), and the pilots contributed to the process (e.g. giving feedback on the innovations assessed, or contributing to interpreting their effects and performance).

Based on their objectives and work contexts, the pilots chose to deploy tracking over different timeframes, often determined by their funding and the significance of this activity within the pilot organization (Table 1): 6 months to 1 year (cases 1, 2, 8, 11, 12, 13), or several years (cases 3, 5, 14). The end date was sometimes not set (cases 4, 6, 7, 9, 10). The pilots also chose to carry out the tracking in different geographical areas (Table 1), often informed by the missions of the pilot's organization, the objectives of the tracking project and the type of funding available: one region (cases 1, 3, 4, 5, 8, 9), several regions (cases 2, 6, 11, 12, 13, 14), or the whole of France (cases 7 and 10).

On an organizational level, the implementation of the tracking (e.g. identifying farmers, analysing innovations) involved between 10 and 100 actors, sometimes from a wide range of professions and institutions. The distribution of tasks between the partners was either centralized (cases 1, 2, 3, 4, 5,

Figure 2 The five stages that structured the tracking process, and different approaches to completing each stage, as observed in the different cases.

Tracking stage	No.	Different approaches to completing the stage	Cases concerned
1. Defining a tracking project	1.a.	Initiating projects around targeted concepts	1, 2, 3, 4, 5, 8, 12, 13, 14
	1.b.	Initiating projects around exploratory concepts and building new farmer networks	6, 7, 9, 10, 11
2. Unearthing on farm innovations	2.a.	Identifying farmers through word of mouth	1, 2, 5, 7, 8, 9, 10, 11, 12, 13, 14
	2.b.	Systematically monitoring innovation in known farmers' networks	3, 6, 8, 9, 11
	2.c.	Identifying new networks of farmers known to innovate	10, 12, 13
	2.d.	Identifying farmers through a database or social networks	12, 13
	2.e.	Inviting farmers to share their innovations	4, 9, 10, 12, 14
3. Getting to know innovations	3.a.	Conducting individual or group interviews	All
	3.b.	Observing innovations under development with farmers	3, 4, 5, 8, 14
4. Analysing learnings from the innovations	4.a.	Producing narratives of each innovation to shed light on the farmers' action logics	All
	4.b.	Assessing the performances of innovations	All
	4.c.	Understanding the agronomic processes that condition the performances of an innovation	All
	4.d.	Comparing variants of an innovation	1, 2, 3, 4, 5, 8, 12, 13
5. Generating agronomic content	5.a.	Testimonies	6, 7, 9, 10, 11, 12, 14
	5.b.	Repertoires of technical options	1, 2, 3, 8, 12, 13
	5.c.	Generic action logics	1, 2
	5.d.	Functional knowledge illustrated in practice	3, 5, 7
	5.e.	Decision-making rules	4

7, 8, 12, 14)—only a few actors guided the choices made and implemented the tracking tasks—or distributed (cases 6, 9, 10, 11, 13) among different actors with varying degrees of leeway in the implementation of certain tasks, depending on their institutions and working environments. For instance, in cases 1 and 2 (centralized processes), researchers defined the tracking target, contacted local advisors to unearth innovations, carried out interviews, and analysed the data gathered. By contrast, in case 11 (distributed process), partners from academia, advisory services, and technical institutes collectively defined priorities for organic vineyard innovation, and local advisors conducted interviews with farmers they spotted in different regions and shared the data with agents of technical institutes who analysed them and produced testimonies.

3.1.2 Unearthing on-farm innovations: how are farmers' innovations identified?

Once the choice has been made to focus on certain areas of innovation, these had to be sought out. All the pilots mentioned that farmers developing innovations were often hard to find, and that they had to develop different approaches to spot them (Figure 2).

i) In most cases (Figure 2(2.a)), the farmers were identified through snowball sampling, by asking targeted actors if they knew either farmers who were innovating or people who might know them (e.g. in case 1, by contacting advisory organic farming networks and going to markets, to find multispecies intercrops in vegetable production). In such cases, to leave room for surprise, the pilots often first asked the targeted actors a general question (e.g. in case 12, do you know innovative, original, or surprising practices to manage thistle in organic farming?). They then often specified their questions with predefined concepts of practices that they knew could surprise these actors (e.g. do you know farmers who manage thistle in organic farming without soil tillage?).

ii) In other cases, the pilots systematically searched for innovations across a geographical area, as in case 6 where, throughout the year, farming advisers were asked to spot innovations which, in their eyes, could help to renew regional agriculture (Figure 2(2.b)).

iii) Some pilots also explored farmer networks known to be innovative (Fig. 2(2.c)), as in case 12, where the pilots contacted the heads of a conservation agriculture network to identify farmers who managed thistle

Table 2 Quotes from interviews illustrating innovations discovered over the course of the tracking processes in different cases studied.

Cases	Quotes
Case 2	"The diversity of [the farmers'] objectives, and how they contrasted with the scientific literature, is something that surprised me (…). The second important finding was also the diversity of practices, of choices of species (…). In this first group, they didn't want to interfere at all between sowing and harvesting, so no mechanical weeding, no fertilizing, nothing, they sow, they harvest and nothing else, and yet they have high-value-added intercrops, grown to sell and they expect to make money from them."
Case 3	"Managing thistle by growing chicory, because chicory is actually a crop that is planted quite late and that is weeded, and weeded again, and again… We realised this one year when a plot had been split in two, on one side there was chicory and on the other side there was onion. On the chicory side, that's where, the first year, there was the most thistle, and the following year there wasn't any at all!"
Case 9	"He took over this farm, settled down and said, 'OK, 80 cows works for me, but I'm going to do group calving, and I'm going to make the most of the pasture', in other words, he grouped all his calvings in March! From March to June, the cows are milked twice a day. In June, he inseminates them and once they are in-calf, that is, confirmed one month later, he stops, he switches to once-a-day milking, so until December. At the end of December, he closes the milking shed, in January and February, there's no milking shed, it's quite something to see that in the Finistère!"
Case 11	"For example, there is a pruning method that helps fight diseases, (…) it's Guillot-Poussard pruning, which is making a real comeback, I say 'comeback' because it's actually an old trick, (…) For the advisors, the partners in Burgundy in the interviews, this method was often put forward as being interesting, (…) in Aquitaine, it came up several times (…) and in Provence nothing, no winegrower we met used this pruning method, so when we pooled all the novelties that seemed interesting to us, ultimately Aquitaine and Burgundy said that Guillot-Poussard pruning is starting to become more and more common, it's not very innovative… but in Provence they said 'no but here there's no one doing it, so we think it's great'."
Case 4	"The initial hypothesis shared by the group of farmers was that they needed to restore fertility in order to sustain the growth of the rapeseed and thus make it less vulnerable, and to break through the yield ceiling. You can't rely entirely on inputs that are only partially effective, so let's try to introduce nitrogen with legumes. Let's do some tests and see what happens."

without tillage in organic farming (practices unknown to them).

iv) In some cases, innovative practices and farmers were also identified exploring existing databases or social networks (Fig. 2(2.d)). For instance, in case 13, the results of an online survey were used to find farmers who said they successfully managed thistle and who had several years of experience to share.

v) Finally, in several cases, the pilots invited farmers to come forward (Fig. 2(2.e)), providing them with a platform for dialogue where they could share their innovation. This was the case of the website associated with case 10, where farmers could share their self-built equipment on a forum.

