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Abstract

This article reports on the long-term involvement of research agronomists in a design process of agricultural systems in a water catchment area. While agriculture is facing increasing challenges to meet current societal expectations, several studies in agronomy have focused on the design processes that allow farmers to change their agricultural systems. Most of these processes have been dedicated to designing target agricultural systems but, more recently, several studies have acknowledged that agro-ecological practices replace farmers as the actual designers of their own production systems. In this context, how can agronomists support such design processes? How does a better understanding of these processes challenge the inputs that research agronomists can propose, to support them? We contribute to answering these questions by reviewing a case study of

a design process supported and analyzed by research agronomists over several years. This case illustrates that the design of agricultural systems is a process that exceeds invention: the implementation of the initial design solutions produces information that should be used to review those same solutions, in order to reach the design goal. The case study shows that the design process depends on a tension between the exploration of an ambitious desirable future and its actual implementation. To foster dialogue between “desirable” and “actual”, we show how the researchers involved in this case provided a range of inputs that supported typical design activities (grounding, fostering design reasoning, reinterpreting this reasoning, and design strategy throughout the process), thus opening new avenues of research in agronomy.

Keywords

Participatory design, innovation, agriculture, water catchment area, design process, longitudinal study

1 Introduction

The literature on agricultural innovation processes has significantly increased with the contemporary challenges that agriculture is facing to meet current societal expectations. A significant number of research studies, mainly by social scientists, have focused on the renewal of agricultural systems (for a review of these studies, see for instance Klerkx et al., 2012). Having shown that innovation is the result of “multiple interactions between components of farming systems, supply chains and economic systems, policy environments, and societal systems” (Klerkx et al., 2012), they have called for a systems innovation approach (Klerkx et al., 2010; Lybbert and Sumner, 2012; Coudel et al., 2012; Lamprinopoulou et al., 2014). But what has agronomy’s contribution to the research on agricultural innovation been? While some research agronomists have started to take on board this challenging systemic approach (e.g. Meynard et al., 2017), most are contributing to innovation studies by developing design approaches, as a growing literature on the subject attests (e.g. Le Gal et al., 2011; Meynard et al., 2012; Malezieux, 2012; Cerf et al., 2012; Martin et al., 2013; Dogliotti et al., 2014; Prost et al., 2017). In many studies, the research agronomists have been the designers of

target agricultural systems, using what Le Gal et al. (2011) have called “design-oriented methods”: they propose new agricultural systems by using simulation models (Bergez et al., 2010) or prototyping methods (Vereijken, 1997; Lançon et al., 2007; Colnenne-David and Doré, 2015), with extensive use of assessment tools and indicators. But recent studies have acknowledged that, given the complexity and uncertainties which are key features of design in agriculture, farmers should be reconsidered as designers of their own production systems, and no longer as users of turnkey solutions (Schiere et al., 2012; Martin et al., 2013; Prost et al., 2017). The role of research agronomists in the design processes is consequently being called into question: their role is seen more as a support for farmers’ design activity than as a substitute for it. This is in line with what Le Gal et al. (2011) have called “design support-orientated methods”, which focus on supporting farmers’ design capabilities and fostering “a progressive transition towards innovative systems” (Meynard et al., 2012 p. 12), rather than on defining the agricultural system to foster.

But how can research agronomists support farmers in their design activity? This is a real challenge as farmers’ design activity has not been described as such. Furthermore, this type of activity is tightly entangled with the activities of other actors (collectors, transformers, institutions, citizens, etc.) who can legitimately claim to be part of the design of agricultural systems (Prost et al., 2017). We think that, to support farmers’ design activity, research agronomists have to reconsider the definition of design. Following Simon (1969 p. 114), who saw design as the process “concerned with devising entities to attain goals”, we can define it as an active and goal-oriented process of invention and implementation of something which does not pre-exist as such in the natural realm. In our opinion, research agronomists have focused most efforts on the “invention” side of design processes when they have worked on target agricultural systems. We claim that supporting farmers’ design activity requires them to extend this focus to the “implementation” part of the design process, in order to take on board the continuous feedback loops and thus to adjust what is intended to what actually happens. This shift is an opportunity for the research agronomists to critically examine the inputs (knowledge, methods and tools in a broad sense) that they should bring or build if they intend to

support farmers in their own design processes. In this paper we contribute to answering these questions by analyzing a case study in which a collective design process was followed and supported by research agronomists over several years. These researchers were involved on a long-term basis in a process where a collective of farmers had to redesign their agricultural systems to restore the quality of water in a catchment area. This level of participation in change processes over the long run is rarely described in the literature (Le Bellec et al., 2012; Dogliotti et al., 2014; Kraaijvanger et al., 2016; Falconnier et al., 2017). In reviewing in this article, the collective design process that was followed, documented and analyzed for over seven years, we aim to substantiate our claims that: (i) the design of agricultural systems is a process structured around feedback loops between invention and implementation; and (ii) that research agronomists need to consider and discuss the agronomic tools that seem efficient and beneficial to support such processes. After providing conceptual inputs on ways to analyze design processes and the support they receive, we describe and discuss two levels of results. First (Section 4), we describe the design process in our case study and the way it was supported. We then (Section 5) highlight several points of analysis about the dynamics of the design process on the one hand and the characteristics of agronomic tools that are useful to feed this process on the other hand.

2 Theoretical background

While designing new agricultural systems has clearly been high on research agronomists' agenda, few have really paid attention to the nature of design as such. Most of the research agronomists involved in designing agricultural systems remain outside the debates taking place within the *Design Studies* field. In this field, which focuses primarily on the industrial sector, many researchers have proposed concepts and methods to develop new ideas and to organize design processes (see Papalambros, 2015 for a review). We can draw on this literature to improve our understanding of the design processes in agriculture and to reflect on ways to support them.

The few studies in agriculture that have been inspired by these approaches (Koerkamp and Bos, 2008; Meynard et al., 2012; Berthet et al., 2012; Cerf et al., 2012; Martin et al., 2013; Elzen and Bos,

2016) have shown that design in agriculture has some particularities: strong uncertainties and unknowns (Voss et al., 2007; Girard, 2014; Duru et al., 2015), long timeframes, and open design processes due first to the lack of a structured organization leading it, and second, to the wide range of actors that can legitimately take part in the process (Koerkamp and Bos, 2008; Berthet et al., 2016; Prost et al., 2017). How can design studies provide guidelines to further analyze and support these processes?

In the design studies literature, design has long been described as a process of “project management” i.e. “the accomplishment of a clearly defined goal in a specified period of time, within budget and quality requirements”(Lenfle, 2008). This “goal” is defined as a vision or intention for the future that is critical in maintaining an innovative ambition and building a design reasoning. It is supposed to be reached through a process characterized by a time frame and progressive work using steps such as initiating, planning, executing, controlling, and closing (Project Management Institute, 2000 p. 4). Debates are taking place in the project management research community about how to define the goal and how to make the process more agile, reactive and exploratory (see Lenfle, 2008; or Garel, 2013 for a review). Yet, this management approach encourages research agronomists to pay attention to the way the goals of design processes in agriculture are defined, and the different steps these processes go through.