3.1.3 Getting to know innovations and innovation processes: what kind of information did the pilots collect?

This stage consisted in gathering data and acquiring knowledge from farmers, who virtually systematically agreed and were glad to share their experiences with others. In some cases, pilots got in touch with farmers they already knew, while others relied on intermediaries (e.g. advisors, researchers, sales representatives) and first made contact with the farmers over the phone. This initial call was often an opportunity to find out more about the innovations (useful information for preparing the upcoming meeting) and to get the farmers' consent to share their experiences. In all cases, the pilots carried out individual or collective interviews (Figure 2(3.a)), during which farmers were invited to explain what they had done—guided by questions from the interviewer or the group. Often, to triangulate and complete the information gathered, interviews were supplemented with observations, measurements, and discussions on the farm (e.g. field organization, crops implemented, equipment), during or after the implementation of the innovation (Fig. 2(3.b)). Some pilots also produced videos and photographs and collected documents tracing what had been done. In two cases (1, 12), the pilots used drawing as a medium to interact with the farmer during the interview (e.g. crop management steps in a timeline, spatial arrangements of fields on the farm).

What was reported during the interviews varied from one case to another? The conversations always took as a starting point the innovations that had already been tried and tested, or that the farmer was in the process of developing (e.g. multi-species intercrops, case 2; a farming equipment, case 10). To obtain information on systemic innovations, pilots often relied on agronomic concepts such as 'intercropping' (cases 1, 2, and 8) or 'crop management or cropping systems' (cases 4, 5, 12, 13), which provided them with heuristic markers to guide the conversation. The interviews revolved around questions regarding seven fields:

i) the facts and actions surrounding the innovation—either a basic technique or a system (e.g. 'What have you done? How?');
ii) the reasons or motivations for developing such an innovation (e.g. 'For what reasons did you develop it?');
iii) the agronomic processes involved in the functioning of the innovation (e.g. 'How did it work? How did these actions achieve these effects?');
iv) the assessment of the innovation (e.g. 'Are you satisfied with the results? How do you assess them?');
v) beyond the description of the innovation, other information—relating to other activities, the sector, the geographical area, the pedo-climatic and socio-economic context, etc.—was gathered in order for the interviewer to get to know the conditions of existence, development, and effectiveness of the innovation at hand, from the perspective of the farmer who had designed and implemented it;
vi) the pilots also often asked the farmers to retrace the innovation process, that is, the trajectory of change in their practices (cases 1, 3, 4, 5, 7, 8, 10, 11) (e.g. 'How did you arrive at these practices? Have you always done it this way?');
vii) some pilots also asked the farmers to outline their future projects, as well as share any advice they might have for other farmers willing to develop their innovation (cases 3, 4, 5, 7, 9, 10).

3.1.4 Analysing learnings: how do the pilots build evidence?

In all cases, the pilots analysed the innovation and the innovation process based on what the farmers told them. We defined four analytical categories corresponding to different objectives (Figure 2 and Table 3). As the pilots always discovered innovations that were unknown to them (and often to the scientific literature), the analysis involved mobilizing knowledge built on a wide variety of evidence, and the decision to use one source over another was at the discretion of the pilot (grey and scientific literature, colleagues' expertise, farmers' accounts, etc.).

Producing narratives of each innovation to shed light on the farmers' action logics (Table 3(4.a)) This work was carried out in 11 cases (Figure 2), to organize and prioritize what the farmer had explained. Such monographs highlighted the systemic relations that the farmers had established in their discourse, between their actions, their intentions and projects, their work environment, the effects they had observed, their assessment of what they had done, and their personal trajectory (Table 3).

Assessing the effects/performance of innovations (Table 3(4.b)) The pilots always sought to assess the effects/performances of innovations in order to demonstrate their value. To do so, they systematically relied on the farmers' assessment criteria and on their perception of the results. For instance, in case 11, regarding the innovation 'sheep in vineyards for weeding and stripping', the farmers concerned assessed their practices in terms of workload reduction during a busy time of year, ease of implementation, and the initial investments required. In several cases (4, 5, 6, 7, 10), the pilots supplemented the farmers' criteria with others to shed light on performance in terms of general interest considerations (e.g. impacts on the environment). In case 7, for example, the pilots used criteria such as greenhouse gas emissions, farm biodiversity (natural infrastructure, crop diversity, etc.), and levels of input use (nitrogen, phosphorus, water, etc.). In the different cases, the assessment involved indicators either proposed by the farmers (e.g. case 5, Table 3), already existing in the literature (e.g. case 7, using a range of digital agri-environmental indicators), or invented by the pilots (e.g. case 8, measuring weed development in a crop mixture). The assessment of the results (i.e. is it satisfactory?) was performed by the farmers and sometimes by the pilots as well (e.g.in case 11, the pilots compared the performance of innovations with that of more common practices—comparing the cost and quantities of pesticide applied using a sprayer from the industry, with one developed on farm).

Understanding the agronomic processes that condition the effects/performance of an innovation (Table 3(4.c)) In many cases (Figure 2), the pilots were surprised by what the farmer had done, or by his/her description of the results obtained. To better understand the functioning of each innovation, the pilots looked for and drew links between existing knowledge (e.g. models, expertise) and farmers' statements. For example, in case 11, the pilots drew on scientific and technical literature and expert opinions to shed light on the conditions under which adding a winter cereal in vine rows helped to improve the soil structure (Table 3). In some cases, this work allowed the pilots to formulate plausible hypotheses about the agronomic effects of the innovative practices. For example, in case 12, by comparing a model of the evolution of thistle root stocks with the period in which the farmer explained that he had topped this perennial in order to exhaust its reserves, the pilots established links that they had never made between a technique, the cycle of the weed, and an effect (topping at the flowering stage, exhausts root reserves and reduces weed population). Other times, however, they had no knowledge to compare with the effects of the innovation observed by the farmer. In such cases, some pilots made analogies or formulated new research questions.