The “adaptive management” approach provides an alternative perspective to analyze design processes. As it emphasizes the adaptive and uncertain nature of complex change processes, it is increasingly advocated by research agronomists and ecologists to be used in describing action in these change processes (Jiggins and Roling, 2000; Diaz-Solis et al., 2009; Darnhofer et al., 2010, 2012; Klerkx et al., 2010; Groot and Rossing, 2011; Altieri et al., 2015; Duru et al., 2015), particularly that of researchers in Agricultural Research for Development (Thornton et al., 2017), with approaches like DEED (Giller et al., 2008) or PIPA (Alvarez et al., 2010). Adaptive management, stemming from the management of natural resources, was first proposed by Holling (1978) and then Walters (1986). It stresses “learning by doing and undertaking actions and policies as experiments” and generally

involves “monitoring and assessing conditions interspersed with components of: scoping or assessing opportunities, designing policy options or experiments, implementing or taking action, and evaluating and adjusting” (ibid). Defined as “flexible decision making that can be adjusted in the face of uncertainties as outcomes from management actions and other events become better understood” (National Research Council, 2004 pp. 1–2), adaptive management highlights the need for adjusting the change process to the impacts of what has been already done. It thereby blurs the deliberate and orientated nature of the process that was key in the project-based management approach, all the while encouraging research agronomists to analyze iterations in order to cope with the irreducible uncertainties of such processes.

We suggest that an accurate understanding of actual design processes of agricultural systems should combine key elements from both project-based and adaptive management approaches. When drawing on the adaptive approach, we should focus on the iterations of the design processes, whereas when drawing on the project-based approach, we should focus on the definition of a goal – an intention for the future –for the design process, and on the steps the process goes through. Combining the two is then an incentive to constantly analyze the dialogue between what is intended and what actually happens. This will help us to build an understanding of actual design processes in agriculture. The next question is how research agronomists can support such a dialogue. Agronomic research may seem to have already provided numerous tools for this support, as reviewed by Le Gal et al. (2011): models, experiments, prototyping methods, participatory methods, and so on. But most of them target the “invention” side of the design processes, that is to say, the design of the target agricultural practices (Bergez et al., 2010; Groot et al., 2012; Dogliotti et al., 2014; Lefevre et al., 2014). When it comes to supporting farmers’ design processes, and especially to supporting the “implementation” part of these processes, the inventory is not as straightforward. The studies that have advocated the use of adaptive and iterative modes of design management in agriculture are mostly conceptual (Le Gal et al., 2011; Meynard et al., 2012) and fall short of proposing methodological tools. Or when they describe how to implement this management approach (Giller et

al., 2011), they are most often focused on one iteration (Falconnier et al., 2017), which raises questions on the management of such processes over the long run and on ways to support it. Decision support tools may be seen as obvious candidates to support the iterative part of design, as evidenced by an extensive literature (e.g. McCown, 2002; Rose et al., 2016). Several of them may in fact support the monitoring of change processes but, as their name indicates, they support the decision and not the design. Yet it turns out that Design Studies have largely insisted on the specific nature of design reasoning that exceeds decision making by being creative, or generative (e.g. Hatchuel 2002). The challenge is thus to support the expansion of the farmers' reasoning while also fostering constant comparison between what is intended and what actually happens.

3 Material and methods

To better understand the actual nature of farmers' design processes and the ways to support them, we draw on the case study of a process where a collective of farmers had to redesign their agricultural systems to restore the quality of water in a catchment area. In this section we describe the case study and then explain the methods that were used to follow and analyze the dynamics at play.

3.1 Context: redesigning agricultural systems in a drinking water catchment area in France

To reduce water pollution and comply with the Water Framework Directive (European Parliament and the Council of the European Union, 2000), EU members must delineate vulnerable zones within catchment areas and implement measures in these zones. In France, more than 1000 priority catchments for water management have been identified, most of them in crop-growing areas (Barataud et al., 2014). In these catchment areas, regional and local authorities are legally required to develop a sequential methodology to delimit the area, conduct a multi-pressure land diagnosis, and develop what is called an "action plan" to steer changes in farmers' practices towards environmentally low-harm approaches (see Barataud et al., 2014 for a detailed analysis of the French water regulations). This dynamic has to be supported, monitored and controlled by a steering committee, a group prescribed by the catchment official protocol, consisting of various stakeholders

(farmer representatives, the regional authority, the water board as a funding agency, the local agricultural and environmental state authority). A project leader has to be designated to facilitate the process. Given the objectives, the diversity of the actors involved, the lack of ready-made solutions, and the complexity of the hydro-geological mechanisms concerned, these catchment areas clearly require specific design processes to ensure that the local agricultural systems evolve consistently with the characteristics of the local environment and with the goal of securing a good-quality water supply.

Our case study is located in one of these catchment areas, in the province of Burgundy, north-eastern France (around 48°00'N, 3°36'E). Annual crops in short rotations (winter oilseed rape/winter cereal/winter cereal and a few winter oilseed rape/winter cereal/spring crop/winter cereal) largely predominate on the 1700 ha of agricultural land within the catchment area, although there is also some livestock. Even though the crops are not particularly diverse, there is some diversity in the agricultural practices: ploughing or no tillage practices, and various levels of fertilization and crop protection. Some 58 farms are present in the catchment, 25 of which account for about 80 % of the agricultural land. The water quality is characterized by high nitrate concentrations, sometimes over the legal threshold of 50 mg l⁻¹. Because the area is labelled as a priority catchment, the local Chamber of Agriculture (CA89, www.yonne.chambagri.fr) was chosen in 2010 as the project leader in charge of diagnosing the area and building an action plan. A 40-member steering committee was also set up (members from the local water authority, eleven farmers' representatives, mayors of the four towns located in the area, local representatives of the regional water supply and public health agencies, representatives of the two main agricultural cooperatives, president and advisors of the local Chamber of Agriculture, local environmental organizations and researchers from the French National Institute for Agricultural Research – INRA).

3.2 Methods used to follow and analyse the dynamics of the case study

In this catchment area, several researchers from the French National Institute of Agricultural Research (INRA) have built long-term collaboration with the facilitator of the catchment area, an agronomist of the local Chamber of Agriculture (CA89, www.yonne.chambagri.fr) in charge of designing the action plan and facilitating the change process. Two research agronomists, working on innovative cropping systems and with an interest in Design Studies, have taken part in the whole process since 2010, working with the facilitator in charge and the other local stakeholders. They entered the process just after the local Chamber of Agriculture had finished delimiting the area, and have thus been present from the point at which the diagnosis was undertaken up to now. Two other agronomists joined the process later, one in 2013 from the facilitation side (CA89), to provide advice to the farmers in collaboration with the facilitator, and one in 2016 from the research side (INRA), to work on the replication of the process in other catchment areas.

To capture the nature of the design process itself, the case was investigated by the researchers through a combination of observation and participation. From 2010, they attended all the steering committee meetings, organized and managed by the facilitator of the area. These meetings were recorded to keep track of every decision made and how they were made, and the different documents and slides that were shared were also collected. Comprehensive semi-structured interviews were held with the members of the steering committee at the beginning of the researchers' participation. Interactions with the farmers of the area were mostly managed by the facilitator of the area. The researchers provided support to organize them, particularly to propose diverse ways of facilitating the meetings. They took part in every collective meeting with the farmers dedicated to the design of new agricultural systems in the area, and in every field visit organized by the facilitator. Documentary evidence was collected of the preparation of the meetings (emails exchanged and detailed reporting) and of the meetings themselves (photos and audio recordings of the meetings and field visits, documents exchanged, slides presented).

Data on the agricultural practices in the catchment were also systematically collected. At the beginning of the project, the facilitator collected data about the farmers' current cropping systems and cropping management in the area. Some 18 interviews were held with farmers in the catchment (Paravano, 2010). As the areas cultivated by these 18 farmers represented about 60% of the cultivated catchment area, these data were used to characterize the main cropping systems in the catchment. The INO_3 indicator of the Indigo Method (Bockstaller et al., 2009) was then used to assess the level of nitrate leaching of these systems. This indicator estimated the amount of nitrate leached during crop growth and after crop harvest, taking into account the N fertilizer rate and crop N uptake capacity, water balance at the moment of fertilization and rainfall risk after fertilization. After that first characterisation, data were collected annually on the crops grown and the agricultural solutions chosen by the farmers, along with their impacts. This was done through observations of the area and sampling in the fields, and then recorded annually in a database for each field.

All these data were processed to build a longitudinal analysis of the actual design process, based on a grounded theory approach (Glaser and Strauss, 1967) with two main lines of analysis. The first dealt with the dynamics of the design process. It aimed primarily at assessing how the process was geared to build a collective goal while being constantly adapted to the actual situation over time. The second focused on the contributions made by the research agronomists to support the process: their nature, content, and timing. These two lines were crossed to capture the research agronomists' contributions at each step of the process to inform the debates about the goal of the process and its adjustments in relation to the impacts the process was having in the catchment.

4 Understanding the design process by identifying different steps (2010-2017)

The analysis of the process over time allowed us to characterize several steps in the design process.

Figure 1 summarizes the description of the design process detailed in the sub-sections below.

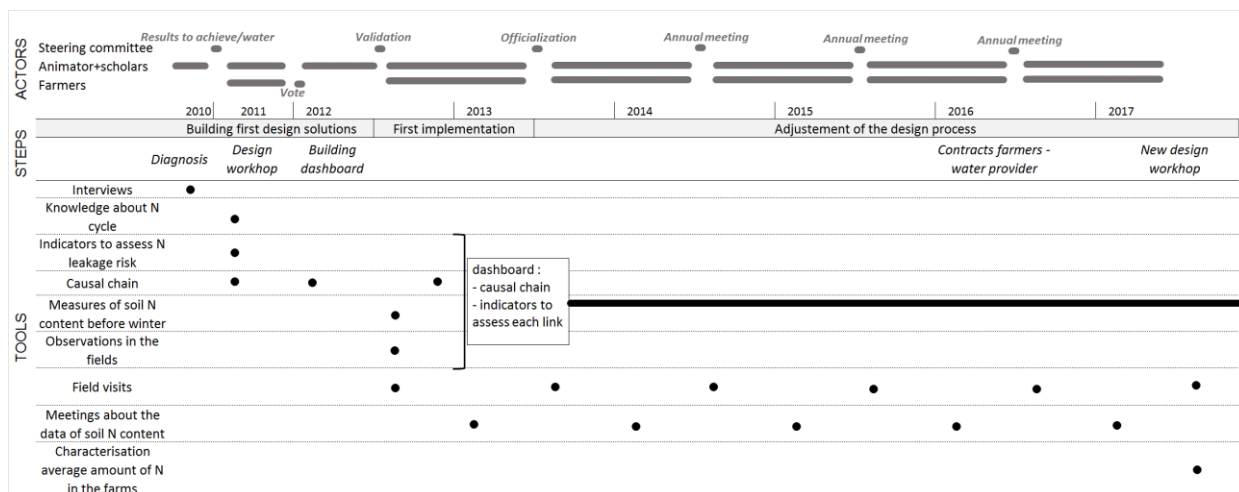


Figure 1 : The design process over time. This figure summarizes the description of the design process set out in Section 4: the role of the different actors, the steps of the design process, and the tools it applied from 2010 to 2017.

4.1 Defining the design issue and first design solutions (September 2010-June 2012)

As summarized in the left part of Fig. 1, during the first two years the researchers contributed with the facilitator of the area to building an understanding of the design issue to solve and first design solutions that could be incorporated into the “action plan” of the catchment area. As mentioned in Section 3.1, an “action plan” is a mandatory document which explains, for a specific catchment, how the actors of the catchment have decided to regain water quality. To build this action plan, the researchers first took part in the agronomic diagnosis by characterizing the cropping systems in the area with their multi-annual logic (e.g. the crop rotations). Their objective was to identify the impact of these systems on nitrate pollution, whereas most of the diagnoses made in catchments only describe the agricultural practices of a given year (Jean-Baptiste et al., 2017). They then organized interviews with 21 stakeholders in the area (farmers, mayors of the towns in the catchment, local representatives of the State, agricultural cooperatives and advisors, environmental organizations) to identify a diversity of stakeholders’ own definitions of cropping system sustainability, and to clarify their perceptions of water quality and of cropping system performance criteria (see Ravier et al., 2015 for more details). These data were shared with the steering committee to determine the water quality that would have to be obtained (Sept 2011) and thus to agree on the overall goal to be achieved.

From this definition of the expected results, a group of voluntary farmers asked to design the action plan themselves, with the support of the facilitator and the researchers. These farmers happened to be quite representative of the diversity of agricultural practices in the catchment, with one livestock farmer and promoters of low-till practices and of ploughing, using different levels of fertilization and crop protection. A four-day design workshop was then organized with this group, spread over one month (mid-November to mid-December 2011). The first two days were dedicated to sharing representations of the issue to solve. There were various interactions between the farmers, the facilitator and the research team: the facilitator presented her diagnosis of the actual agricultural practices in the area, the researchers provided information on the way of assessing the impacts of agricultural practices on water quality and the nitrogen dynamics in agricultural fields, and some invited farmers brought their testimonies about innovative types of nitrogen management they had tested. All these presentations and testimonies were discussed in depth. At the end of these two days the farmers devised a design strategy and set a design target. As regards the design strategy, they decided not to try first to limit the amount of nitrogen fertilization, but rather to limit the winter nitrogen leaching. At this stage of the process, the farmers expressed the feeling that they already had fertilization well-adjusted to their yield and quality objectives, calculated using the balance-sheet method. Based on the results of the agronomic diagnosis, the facilitator and researchers thought differently, given also that the use of the balance-sheet method has several shortcomings and often leads to N losses (Ravier et al., 2016). However the farmers insisted, arguing that they could rather act to limit nitrogen leaching in winter. The facilitator and researchers deemed that this was a rational strategy to obtain good water quality. In fact it was result-oriented and was thus likely to contribute towards the targeted result: it would help to remedy not only over-fertilization but also soil nitrogen mineralization in the autumn. This was moreover the design strategy preferred by the farmers: insisting on focusing on N fertilization would have interrupted the design process. This strategy was therefore finally selected and the farmers decided to design systems that would limit the winter nitrogen leaching by limiting the amount of soil mineral nitrogen in mid-autumn. As