Comparing variants in the operationalization of an innovation on several farms (Table 3(4.d)) Such analysis focused on identifying points of convergence and divergence between the innovations described in specific situations. This involved different analysis methods (Figure 2). The first consisted in analysing the variants of an innovation in different conditions encountered during the tracking (e.g. two instances of a permanent clover cover crop to manage thistle, in different conditions, case 12). The second approach consisted in building decontextualized models of action logics, describing how several farmers activated agronomic processes by articulating the same techniques (e.g. techniques to foster a physical barrier to the dispersal of pests in vegetable production intercrops, case 1, Table 3). The third approach sought to establish typologies of technical systems (Table 3). Finally, a fourth approach, observed in cases 1, 2, 8, 12, and 13, analysed both (i) different ways of implementing an innovation to fulfil the same objective (e.g. case 2, limiting the development of weeds in crop mixtures by working with densities, sowing dates and patterns, and the associated species and/or their development cycles) and (ii) different previously unknown ways of implementing an innovation (Table 3—different spatial arrangements of the species intercropped).

3.1.5 Generating and formalizing agronomic content for farmers and other R&D actors

In all cases, through tracking, the pilots generated agronomic content intended for a large number of farmers and, often, other R&D actors as well, always with a view to fostering innovation elsewhere (contributions to distributed design processes).

We identified five types of agronomic content (Figures 2 and 3):

Testimonies (Figures 2(5.a) and 3a) were drawn directly from the narratives describing the farmers' action logics (Fig. 2(4.a)) and the assessment of innovations, to capture the systemic logic informing a farmer's reasoning in his/her situation. In all these cases (with the exception of certain testimonies in case 11), the farmers' narratives included assessments of the innovation, functional knowledge linked to that innovation, its conditions of existence and effectiveness, and sometimes, tips to tailor the innovation to conditions other than those of the innovating farmer. These testimonies were produced to 'inspire' other farmers; they were formalized into written documents, shared in videos, or presented by the innovating farmers at open days on their farms.

Table 3 Illustrations of data associated with the four categories of analysis. These data are drawn from written documents tracing the results of the analysis (*) and interviews with the tracking pilots (**).

Analyses	Quotes
4.a. Producing narratives to shed light on the farmers' action logics	"[Innovation – flower strips] In 1991, the farmer established himself on the estate, which at the time was exclusively arboricultural. As soon as he arrived, he decided to rip out the old orchards and replace them with vines. (…) As the winegrower was already committed to respecting the environment, he decided to switch to organic farming. (…) The winegrower was looking to improve biodiversity in his vineyard by increasing insect populations and developing the biotope. With spontaneous grassing already in place across all the rows, he then opted to set up flower strips in his vines. Beforehand, he decompacted the soil to prepare for sowing, after the harvest between late October and early November before the traditionally rainy periods. At the beginning of March, he sowed a flower strip by hand every six rows. The winegrower went around his rows of vines planting a bucket-full of seed mix along each row. It took a good day's work to sow across the whole estate. He used a commercial mix of about 15 Mediterranean plants." (Case 11)*
4.b. Assessing the effects/performances of innovations	"Our work is based on farmers' statements, they provide us with the information, reliable figures; by carrying out the assessment [with computerized models], this will provide objective results on the performance of systems; it adds credibility to the system (…) when you look at agro-environmental indicators, it attests to real agro-environmental performance." (Case 7)** "When the farmer has given me an indicator to observe his system, I prefer it to my observations, or if he gave me this indicator and I know that there are biases that mean it's not always suitable, then I add another measurement to tell the farmer, you see there you had observed that it was good, but when I measure I find a different result, where does it come from, is it your indicator that's not good, or my measurement?" (Case 5)** "[innovation – integration of sheep in vine rows for defoliation] Financially, in this example, the initial investment can therefore be recovered within four years. However, this calculation does not take into account the working time needed to maintain the flock, which the winegrower was unable to estimate. Moreover, it is assumed that the farm has enough fodder to feed the herd all year round, as is the case here. The purchase of fodder supplement would represent a significant additional cost." (Case 11)**
4.c. Understanding the agronomic processes that condition the performances of the innovation	"[Concerning the rule: slow down tilling to limit geranium germination]. Here again it's things that have made a comeback because little by little, through observation, there are farmers for whom it worked and others for whom it didn't work so well. And we realised that those for whom it didn't work so well were going too fast, because there was a flow of earth (…). In the end, even with direct sowing, you can create a profusion of soil when sowing and so the geranium still starts to germinate. If you go very slowly, you really only work on your seed line without disturbing the soil at all, and when you don't disturb the soil, you don't stimulate weed emergence (…) we haven't done any speed tests but it's more by seeing all the farmers and seeing what happened that we gained this knowledge and so we're valorising it in the intercropping oilseed rape guide." (Case 4)** "For example, sometimes [the farmer] will explain: 'Well, yes, I have increased the rate of organic matter in my soils, so my soil water reserve has increased'. For us, the idea is to gently re-explain the link between the rate of organic matter and soil water reserve, causal links (…). When I don't see how it works from an agronomic point of view, I do research [in the bibliography, experts' reports]: it has happened many times. For example, it will say that there is a crop that attracts one pest more than another, things like that I'll look to see if it holds up in practice." (Excerpt from an interview, Case 7)**
4.d. Comparing variants of the same innovation	*Example of decontextualized modelling of an action logic.* The cross-analysis of species associations uncovered convergences in the technical principles used to limit the development of populations of phytophagous insects (e.g. two market gardeners created physical barriers at the centre of the covered area to prevent the spread of pests, the one using trellised beans, the other using tomatoes, by working with the sowing dates, trellising methods and planting densities to maximize the barrier effect). (Case 1)* *Example of a typology*. The pilots highlighted four types of crop management sequences for field crop intercrops, corresponding to farmers' different objectives and specifications. (Case 2)* *Example of the identification of different ways to implement an innovation*. The pilots discovered various spatial arrangements for intercropping vegetable species (e.g. rows, mixed rows, half rows), as well as diverse fertilization methods (e.g. each specie is fertilized separately, fertilization management is homogeneous in the tunnel). (Case 1)*

Repertoires of technical options (Figure 2(5.b)), established by comparing variants in the operationalization of an innovation across several farms, provided an overview of options, organized in such a way as to reflect the range of techniques mobilized by farmers to reach a particular objective. In some cases, methods for implementing these techniques were also described (e.g. Figure 3b). These repertoires, built on the innovations tracked, provided the farmers addressed with an overview of a range of known options that could be implemented to achieve specific objectives.

The generic action logics (Figure 2(5.c)) generated in cases 1, 2, and 12 were conceptual models of combinations of techniques which, mobilized together, activate certain agronomic processes in the field (e.g. fostering a physical barrier to the dispersal of pests with a species mixture, Figure 3c). They provided decontextualized combinations of actions, which could help a farmer to think about the activation of a process in their own situation. These generic action logics were the output of a comprehensive analysis of the innovations (Fig. 2(4.c)), often based on comparisons (Fig. 2(4.d)).