regards the design target, they collectively defined a maximum target of $30\text{kg}\cdot\text{ha}^{-1}\cdot\text{year}^{-1}$ of nitrogen leached on average in the area. This target was the subject of much debate. In fact, the farmers were looking for an indicator that would be more directly related to their practices at a field scale than the nitrate concentration in the water. The amount of winter leached N seemed an interesting possibility. The initial diagnosis had estimated that the average winter N leaching in the catchment was about $60\text{kg}\cdot\text{ha}^{-1}\cdot\text{year}^{-1}$. Confronted with the impossibility of linking a level of N leaching to a nitrate concentration in the water without a hydro-geological model – which did not exist in the area –, it was collectively decided that targeting a level of $30\text{kg}\cdot\text{ha}^{-1}\cdot\text{year}^{-1}$ of nitrogen leached would be ambitious enough. The following two days were devoted to the design of agricultural systems that were expected to reach this target. In more detail, on the third day, the group was asked to imagine disruptive cropping systems that would achieve the target. The designed propositions of cropping systems were assessed before the last day (see also Ravier et al., 2015) to estimate the amount of nitrate leached in each system (using INO_3 again). The farmers used these assessments to discuss the various propositions of systems they had imagined and to select the practices to be recommended. They chose to translate these design solutions into an action plan that was result-oriented and that would aim at a maximum target of $30\text{ kg}\cdot\text{ha}^{-1}\cdot\text{year}^{-1}$ of leached nitrogen on average in the area. To achieve this aim, the farmers detailed in the action plan that they would have to limit the amount of mineral nitrogen in the field to $60\text{ kg}\cdot\text{ha}^{-1}\cdot\text{year}^{-1}$ in mid-autumn – a rough estimate obtained with the Burns model (Burns, 1977). To get this result, they would have to make an efficient use of cover crops in two situations: covering the soils before spring crops, and fostering volunteers of rape and pea crops, two crops that are known to leave a lot of nitrogen in the soil after harvest. They for instance decided to sow cover crops early to encourage their growth and, just after the harvest of rape or peas, to till the soil in order to foster volunteers, which they would leave in for at least 50 days. Since the action plan was meant for all the farmers in the catchment, a meeting was organized to present these commitments to all the farmers. The propositions were voted by secret ballot and almost unanimously accepted (February 2012).

The facilitator and researchers proposed to formalize the commitments designed by the farmers in a dashboard (Girardin et al., 2005) for the area, which would be presented to the steering committee. The idea was that this dashboard would represent the reasoning behind the design solution built by the farmers, and provide a way of monitoring its implementation every year, which would allow the steering committee to check and contribute to the design process at the area scale. This dashboard thus translated and embodied the action plan. It linked the targeted results (in terms of water quality, nitrogen leaching and mineral nitrogen left in the field in the autumn) with the chosen agricultural practices to make visible the farmers' reasoning underpinning their propositions. Every link of this causal chain was accompanied by an indicator measuring a value in the area (average value or percentage of the surface area achieving the targeted result). Two thresholds were defined for each indicator to define three color classes for every link. To achieve the targeted results, the most exigent threshold had to be reached for each indicator. The second threshold was the one under which the indicator should not go (Fig. 2).

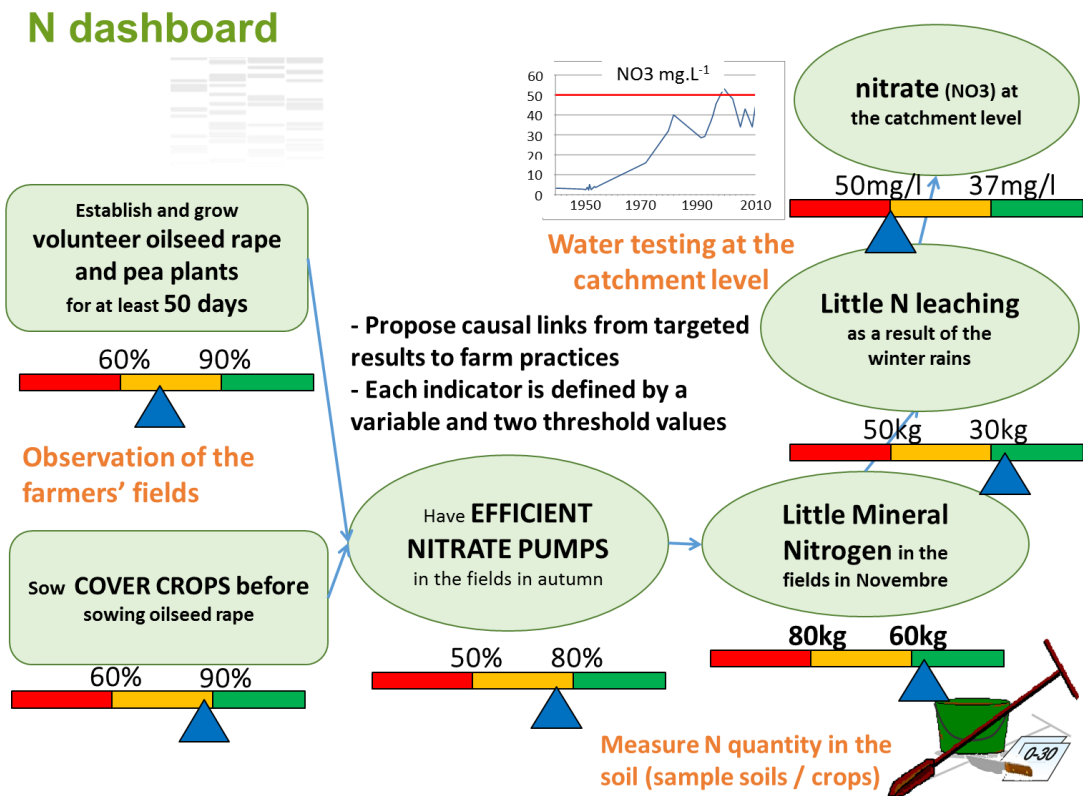


Figure 2 : The dashboard. We follow the causal chain from farmers' actions to water quality. Each link is assessed with a specific indicator (% area for the left and middle links, kg.ha⁻¹ for soil N water content and N leaching on average over the

area, mg.L⁻¹ NO₃ in water for water quality). Two thresholds are defined for each indicator to define 3 color classes for each link. E.g.: with regard to the efficient pumps, if less than 50% of the relevant area is covered with efficient pumps, the link is red; if more than 80% of the relevant area is covered, the link is green; for anything between the two, the link is orange. The blue triangle represents the value actually achieved.

When consulted about this work (June 2012), the steering committee validated the different choices made: the design solutions proposed by the farmers in the action plan, the translation of the action plan through the dashboard, and the principle of managing the design process dynamically by assessing the dashboard every year. It thus acknowledged that the farmers' reasoning had been convincing, and that the dashboard would allow the steering committee to assess its actual efficiency, year after year, and to make the action plan evolve if necessary. At the farmers' request, the steering committee gave them one year to actually test the implementation of their commitments and of the dashboard (i.e. how to fill it in) before the commitments and the use of the dashboard became official. This implementation is described in the following section.

4.2 A year to implement the design solutions (September 2012-June 2013)

For one year, from September 2012 to June 2013, the farmers voluntarily began to apply their technical propositions to learn about them: they tested the management of volunteers, how to encourage their growth, how to remove them and when. Demonstrations were organized in the fields to compare the volunteers' growth according to different soil tillage practices implemented by the farmers, or to test different machines used to remove the volunteers. The operation of the dashboard was also tested during that first year. It was first necessary to decide which data on the board should be filled in. The main idea was to limit statements on practices, and instead to use observable data that were available to everyone and quantified data. Observable data were thus used to assess the performance of cover crops and volunteers. By visiting the entire area in September, the facilitator could assess the presence of cover crops or volunteers and their efficiency in capturing soil nitrogen (density, growth). Measurable data were used to assess the amount of mineral nitrogen in the soil in November (beginning of drainage). It was decided to measure soil mineral N content before winter in about 100 fields of the territory (1/4). During this first year, the facilitator and researchers proposed to organize a farmers' field visit in September, to collectively

assess the state of the cover crops and volunteers. From one field to another, the farmers discussed the state of the crops (were they successful?) and how they had managed them. Oilseed rape volunteer plants were sampled and weighed so that the farmers could roughly estimate the amount of nitrogen uptake. Debates followed on whether there was still mineral nitrogen available in the field or not, and how to capture it. The measures of soil N content before winter also provided an opportunity to meet the farmers in their fields and to discuss the action plan and its implementation. When the results of N content assessment were available, they were used in meetings in January about N management: individual meetings to discuss each specific situation, and then collective meetings to share the collective performance in the area. Additional learning was then necessary to fill in the dashboard, on how to collect the observable data, to sample the measurable data, and to extrapolate these data for the whole area. The first dashboard that was developed was presented to the steering committee in June 2013, as a snapshot of the situation in the area before the action plan was officially launched (see Fig. 3, 2012/2013 dashboard).

The steering committee decided that the action plan seemed promising, as did the use of the dashboard to monitor and assess the design process. The action plan thus became official in the following crop year. Since this validation by the steering committee, we have entered a phase of continuous adjustment over the years, described below.

4.3 Adjustment of the design process over the years (September 2013-June 2017)

The dashboard has been used to monitor the design process in the area for four years now. The way it was used during the first year is now well established. Every year, it supports the farmers' work and group dynamics since the collection of data about the state of the volunteer and cover crops is an opportunity, every autumn, to organize field visits and exchanges between the farmers. The measures of soil N content collected every autumn are also individually and collectively discussed with the farmers during the winter: is the targeted result of $60 \text{ kg}\cdot\text{ha}^{-1}\cdot\text{year}^{-1}$ of soil mineral nitrogen achieved in each field and collectively? Why? How can it be achieved? Finally, volunteer farmers who participate in the steering committee present the dashboard to the committee every year, in late

spring or early autumn. By presenting the dashboard themselves, they show their involvement in the action plan and are able to discuss their reasoning, its successes and its failures.

Looking at the evolution year after year of the results shown by the dashboard, we see that two main adjustments were implemented. The first adjustment stemmed from the results obtained year after year on the left half of the dashboard, which is focused on the farmers' practices. The second one stemmed from the results obtained on the right half of the dashboard, which shows the impacts of the practices.

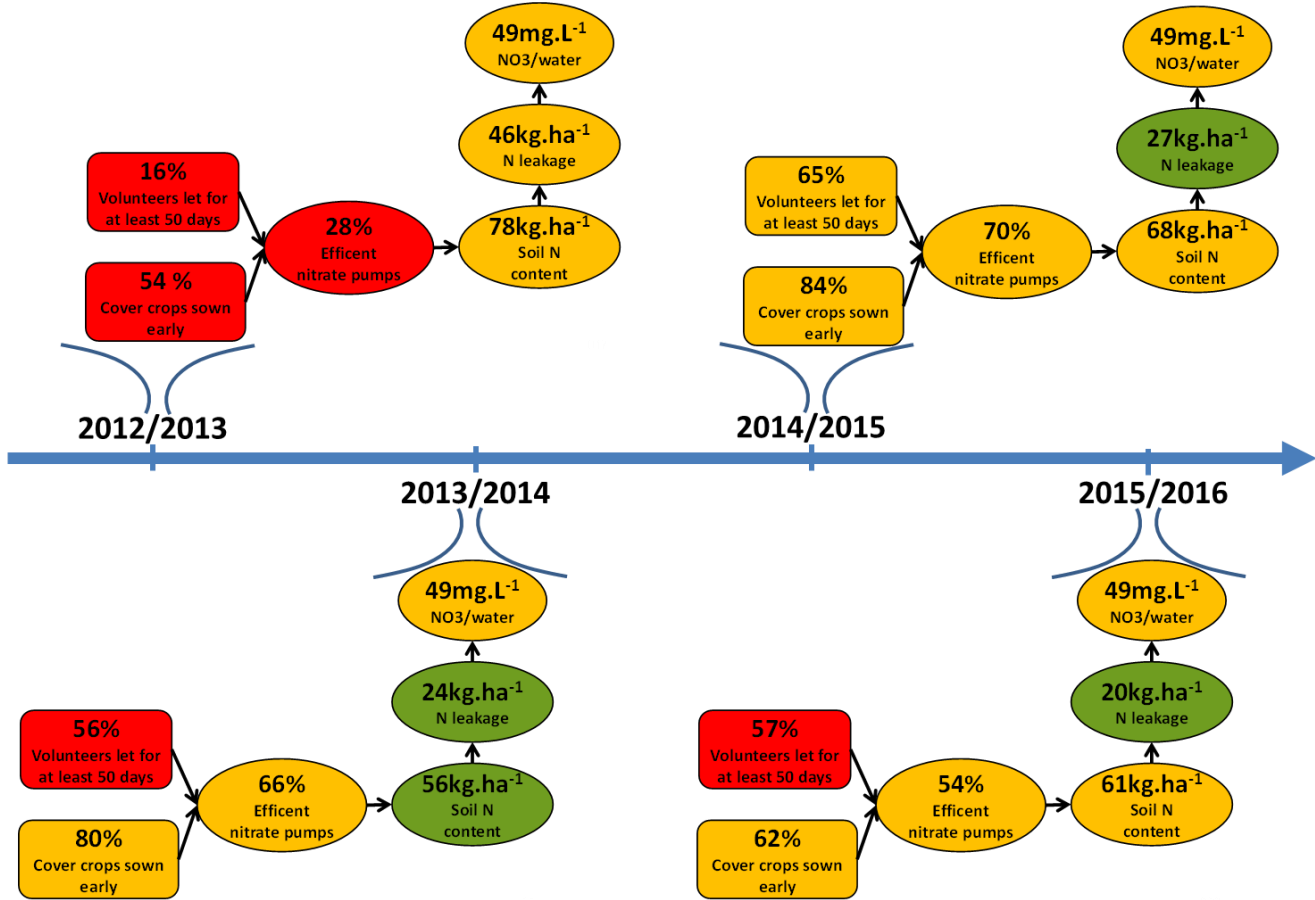


Figure 3: The results shown by the dashboard over the years. The colors of the links fit the thresholds defined in Fig. 2. In each link, there is the value of the indicator reached each year.

The left half of the dashboard (Fig. 3) shows the farmers' commitment as it represents their own actions and changes of agricultural practices. During the first two years, the results entered into the dashboard showed that the farmers radically improved the success rate of their volunteers and cover crops: in autumn 2014, 70% of the fields after peas and rape, and before spring crops, had efficient

nitrate pumps (28% in 2012, 66% in 2013). But the following years were less successful. In 2015, even if the level of cover crops was still high (see Fig. 4), it had decreased: only 54% of the fields had efficient nitrate pumps, notably because the summer and early autumn had been very dry (53 mm between 15 July and 30 August in 2015, 152 mm in 2014, 76 in 2013), which had discouraged the farmers from putting effort into their cover crops. Faced with the weakening of the collective momentum among the farmers, some farmers and the local water provider proposed in 2016 to formalize a contract between each farmer and the water provider in order to renew the farmers' involvement. The local water provider would use the contractual commitment of the farmers as an argument to convince the steering committee and notably the local government officials that the farmers' involvement was real and that they were able to reach their design target. Its support to the existing momentum would thus be conditional to a high proportion of agricultural land contracted. Conversely, this would allow the water provider to report to the local government official the case of a farmer who would not implement the practices defined in the dashboard (previously, only the average results were given to the steering committee, which could not access the individual data). This contract was signed by 30 farmers, representing 83% of the agricultural land in the catchment area.