Functional knowledge illustrated in practice (Figure 2(5.d)), gained by understanding the agronomic processes that condition the effects of an innovation, focused on a component of the agro-ecosystem to manage (e.g. organic matter, case 5; perennial weeds, case 3). The functional knowledge presented in writing was coupled with examples of farmers' innovations which, according to the pilots, allowed for sustainably managing this component of the environment (e.g. Figure 3). This content was circulated to help farmers understand how certain components work (decontextualized knowledge), while showing them how some farmers had used that information to change their practices.

Decision-making rules (Figures 2(5.e) and 3e) combined technical options with conditions of production (e.g. tools, soil, climate) to reach performance objectives. These predictive rules followed the formalism 'if (conditions met), then (action)' and were formulated in such a way to be applied by a farmer based on his/her situation. Most of the time, they related to basic techniques.

3.2 Six contributions of innovation tracking to farming system design

Our analysis of the interconnections between tracking and design processes, across the cases revealed six contributions of tracking to the design of farming systems (i.e. six generative functions).

3.2.1 Giving rise to creative anomalies

In all cases, the study of farmers' innovations gave rise to creative anomalies, which had the effect of renewing the pilots' representations. In other words, the discovery and analysis of innovations tried and tested on farms highlighted the pilots' fixations (i.e. cognitive biases that cause a person to only consider certain options when innovating) and fostered profound change in their representations of the management of certain farming systems. Moreover, this process opened up and led to further exploration of new fields of knowledge and/or new fields of innovation. For example, in case 12, while tracking thistle control strategies in organic farming, the study of on-farm innovations revealed that some farmers considered that these perennials could be helpful (e.g. as indicators of the agro-ecosystem status, a shelter for auxiliaries, or a source of fodder). This finding revealed that, in their cropping system design activity, the pilots implicitly thought of thistle as a pest to be destroyed. This observation led the pilots and their partners to refocus their design project from 'managing these perennials as pests to be controlled' to 'living with these perennials because they could be useful'.

3.2.2 Uncovering new research questions, the exploration of which could fuel future design processes

In all cases, the pilots explained that, when analysing innovation processes, comparing farmers' accounts with available agronomic knowledge enabled them to identify knowledge gaps. In other words, they found that no publications (scientific or grey literature) offered information that corroborated what the farmers explained. In some cases, as they knew that answers to these questions could fuel design processes on other farms, the pilots formulated new questions that they themselves explored or that they passed on to research organizations. For example, in cases 11 and 12, respectively, after studying on-farm innovations, the pilots asked themselves: 'through which mechanisms does spraying horsetail preparations promote the healing of vines after hail?', and 'when thistle is topped—which seems to exhaust its underground reserves—is a branching effect always observed and under what conditions?'.

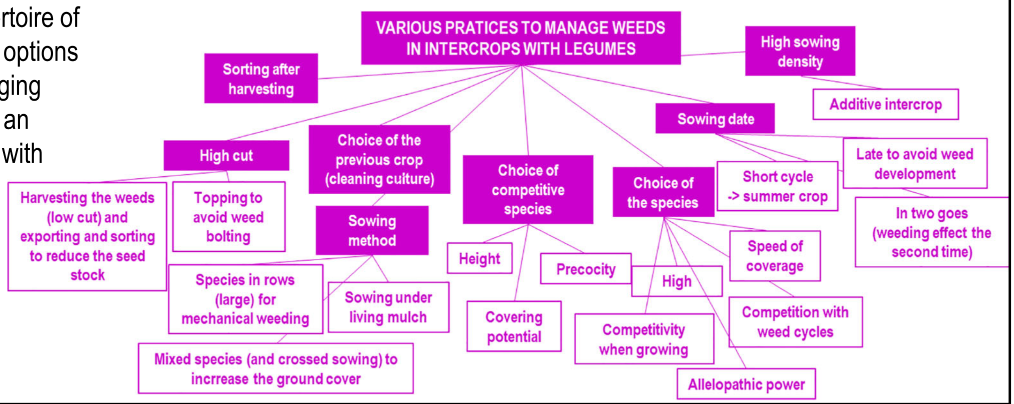
3.2.3 Highlighting systemic links between techniques, agronomic processes, their conditions of implementation, and their performance to fuel the design of other farming systems

In all cases, the pilots discovered innovations that were unknown to them, and their analysis highlighted new systemic links between techniques, performance, and farmers' working conditions. These systemic links constituted a resource, which the pilots accumulated to fuel farming systems design. To foster distributed design processes, they freely circulated this

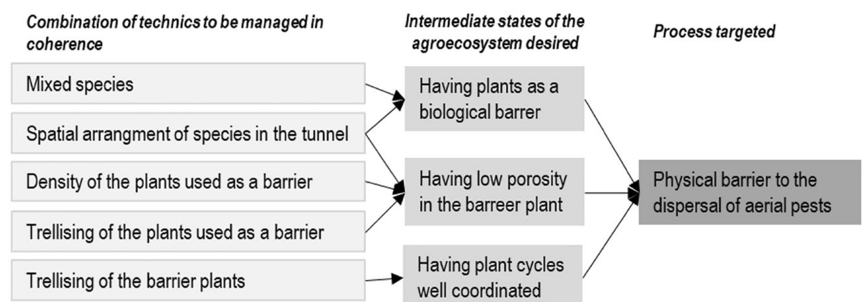
a) Excerpts from the testimony of a farmer who used sheep for grass management and defoliation in vines

“This farm has been run in organic farming since 1988. (...) When the winegrower arrived, the main problem was grass management because he had little equipment available. He invested in second-hand equipment as he went along, but it proved to be poorly adapted to the different planting densities in his fields. Looking for the preservation of biodiversity and animal/plant associations, the winegrower tried to find solutions to his grass invasion problems using farm animals. (...) During the winter of 2010-2011, sheep were gradually installed in the vineyards. At the beginning, the livestock was composed of about ten animals and then reached 25 heads. (...) On most of his plots, every second row is grassed. The grassed row is mowed during spring, while he uses minimum tillage in the other. (...) The integration of sheep in the vineyards involved numerous changes and investments (...) In addition to the "efficiency" of the sheep in managing the grassing, the winegrower also benefits from feeling less stressed and overwhelmed at the end of the winter.”

b) A repertoire of technical options for managing weeds in an intercrop with legumes



c) A generic action logic to promote the process of a physical barrier to the dispersal of pests in protected vegetable intercrops



d) Excerpts about functional knowledge illustrated in practice, on the theme of organic waste management