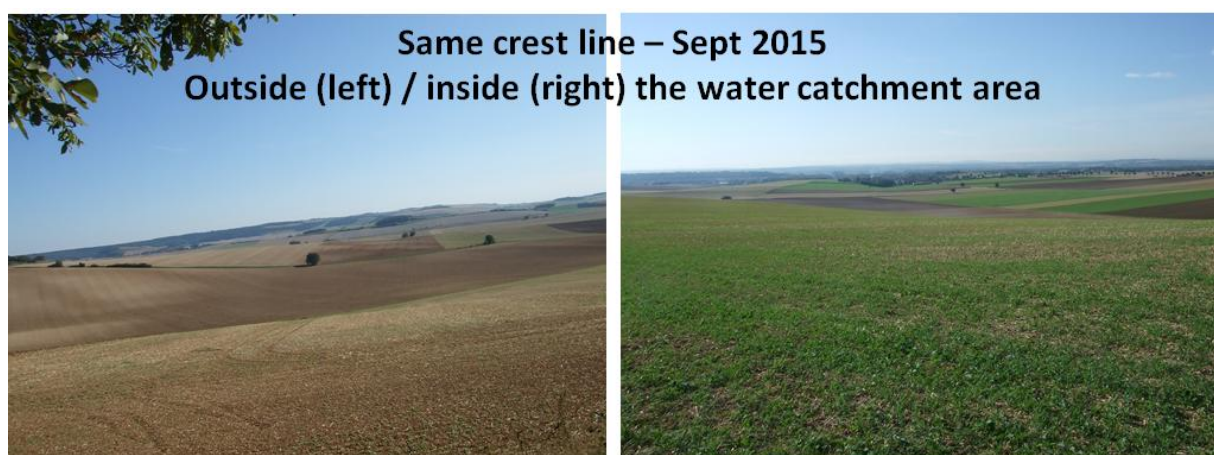


Figure 4 : Photographs taken from a crest line of the catchment area in September 2015, outside the area (on the left) and inside the area (on the right) showing fields with cover crops and volunteers (pictures L. Paravano)

The right half of the dashboard formalizes the reasoning that links the farmers' actions with the actual impact on water quality. They had chosen to limit the soil N content in mid-autumn to limit N

leaching and then the nitrate concentration in water. Across the four years, the nitrate concentration in the water in the catchment area remained at around $50\text{mg}\cdot\text{L}^{-1}$ (see Fig. 3). The different actors in the area were not surprised by this result, as they knew the groundwater would not react for at least 15 years. Furthermore, the N leaching was estimated from the soil N content in relation to the winter climate (rainfall and temperatures), and over the years the influence of climate had been felt. For instance, in 2015, even if the soil inorganic N content at the beginning of winter was high ($61\text{kg}\cdot\text{ha}^{-1}$), the leaching was considered low ($27\text{kg}\cdot\text{ha}^{-1}$) because of low winter rainfall. This indicator thus gave important information about the results to be achieved but not about the farmers' commitment. The actors thus learned to consider both the actual N leaching and the data on soil N content before winter to assess the success of the action plan, that is, the relevance of the design solutions. The monitoring of the right-hand side of the dashboard over the years has shown that the soil N content stays high, even when efficient pumps are established in the fields (like in the autumn of 2014 or 2015). The analysis of the individual data of soil N content over the years has shown that this could be explained by high values of soil N content among livestock farmers and farmers who repeatedly used organic waste products in summer. In spite of the farmers managing to get efficient nitrate pumps before winter with their cover crops and volunteers (for instance, in one field, rape volunteer plants were estimated to have taken up more than 70 kg of nitrogen per ha), there was still too much mineral nitrogen in their soils. The facilitator and researchers therefore suggested starting a new study to see how they could make the first design solutions – and then the dashboard – evolve: were new solutions needed? How could these solutions change the dashboard, whether that be its overall causal chain, one of its links or its indicators? To support this work, the facilitator and researchers used the data gathered over the years and represented the average soil N content of each farm over the rotation in mid-autumn, according to the average amount of N taken up in the field at that time (by volunteers, sown cover crops, and new crops – mostly rapeseed that has grown enough to absorb nitrogen). They thus sorted the farmers according to the average amount of nitrogen (mineral and uptake) on their farms over the years. This representation allowed the facilitator and the researchers

to discuss the different profiles with the farmers: those who reached the target, either by succeeding in having very efficient nitrate pumps on their fields in the autumn, or by using low N inputs in their fields; those who had not reached the target yet, but who could do so by following the current action plan and improving their cover crops; and those who would not be able to reach the target by just improving the management of their cover crops. For the latter group mainly composed of the livestock farmers, the current design solutions were not sufficient and their agricultural systems had to be redesigned to meet the target. This analysis was shared with the farmers of the area who took ownership of this analysis. They appreciated the research team’s recognition that there were different ways in which they could meet the targets. It led the livestock farmers to restart design workshops in 2017, and to devise cropping systems and N management that were better-suited to their particular circumstances, acknowledging that cover crops would not be sufficient for some of them. More broadly, these debates were an opportunity to raise once again the question of N fertilization which had been set aside by the farmers at the beginning of the process. With the data collected over the years and their representation in Fig.5, the famers acknowledged that some of them still had some leeway to better adjust their fertilization.