Functional Knowledge - "Organic Residual Products (ORP) refers to effluents from livestock, agro-industrial and urban areas that are used in cultivated fields. They contain two nitrogenous fractions: one is mineral, in the form of ammonia (NH3) or urea which is easily assimilated or volatilized; the other is organic (COMIFER, 2013). The effect of ORPs depends on their composition and in particular on the total Carbon/Nitrogen (C/N) ratio. The lower this ratio is, the quicker the nitrogen will be available. (…) NB: The lignin and cellulose content of PRO also conditions its degradation. Lignin is very complex, therefore more difficult to degrade than cellulose. When to use ORP with C/N > 8 ? The degradation of these ORP requires bacteria (…). »
Illustration of the use of this knowledge in practice - "At the farm *de La Poste*, bull calf rearing produces 6,000t of manure per year, mainly for beet fertilization. They have chosen to compost this manure to make the nutrients more available. They bring it in after collecting straw and before sowing mustards in interculture (rapid development and high nitrogen absorption). (…) the cover absorbs the nitrogen remaining after the wheat harvest and the nitrogen coming from the mineralization of the compost, to return part of it to the beet. They are also thinking about fertilizing spring barley with highly decomposed manure after winter. (…) »

e) Decision-making rules

	Cereal seed drill (with single hopper)	Monograin seed drill (with microgranulator)	Double hopper seed drill (cereal or monograin)
Sowing od oilseed rape and legumes (1 run)	All grains apart faba bean mixed with oilseed rape	Small grains only (clover, lentils etc.) ditributed with the microgranulator	All grains, even faba bean, in the hopper; the second hopper is dedicated to oilseed rape
Sowing of legumes then oilseed rape (2 runs)	All grains, even faba bean, sowed during the first run; the second run is dedicated to oiseed rape		Non justified

◀ **Figure 3** Illustrations of the five types of agronomic content generated over the course of innovation tracking projects. Box **a** shows excerpts from the testimony, case 11 (Petit et al. 2018). Box **b** presents a repertoire of technical options, case 2 (Jeuffroy et al. 2018). Box **c** presents a generic action logic, case 1 (Dupré 2015). Box **d** presents excerpts about functional knowledge illustrated in practice, case 5. Box **e** presents a decision-making rule concerning the type of seed and distribution recommended based on the seed drill and sowing method used in rapeseed-frost-sensitive legume associations, case 4 (Cadoux and Sauzet 2016).

content through websites, newspapers, newsletters, public presentations, and/or courses. For instance, in case 1, repertoires of options for the arrangement of different vegetable species in a shelter, and their assessment by the farmers, provided alternative options for the design of market gardening cropping systems based on intercrops. In case 2, the analysis of the convergences between species mixtures encountered on farms revealed that all farmers who established species mixtures that cover the soil well (e.g. intercrops with forage pea, or with more than two species), and increased seeding densities, weeded less often. The pilots, therefore, proposed to combine a high density, a high number of species, and competitive species to reduce weeding, a time-consuming technique, especially in organic farming (Lamé et al. 2015).

3.2.4 Stimulating design in orphan fields of innovation

In orphan fields of innovation (i.e. little explored in R&D), some pilots (cases 9, 11) used innovation tracking as a way to orient R&D work based on what was starting to be explored and tested by certain farmers. For example, in case 9, the pilot initiated innovation tracking when he was put in charge of developing agroecology within his department. Given the multitude of R&D directions available, he set up an information-exchange network for innovative farmers which, according to him, provided an 'innovation breeding ground'. This network of farmers thus helped local R&D to establish their research agenda on the topic of 'agroecology', and farmers' practices demonstrated what could be done in this orphan field of innovation.

3.2.5 Connecting geographically scattered farmer-designers

In several cases (cases 6, 7, 9, 10), the purpose of tracking was also explicitly to contribute to building new networks of farmers innovating with their farming systems. To this end, the pilots set up mechanisms to enable the farmers they had identified to make themselves known, to meet, or to make contact with each other. For example, in case 10, the pilots provided an interactive map on their website showing the contact details of farmers and the agricultural equipment they had designed on their farms (https://www.latelierpaysan.org/Cartes-des-autoconstructeurs). In case 9, the pilots helped farmers connect by organizing annual forums, where farmers presented their innovation process to a wide audience, and by publishing a magazine (http://www.bretagne.synagri.com/synagri/la-revue-des-agri-novateurs%2D%2D-edition-2016).

3.2.6 Circulating innovation concepts to give designers in other contexts ideas

In all cases, the pilots shared innovation concepts with farmers and other R&D actors, reporting on innovations which they could not necessarily appraise or understand, but which they still considered desirable for the future of agriculture. In so doing, they sought to attract the interest of other farmers who might test and even improve the concepts they shared. Many of the testimonies circulated related to innovation concepts, such as the sheep used in a vineyard's inter-rows to defoliate the vines and control grass cover (case 11) or the use of animal traction, for animal-powered tillage in vineyards (case 7).

3.3 Three strategies for tracking innovations in design processes

In this section, we present three innovation tracking strategies that emerged from a cross-cutting analysis of the 14 cases studied (Table 4, Figure 4).

3.3.1 Strategy 1—targeted tracking of proven innovative practices

These tracking processes focused on targeted innovations (e.g. intercrops with legumes, ways to manage thistle in organic farming) in a context where the scientific literature or local advisors only considered a few methods to implement a technique (e.g. scientific knowledge on crop mixtures focused on pea with wheat or barley, case 2) or concentrated on a specific problem (e.g. controlling weeds as pests, case 12). In that context, tracking innovations aimed to renew and enrich the scarce knowledge about these targeted innovations. The process gave rise to creative anomalies: what was discovered on farm challenged and caused a shift in the pilots' representations of the technique (e.g. whereas, in the scientific literature, crop mixtures in market gardening generally include two different species, farmers associate up to seven different species, case 1) or of the ways to approach a problem to be managed (e.g. from perennials as pests to perennials as helpful, case 12).

In some of these tracking processes, all tasks were centralized among two to three actors (Table 1). They agreed on what innovations to look for and decided to study them after they had been implemented and assessed by farmers. These tracking initiatives were carried out within short timeframes (about

6 months), to rapidly gain knowledge about the innovation with which they wished to support the design on other farms. The pilots identified farmers through snowball sampling, exploring networks of farmers known for innovating. As their tracking was targeted, they were also able to find innovations through databases and social networks. Since the innovations shared a common base (a technique, a component of the environment), the pilots were able to conduct cross-cutting analyses and generated generic action logics (highlighting new systemic links— sect. 3.2.2.) and/or generated repertoires of technical options. The farmers interviewed were sent written feedback about the results of the analysis, and sometimes, they were invited to project meetings on the topic explored in the tracking.

3.3.2 Strategy 2—targeted tracking of innovations under development

By contrast, other tracking processes followed a twofold objective: to foster innovation processes under development on several farms and to use the learnings about the process and the innovation to generate generic agronomic content addressed to a wide range of farmers.

These tracking initiatives also focused on targeted concepts and lasted at least 3 years. Real-time discussions both among farmers and with the pilot, as well as their observations of the agroecosystem, helped to explore and hierarchically organize knowledge useful for understanding and evaluating the interactions between techniques, the socio-ecological context, the processes involved, and their effects. Thus, both the pilots and the farmers benefited from the analyses, and the latter was able to use them to decide on how to proceed in the following year (co-design process). Based on what they learned, the pilots generated generic agronomic content such as decision-making rules or functional knowledge, which they illustrated with examples of successful innovations. As a result, these tracking process helped both the pilots and the farmers to uncover new knowledge that could be mobilized in the design of agricultural systems. Furthermore, these tracking processes served to give rise to creative anomalies and to uncover new research questions.

3.3.3 Strategy 3—exploratory tracking of proven innovative practices

The third strategy differed from the first two, insofar as the tracking was exploratory and aimed to explore new innovation fields (e.g. agroecology in Brittany, case 9; innovation in organic winegrowing, case 11). These exploratory processes contributed to developing orphan fields of innovation by shedding light on innovations that could be further investigated in R&D projects and contributed to building innovation networks, by connecting geographically scattered farmer-designers and circulating innovation concepts.

Table 4 Three innovation tracking strategies. The rows show the five steps that structured the tracking approaches and their contributions to design processes, while the columns detail the implementation of each strategy.

	Targeted tracking of proven innovative practices	**Targeted tracking of innovations under development**	**Exploratory tracking of proven innovative practices**
1. Formulating a tracking project	Targeting a particular innovation already proven	Targeting a particular innovation under development	Exploring widely proven innovations
2. Seeking out farmers	Snowball sampling, identifying new networks of farmers and use of databases	Snowball sampling, inviting farmers to share their innovations	Systematizing an innovation monitoring system, inviting farmers to share their innovations, snowball sampling
3. Getting to know the innovations	Individual interviews about proven practices	Interviews and field observations before, during and after the implementation of innovations	Individual or group interviews on proven practices
4. Analysing innovations	Writing narratives, assessing performance, understanding agronomic processes, comparing variants	Writing narratives, assessing performance, understanding agronomic processes, comparing variants	Writing narratives, assessing performance, understanding agronomic processes
5. Generating agronomic content	Generic action logics, repertoires of technical options	Functional knowledge illustrated in practice, repertoires of technical options, decision rules	Testimonies
Key contributions to design	Giving rise to creative anomalies, shedding light on new systemic links, uncovering research questions	Highlighting new systemic links, raising new research questions, giving rise to anomalies	Developing an orphan innovation field, connecting farmer--designers with each other, circulating innovation concepts
Cases	1, 2, 12, 13	3, 4, 5, 8, 14	6, 7, 9, 10, 11

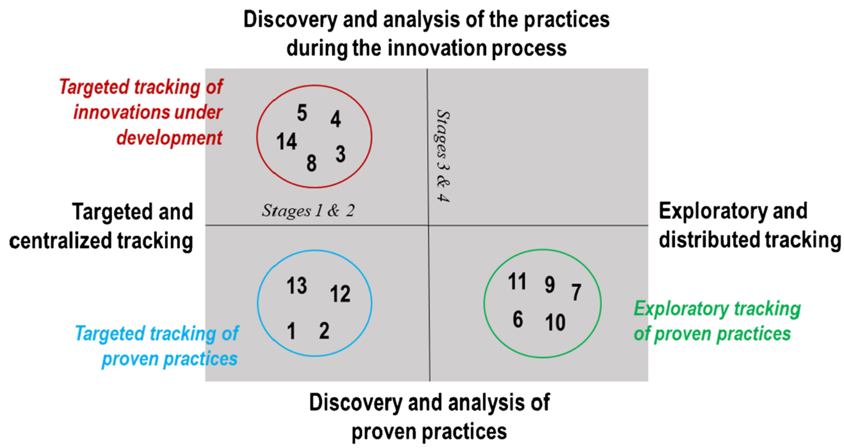


Figure 4 This figure visually captures the contrasts between the three strategies which differ, along the *x*-axis, in the formulation of the tracking project (targeted or exploratory) and the organization of tasks (centralized or decentralized), and along the *y*-axis, in the ways of gaining knowledge about and analysing the innovations, whether proven or under development.

In these processes, the tasks were often distributed among many actors, who studied innovations that had already been tried and tested by farmers, and within long-term projects, the innovations were often monitored over several years. Innovations were identified through snowball sampling, by systematically monitoring a network of known farmers and/or inviting farmers to share their experiences. What constituted an innovation was often subject to debate, given the diverse frames of reference of the actors involved in the identification process (e.g. agricultural advisers, researchers). In these tracking processes, the pilots shared the goal of circulating innovation concepts informed by what they had discovered, and they produced testimonies based on their accounts of their experiences. In several cases, these accounts were supplemented with evaluation results, insights into systemic links between techniques, environmental conditions, agronomic processes and effects, and tips for adapting innovations to other conditions.

4 Discussion

4.1 Tracking farmers' innovations: a particular way of studying farmers' practices

The current multiplication of initiatives in French agricultural R&D, on which this article is built, provides a testing ground for the development of approaches we proposed to call 'farmer innovation tracking'. The present research contributes to the theorization of these approaches, which are still little known in the literature. We here discuss four dimensions of our findings in this respect.

1. Innovation tracking aligns with the approaches developed since the 1970s in the Farming System Research community (Byerlee et al. 1982; Biggs 1985; Zandstra 1979) and built around the drive to recognize both the diversity of on-farm practices and farmers as innovators (Chambers et al. 1989; Seyfang and Smith 2007). Innovation tracking differs in at least two ways from other approaches developed in this community. In standard on-farm studies, R&D actors seek to study the more frequent on-farm practices, or their diversity, and when they encounter unconventional, deviant practices, it is merely by chance. By contrast, the objective of innovation tracking is from the outset to discover practices that are singular, unknown, and desirable, and this approach involves steps to identify the innovations farmers to seek out.