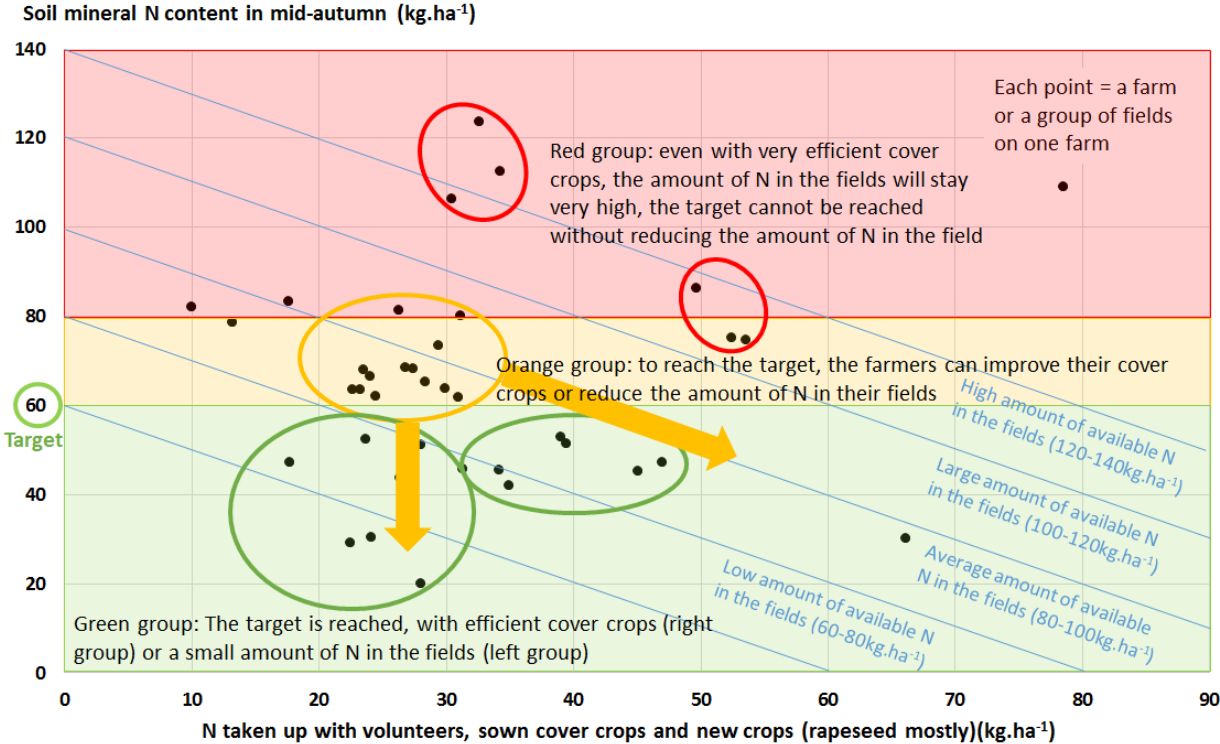


Figure 5 : Average soil N content of each farm over the rotation in mid-autumn according to the average amount of N fixed in the field then (by volunteers, sown cover crops and new crops- mostly rapeseed). It sorts the farmers according to the average amount of nitrogen on their farms (mineral and uptake) over the years.

5 Lessons from the analysis of the process over time: how can research agronomists support design processes?

The case study described here combines various strong features: it involves actors strongly committed to the case – whether it be the local actors or the researchers who chose from the beginning to take part in the situation with participatory approaches; long-term work has been made possible by the funding found by the researchers as well as that available from the regulatory framework for priority catchment areas; and in spite of this regulatory framework, the actors have had some leeway to try different solutions and innovative ways of organizing an agricultural system design process on their own. The analysis of this case study therefore offers us a rare opportunity first to draw some lessons about the actual nature of the design of agricultural systems and second to discuss how research agronomists can support this design.

5.1 Insights about the design processes of agricultural systems

The most direct interest of this case study is the reminder that design does not stop at invention. We argued in Section 2 that most research agronomists have dedicated their efforts to the invention part of the design process, i.e., to propose design solutions, by generating or supporting the generation of target agricultural systems. They have thus focused on the creative characteristic of design. And yet, our case study underlines another characteristic of design: it illustrates that design is a process and that invention is only just the beginning of this process. Through the implementation of the first design solutions, the design continues: new questions are raised, new ideas emerge. This dual focus on design is clearly apparent in Design Studies. While one stream of research focuses on ways to improve creativity in design or to limit design fixation (see Crilly and Cardoso, 2017 for a review), another one focuses on ways to organize design processes, from the invention to the implementation of design solutions (e.g. Dubberly, 2004; Cross, 2008; Pahl and Beitz, 2013). Our case study calls for a new balance to be established between design activities in agricultural research

so that they focus more on design as a process, in line with the proposition of Meynard et al. (2012) to consider “step-by-step design”.

A second interest of our case study is to afford some insights on the drivers of design processes. It reveals that the design process unfolds over time by articulating a design goal and an adjustment to the actual situation. By design goal we mean the intention that is pointed to through the design process; it defines a design “project”. In relation to the idea of defining the design issue, which is a critical step in design processes (Buchanan, 1992; Dorst and Cross, 2001), the formulation of this design goal results from specific work in our case study. It was based on a diagnosis of the inter-annual effects of agricultural practices on water quality, and on the discussions organized with the steering committee at the beginning of the process (see 4.1) to build a common design goal. It continued with the translation of the very generic goal of restoring water quality to a design target for the farmers (from less than 60 kg.ha⁻¹.year⁻¹ of mineral nitrogen in the field in mid-autumn to less than 30 kg.ha⁻¹.year⁻¹ of leached nitrogen). This design target is a reference throughout the process. For instance, during the first design workshop, the farmers constantly reassessed their propositions with regard to this target. It also helped the steering committee and the farmers to assess the actions undertaken every year. As explained in Section 4.3, it was also this constant reference point to the design goal that allowed the farmers, facilitator and researchers to reopen the debates about N fertilization, acknowledging that some farmers would not be able to reach the design goal (low soil mineral N in the autumn) without rethinking their fertilization practices. Constantly referring to the design goal is thus critical to keeping “the project’s level of ambition high” (Van Mierlo et al., 2010). But, as the adaptive management approach emphasizes, such processes are on-going and iterative and they have to adjust to the evolution of the situation. There is thus a need to create dialogue between the design goal (the desirable) and what happens when the first design solutions are implemented (the actual). As explained by Béguin (2007): *“On the one hand design is initially a concept, an intention, a will relative to the future, or an order to happen. On the other hand, these orders and intentions have to be concretely realized to occur in action. But action will meet*

resistances, setting the initial ideas in motion.” This dialogue – for which Schön (1992) used the word “*conversation*” – puts into motion the design solutions (see also Cerf et al., 2012). In fact, results cannot be guaranteed when dealing with actual agricultural practices performed in actual pedoclimatic conditions. By making visible the agronomic reasoning that links practices to expected results on the dashboard, the participants can check and possibly revise their assumptions and actions throughout the process. They learn to adjust and question the process as it unfolds. For instance, there were debates during the field visits about the way to assess the efficiency of the rapeseed volunteers as nitrate pumps (middle link Fig. 2): considering the rape volunteers, were they successful when they could be described as highly developed and nearly “blue”, showing they had absorbed a lot of nitrogen available in the soil, or when they appeared to be dense, but thin and reddish, showing that there was little mineral nitrogen left in the soil? These debates were an opportunity to come back to the design goal. They were also, for all the participants in the design process, an opportunity for learning (about the nitrogen dynamics in the fields and the uncertainties of such dynamics) – a point stressed in adaptive management (Plummer, 2009) and in studies about the change and innovation processes in agricultural systems (e.g. Blackmore et al., 2012; Sewell et al., 2014; Chantre et al., 2015; Martin, 2015; Falconnier et al., 2017).

The analysis of the case study finally shows that the design of agricultural systems is a process both of project management and of adaptive management: a balance has to be found between the design goal and the adjustment to the actual situation. This design goal can also be discussed, as debated extensively in the field of transition studies (Steyaert et al., 2016; Brédart and Stassart, 2017): inflexible targets can block change. When implementing such processes, it is important constantly to bear in mind the chosen design direction, as recommended by the project management approach, and continually to adjust the actions taken to meet the desired outcome, as advised by the adaptive management approach.

5.2 How can research agronomists support such processes?

What were the inputs made by the research agronomists to support the design process described in the case study? We have mentioned several of them. Their combination might appear to be bricolage, resulting from the know-how of researchers familiar with such processes. Actually, this combination of inputs is consistent with what is known of design processes. In the following, we come back to the inputs in the order that they were used during the design process (see also Fig. 1) and explain how each of them refers to known design activities.