2. Our results reveal common features of innovation tracking processes and shed light on three implementation strategies. These results make it possible to revisit other farmer innovation tracking processes explored in the literature, which are all organized according to the five stages we have described, and can be linked to the three strategies identified (e.g. Salembier et al. 2016; Feike et al. 2010; Blanchard et al. 2017, and Verret et al. 2020—targeted tracking of proven practices; Elzen et al. 2017—exploratory tracking of proven practices). Some of these tracking processes also reveal other implementation approaches (e.g. Modernel et al. (2018) and Adelhart Toorop et al. (2020) used statistical tools to identify 'positive deviant farms'). At the same time, these results show that there is no right way of tracking innovations; rather, the approach followed should be tailored to the objectives and institutional contexts in which it is deployed (as also observed by Klerkx et al. 2017, about co-innovation approaches). Our results offer heuristic markers for actors who might wish to mobilize farmer innovation tracking in different contexts in the future; each of the five stages provides a space for these actors to imagine different ways of unearthing innovations, understanding them, analysing them, etc. The logics guiding each of the three strategies could also inspire future tracking.

3. The approaches we studied centred around agronomic R&D. Earlier research from the social sciences proposed complementary approaches for studying innovation processes (e.g. Klerkx et al. 2010; Djanibekov et al. 2012) on the scale of AIS, food systems or sectors, and from a non-agronomic perspective (e.g. taking into consideration the articulation of institutional, social, and commercial changes). In our results (sect. 3.1.4), we show that tracking pilots strive to take into

account the social or institutional dimensions of innovative farming systems, with a view to understanding the reasons and conditions for their development and effectiveness. To this end, they ask questions such as 'for what reasons did you develop this practice? What are the conditions for its development, or effectiveness?'. The information related to commercial, institutional, or even social issues is then merged into narratives, provided it was mentioned by the interviewee but without reference to associated theoretical underpinnings. As several authors have argued (e.g. Jansen and Vellema 2011; Duru 2013), a social science perspective would enrich agronomic approaches, and particularly tracking farmer innovation (e.g. Penvern et al. 2019).

4. Finally, our results confirm that the definition of what constitutes 'innovation' is not consensual, thus echoing the observation by Le Masson et al. (2006) that 'the notion of innovation has no inherent meaning, and faced with an innovative proposition, two observers will have varying judgements'. Innovation tracking raises two questions: who defines what constitutes an 'innovation' and an innovation process? And how? Our results show that there is no right way to define what 'innovation' is; it is a choice made by the stakeholders, based on their frames of reference (e.g. scientific literature, dominant practices in a geographical area, a farmer's practice on his/her own farm) informing what, according to them, is unknown and desirable for the future of farming. They also highlight that, since tracking involves a variety of actors, this choice is often subject to debate. For future tracking processes, our results call for reflexivity in the choice of what to consider as 'innovation' based on the intended end use of the results of the tracking (e.g. who should be involved to define what is innovative, if the goal is to stimulate innovation in a given geographical area? And what about when the purpose of the tracking is to change historically inherited scientific representations?).

4.2 The contributions of farmer innovation tracking to the design of farming systems

Our results show that, in contexts where different stakeholders need to change together in order to innovate (e.g. agricultural advisers, farmers, researchers), innovation tracking contributes to the design of farming systems in different ways.

By giving rise to creative anomalies (we borrow this concept from Fallen 2012), tracking helps to shed light on the cognitive deadlocks induced by the productivist paradigm (Vanloqueren and Baret 2009) and fosters the emergence of alternative approaches to crop management or farm organization. Tracking thus contributes to challenging the representations of the actors involved in design processes, a key mechanism for driving creativity and exploring alternatives, as shown by Jansson and Smith 1991 (these authors speak about going beyond design fixations). As some of the pilots interviewed pointed out, this mechanism is all the more significant with tracking, as the innovations that give rise to these anomalies are being or have already been tried and tested by farmers, in 'real situations'.

By developing orphan fields of innovation in R&D work and identifying new research questions, innovation tracking also helps R&D actors to determine their priorities, based on new expectations among farmers, and building on what some have already started to explore on their farms. This process thus allows for identifying what Ansoff (1975) calls weak signals, which can serve as a basis for developing innovative R&D programmes. Shedding light on systemic links—between techniques, their conditions of implementation, agronomic processes, and their performance—also opens avenues for further research and design. We should note that the other approaches for the study of practices, such as agronomic and agrarian diagnosis, also foster such systemic functional links (Doré et al. 1997; Cochet 2015).

Through the circulation of knowledge and of innovation concepts, and through the creation of farmer-designer networks, our results show that the innovation tracking approaches we studied contributed to stimulating open and distributed innovation processes (Chesbrough and Bogers 2014; Von Hippel 2005) in agriculture, with farmers considered no longer solely as end-users of R&D propositions, but as designers of farming systems (Joly 2017; Klerkx et al. 2010; Prost et al. 2016; Berthet et al. 2018). Tracking approaches contributed to circulating agronomic content (e.g. testimonies, generic action logics) to stimulate design on other farms.

Several tracking pilots offer examples of what Klerkx (2020) calls 'grassroots advisory movement[s]', which 'develop in response to transitions which are induced from the bottom up'. Tracking pilots are vectors of innovation experiences, and we observed that this process often relies on digital technologies (such as forums, digital platforms, websites). As a result, R&D services move closer to what Le Masson and Weil (2016) call conceptive research and development, that is, R&D which contributes to supporting design capabilities among agricultural innovation systems. As mentioned by Keating and McCown (2001), this role challenges the standards of production of agronomic knowledge. The role of R&D organizations—particularly advisory services—is, thus, not just to produce validated and stabilized knowledge or models predicting the effects of techniques; we observed that they also circulate innovative ideas, knowledge built on few cases, hypotheses, intuitions, etc., to contribute to fostering innovation in different contexts. This observation captures the transition, described by Salembier et al. (2018), from 'a decision-making paradigm' in which agronomy supports farmers' decision-making—i.e. helps them to find the best existing techniques to reach an expected effect—towards a 'design paradigm', where farmers are considered designers and thus use different resources to imagine and test solutions, gain knowledge, explore alternatives, etc., regarding their own farming systems.

4.3 Agronomic content based on on-farm innovations, intended for farmer-designers

There is now an abundance of agronomic content being circulated by agricultural R&D to support the evolution of farming systems towards greater sustainability, but little is known about the diversity of this content and how it is developed (Meynard 2014). Two contributions of the present work consist in shedding light on (i) the characteristics of content, which, to our knowledge, have been little described in the literature and (ii) the relationships between tracking approaches and the types of content produced.

The first type of content consists of *decision-making rules*, the best-known prescriptions in agronomy at present. These decision-making rules are usually produced through controlled experiments, which make it possible to repeat observations in time and space and produce predictive prescriptions using models (Keating and McCown 2001). Case 4 challenged this standard, since the pilots generated rules based on singular cases. In other words, they considered that a few observations—without statistical evidence—were sufficient to formulate decision-making rules (e.g. Figure 2(2.e), recommended types of seeds and distribution based on the seeder and sowing method used). This result raises questions about the future of 'decision-making rules', and their interests and limits within the emergent 'design paradigm' (e.g. In which conditions do they contribute to farming system design? How can they take over uncertainties inherent to agroecological farming systems?).