First, some agronomic knowledge about the definition of cropping systems was used to map the farmers' practices across their crop rotations rather than over a single year. This "map" was used to understand the farmers' crop rotations and their possible impacts on N leaching. To initiate the building of the action plan, fundamental agronomic knowledge was then shared between the participants during the design workshop on the nitrogen cycle: N dynamics in soil over a year, N amount left by different crops, links between the soil N content in mid-autumn and N leaching during winter, etc. The diagnosis and the exchange of fundamental knowledge were determinant for unlocking the building of a design strategy that would not be focused on N fertilization. This is consistent with what Toffolini et al. (2017) have described about the critical role of knowledge in design processes, and can be linked with what is called "grounding" in the field of research on design activities (Détienne et al., 2012). Acknowledged as a mandatory step in design processes (Stempfle and Badke-Schaub, 2002), this grounding ensures a shared understanding and representation of both the design issue (what is at stake) (Buchanan, 1992; Détienne, 2006) and the knowledge that is known or missing (Le Masson et al., 2013). Second, after this grounding process, assessment indicators were used to assess the N leaching risk from the current and future cropping systems (IN03-Indigo). They were used first to define a target to reach, and then to assess the solutions devised during the design workshops. In this sense, the inputs were mobilized to define and keep the ambition high and thus to foster design reasoning by "devising artifacts to attain goals" (Simon, 1969). Third, once consensus was reached on the action plan, the main tool used in the process was

the dashboard, which was itself an assembly of several elements: a causal chain representing the agronomic reasoning that was proposed to obtain a good water status in the catchment; a set of observable or easily measured indicators used for evaluation purposes at each link in the causal chain; a protocol to sample and collect data for monitoring purposes; and a set of thresholds for each indicator designed to ensure that the changes were efficient. The dashboard was thus a collection of tools intended: 1) to allow the different actors to monitor the achievement of design targets in the area; and 2) to formalize, with transparency, the agronomic reasoning chosen to meet the challenges. As such, the dashboard is a key tool to articulate a design intention to the actual situation and then to inform the dialogue we mentioned above. Fourthly, some new tools have emerged as a result of the process, like the characterization of the fields according to their amount of available N in autumn (Fig. 5: soil mineral N content and N uptake in the cover crops and volunteers). This characterization has provided the farmers with new insights and has thus allowed them to develop their own strategies. By breaking down the effects that allow the farmers to have little mineral nitrogen in their fields in mid-autumn, it shows that different approaches can exist and are required in particular farm contexts to meet the targets (Fig. 5).

If we come back to the fact that the design processes of agricultural systems combine invention and implementation, we can see that most of the inputs made by the research agronomists in our case study support both. Indicators, notably, were extensively used to qualify the intermediate states of the agricultural systems and adjust the design process as it unfolded. They depicted the relevance of each link of the causal chain, to confirm or invalidate the design solutions chosen. They produced information from the implementation of the design solutions to adapt, in return, the solutions proposed to attain the design goal. This use of indicators is original. In fact, as discussed by Toffolini et al. (2016), most indicators produced in agricultural science inform only a very small portion of farmers' needs during the design processes of agricultural systems. They are built mainly to assess the overall performance and the impacts of cropping systems, whereas farmers actually use indicators mostly to identify ongoing dynamics and intermediary states, so that they can adapt their actions and

reinterpret their reasoning and strategies (Toffolini et al., 2016). The indicators used in our case study fit these functions.

We mentioned above the specific role of the dashboard to support the design process. We believe that it is a useful design support system and it may help to understand why decision support systems, largely developed in the agricultural world, are not necessarily good design support systems. By clarifying the intention that defines the design project, and by informing the dialogue between this intention and the actual situation, the dashboard supports not only decision making but design reasoning, which has been discussed as being very different. As Le Masson et al. (2013) pointed out, decisions are made in design, but design is more than decision making. Design entails exploration and generativity (Hatchuel, 2001) that exceed decision making. Although decision support systems are claimed to support learning processes for problem solving (e.g. McCown et al., 2002; Hochman et al., 2009; Thorburn et al., 2011), they have not been assessed with regard to their ability to support design processes, i.e. both design reasoning and management. This might contribute to explaining the relative failure of DSS (e.g. McCown, 2001) when it comes to supporting the farmers' processes of technical change, which can be analyzed as design processes. We therefore believe that the contributions of research agronomists to innovation processes may be improved if they think in terms of supporting design processes, i.e. design reasoning and management. They can do so either by intervening at some specific steps of the design processes (e.g. the grounding steps, or the definition of an ambitious design goal, or the building of appropriate indicators, as mentioned above) or by intervening in the long run to inform the dialogue between the design goal and the adjustment to the actual situation.

A last point, in order to open some perspectives for discussion: we have insisted in this section on the inputs that research agronomists can make to support design processes, whether it be fundamental knowledge, indicators, the building of agronomic reasoning, tools or representations. We have done so to illustrate how the understanding of actual design processes could open new avenues of research in agricultural science (and not only in social sciences) to support design processes. The

support that research agronomists can provide is however also contingent on the position the scientists take in the design process. In our case study, they acknowledged the legitimacy of several actors and of their knowledge, to design by themselves. They also considered themselves as learners among the others. They thus acted as facilitators (Ingram, 2008) or intermediary workers (Steyaert et al., 2016) with a design specificity: to maintain tension between the exploration of an ambitious desirable future and its actual implementation. Such reflection about the role of research and researchers is consistent with that of Schut et al. (2014) about the need for dynamic research configurations to enhance the contribution of research to innovation processes. It however specifies the role of research by insisting on the need to support design processes inside innovation processes.

6 Conclusion

This article is based on the analysis of an agricultural system design process to which research agronomists contributed, over several years. In a catchment area, farmers were asked to change their farming systems to improve water quality. Seven years after the beginning of the process, various contributions had been made by the research agronomists working on the case study, which evolved over time according to the social and biotechnical dynamics. This type of study is original in agricultural science. Most of the literature on design in agronomy has focused on the invention part of the design process: it explains how ideas of design solutions were elaborated, via models that foster optimization or foresight and/or through participatory actions that allow people to imagine suitable solutions. These studies are effective to foster creativity and to ensure the broad exploration of an issue. Yet they do not examine the way the propositions are actually implemented, nor continue the design process by looking at how the situation talks back, to use Schön's (1992) expression. Some methods actually propose to simulate virtually the designers' conversation with the situation, by making visible simultaneously the design targets, the actions imagined, and their impact assessment (Martin et al., 2011; Étienne, 2013), but with the restriction that these methods are, for now, based on simulation models, thus on what the modeler is able to anticipate. As they are

moreover attempts at organizing a dialogue with the situation, they pay no attention to the tools and the means by which they can support adaptive management

Allowing a conversation with the situation in the long run has implications in terms of the inputs the research agronomists should produce to equip those who engage in design processes. Some of them exist, but most of them are still waiting to be produced. In our case study, we showed how the research agronomists combined fundamental knowledge, indicators and simple models with several objectives: allowing the farmers to keep in mind a design goal; raising the profile of the causal relationships that link the farmers' actions to the targeted result; and allowing the farmers to regularly reconsider the target and the linked actions when necessary. To do so, they mobilized agronomic tools that support monitoring and adaptation with regard to a design goal.

Finally, this review of a long-term dynamics of design afforded an opportunity to further our understanding of design processes in agriculture, and enabled us to open a discussion about the contribution of agricultural research to supporting design. We are aware that most researchers may not have the opportunity to be involved in a design process over so many years, and we do not claim that such longitudinal studies should become the norm. However, such studies are helpful to grasp the challenges that have to be met when research agronomists wish to support agricultural transitions. They emphasize the need to develop agronomic tools that inform a dialogue between a design intention and the way the situation "talks back". The dashboard tested in the case study, along with the method for building it and the indicators that inform it, are a proposition in this direction. Actually, for the last eighteen months, we have been testing the relevance of such a tool in other catchment areas. We focus on methodological ways to equip the facilitator and the collective of farmers with tools to capture the way the situation "talks back", and to keep together a design intention and the means to achieve it.

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