Other types of content are intended as resources to help tailor an innovation to another situation, by stimulating the imagination: such content is based on original combinations of contextualized and decontextualized knowledge. Girard and Magda (2018) speak of a balance between the generic and the situated. This is the case of *functional knowledge illustrated by practices*, whereby practical cases are used to illustrate agronomic processes presented out of context (e.g. the functioning of organic matter). As Goulet (2017) points out, *testimonies* often show how farmers establish systemic relationships between their projects and experiences, their production situations, their actions, what they observed, the evolution of environmental conditions, etc. They capture the systemic logic of farmers' practices in their respective situations. Some testimonies are coupled with knowledge that specifies the conditions under which a farmer's situated actions have similar effects (the conditions of extrapolation, as mentioned by Sebillotte 1978), or even technical alternatives. Agricultural journals, the technical services of R&D organizations, and authors of websites are increasingly publishing written testimonies by farmers. Our results show that they involve knowing how to write narratives, by organizing and prioritizing the systemic relationships put forward by the farmer in their discourse. Written testimonies are the most common way of making these innovation processes and innovations rapidly available to other farmers. However, to our knowledge, more research is needed: (i) to map and compare the different types of testimonies that exist (e.g. videos, writings), (ii) to develop rules for writing or recording testimonies (e.g. informing users on the robustness of the hypotheses formulated by farmers), and (iii) to investigate how such narratives are used by farmers to implement change, or by agricultural advisors to support such change (as well as their articulation with demonstrations, e.g. Adamsone-Fiskovica et al. 2021).

These combinations of generic and situated knowledge are also found in *repertoires of technical choices* and *generic action logics*. Both are based on the comparative analysis of innovations encountered on diverse farms and assume that the user has the skills required to draw from the alternatives and tailor them to their situation. These two types of content are also informed by systemic reasoning: the repertoires rely on identifying relations between a targeted objective and a diverse range of associated technical responses, found in different innovations, while generic action logics derive from a hierarchical organization of techniques which, combined, can be used to manage a specific agronomic process (e.g. a physical barrier to the dispersal of pests).

Irrespective of the R&D tracking pilots, we observed that, when analysing innovations, all of these actors mobilized bodies of knowledge from a range of sources (scientific publications, grey literature, expert opinions, etc.). This observation raises questions that have received little attention in agronomy (Doré et al. 2011), on the use of different sources to build evidence (Which sources to choose? For what? Can knowledge from different sources be given the same weight? How to inform the users on the evidence-building process? Etc.).

5 Conclusion

This article proposes a theoretical framework for farmer innovation tracking as an approach to unearth and study farmers' innovations and highlights the value of this approach for fostering the design of farming systems. It does not provide a turnkey method, but it brings to light concepts, mechanisms, and points of reference for actors who might wish to mobilize farmer innovation tracking in different contexts in the future. At present, however, R&D initiatives that mobilize innovation tracking remain a minority. The pilots we interviewed often stressed the difficulties they encountered in getting the value of this approach and the generic agronomic content generated (considered less ‘scientific’) recognized, and in gaining authorization from their superiors to implement such an approach. This is despite the growing injunction, in many calls for projects and public policy documents (e.g. EIP-Agri EU; H2020 ‘fuelling the potential of advisors for innovation’), to rely on farmers’ innovations. This work adds another building block to help develop tracking projects in different contexts and supports the institutionalization of this approach by recognizing its generative capabilities and shedding light on the wealth of knowledge production processes it involves.

Our findings point to questions and issues that will need to be carefully addressed by any actors who might decide to engage in such studies in the future, such as the benefits for the farmers interviewed, the recognition of the origin of contributions, transparency about the use of the results, and reflection about who to involve in the definition of what is considered innovative (Briggs 2013).

At least four research pathways emerge from this work. The first would be the study of the uses (by farmers and R&D actors) of the agronomic content circulated. In line with earlier research (e.g. farmers as advisors and demonstrators, Adamsone-Fiskovica et al. 2021; Klerkx 2020; support for inquiry in transitions, Slimi et al. 2021), the second pathway would involve exploring whether and how farmers track innovations on other farms, and the role of R&D actors in these processes. A third avenue would be the investigation of whether and how the farmer innovation tracking processes we studied could be tailored to other types of innovations within and beyond the farming sector (how to track forms of organization, breeding systems, public policies, etc.), and how this investigation could benefit from cross-disciplinary approaches (particularly with the social sciences). Finally, this research opens up a new field of inquiry in agronomy: the contributions of agronomic approaches to the design of innovative agricultural systems. While previous research has implemented tracking approaches to study farmers’ innovations, in this article, we studied approaches developed by different R&D actors to track farmers’ innovations, with a view to fostering the design of other farming systems. The conceptual framework and the research method deployed in this work (sect. 2) could be remobilized to study the contributions of other approaches in agronomy (e.g. diagnosis, design workshops, experiments), to clarify and enrich their use in farming system design processes.

Acknowledgements We are deeply grateful to all the farmers who developed innovations on their farms and agreed to share them in these tracking processes, and to the people whose work contributed to the 14 initiatives we refer to in the article—Gilles Sauzet (Terres Inovia), Florent Rodot, Gautier Vancleenputte, Marie Dupré, and Alice Lamé.

This work was carried out under the umbrella of the Initiative for Design in Agrifood Systems (IDEAS). We would like to thank Michel Duru, Sylvain Lenfle, Marion Casagrande, Julie Labatut, Thierry Doré, and Christian Huyghe for their very rich feedback on this research. We extend our gratitude to the two anonymous reviewers and the associate editor for their rich comments and suggestions, which significantly helped us improve the article. Finally, we warmly thank Nonta Libbrecht-Carey for editing the English version of this article.

Authors’ contributions Conceptualization, C.S., B.S., B.W., and J.M.M.

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Writing—original draft, C.S.

Writing—review and editing, C.S., J.M.M., B.S., M.H.J.

Funding acquisition, C.S. and J.M.M.

Supervision, J.M.M.

Funding This study was funded by INRAE’s Science for Action and Development (SAD) division, and by the French Environment and Energy Management Agency (ADEME) for Chloé Salembier’s PhD grant (Salembier, 2019) and the Eco3vic project.

Data availability The datasets analysed during the present study are available from the respective authors on reasonable request.

Declarations

Ethics approval and conflict of interests The authors hereby declare that they have complied with ethical standards and have no conflicts of interest.

Consent to participate and for publication The participants to the study were informed about the conditions and purpose of the research. Verbal informed consent was obtained prior to the interviews.

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