A participatory method to design farm scale scenarios for recovering groundwater quality

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Abstract: *There is an increasing societal pressure on agriculture to limit groundwater pollution caused by the intensive use of synthetic pesticides and fertilisers. In France, 1000 sensitive water catchments face a legal obligation to develop and implement agri-environment measures to reduce pollution from agricultural practices. However, these measures are generally not suitable for diverse farm management types and then improperly applied to preserve or restore groundwater quality. In this context, we developed a participatory approach exclusively with farmers. The objective was to co-design scenarios that encompass farm structure and strategy, and support adapted agroecological practices, to improve water quality. Each scenario is a combination of changes including farmer's practices, cropping systems, material or human resources. The participatory approach involved rounds of workshops with individual and groups of farmers and was applied in one case study in South East of France. The designed scenarios have been evaluated in terms of agronomical, social and economic performances and their efficiency to reduce pressure on groundwater quality. Our results show that this approach tailored scenarios for farmers predicated by collective expertise. This approach makes it possible to take into account individual farm management constraints and helps to breakdown local lock-ins. It fosters involvement of farmers in a participative process, and should favour long-term changes of agricultural practices to recover groundwater quality. This facilitation method can be used by local stakeholders in order to facilitate the development of catchment-specific programmes including measures suitable for farm management diversity and assumed to recover groundwater quality.*

Keywords: *farming system, agroecological practices, co-development, farm-scale evaluation, groundwater quality, tailored scenario*

Introduction

The protection of water resources is a major issue in France as 64% of drinking water comes from groundwater catchment (Ifen, 2003). According to the French general direction for health, from 1998 and 2008, 4 811 catchments have been abandoned including 878 due to quality water deterioration by nitrates and/or pesticides, the leading source of abandonment ahead of a flow-rate too low, technical problems, etc. In 2010, an EU commission report showed that 41% of groundwater in France has pollution problem according to criteria set by the Water Framework Directive (WFD)[1]; and 94% of this pollution was linked with agricultural activities. Since the 2013 environmental conference, 1000 French water catchments are designated as "priority catchments" and face a legal obligation to develop and implement action programmes to reduce pollution. However, action programmes reflect more a formal implementation of protection approaches than a search for efficiency by defining suited measures and the setting-up of a consistent support scheme (Menard et al., 2014). Farmers do not always implement voluntary measures from action programmes as such measures are not suitable for their farm management (Richard et al., 2018). Therefore, the challenge is to design scenarios supporting agricultural changes addressing groundwater quality issue in coherence with farm management that farmers would be able and willing to implement.

[1] The EC Council Directive 98/83/EC of 3 November 1998 on the quality of water intended for human consumption set up a maximum admissible nitrate concentration of 50 mg $NO_3.L^{-1}$ and allowable concentrations of 0. 1 µg/l for any pesticides and 0.5 µg/l for total pesticides in drinking water irrespective of toxicity

For this purpose, it is relevant to guide the design towards agroecological practices that "produce significant amounts of food, which valorise in the best way ecological processes and ecosystem services in integrating them as fundamental elements in the development of the practices, and not simply relying on ordinary techniques, such as chemical fertiliser and synthetic pesticide application" (Wezel et al., 2014) to recover groundwater quality. For a broader implementation of agroecological practices, it requires promotion of individual and collective learning and development of a systemic approach, giving up the simplification "one problem, one input" (Berthet et al., 2015; Meynard, 2017). Yet, an increasing number of authors insist on the necessity to take into account the complex farm management components during design process (Bellon et al., 2007; Le Gal et al., 2011; Lefèvre et al., 2014; Prost et al., 2017). The implementation of agroecological practices involve change of interconnected elements of farm management as cropping systems, material and human resources requiring holistic and participatory approach.

Nowadays, participatory approaches seeking the improvement of groundwater quality provide scenarios at two levels, (i) cropping systems (Barataud et al., 2016; Hellec et al., 2013; Paravano et al., 2016; Ravier et al., 2015; Reau et al., 2012) *e.g.* implementation of spring crops combined with their cover crop on Brienon catchment (Reau et al., 2012) or (ii) catchment level (Allain, 2013; Barataud et al., 2016; Chantre et al., 2016; De Girolamo and Porto, 2012), *e.g.* the conversion to organic farming of 5% of the agricultural land of a catchment area resulting from scenarios simulation by Co-click'eau model (Gisclard et al., 2015).

This paper aims to present a participatory approach that addresses farming system level and provide scenarios of agroecological practices tailored to farm management. The paper offers a facilitation method for stakeholders to design scenarios addressing groundwater quality issue that are ambitious and that farmers would be able to implement. The implementation of the approach relies on a set of methods and tools that would be presented in the first part. In the second part, we present and discuss some results from this design process organised with a group of farmers from sensitive watersheds in South East of France. In the last part, we conclude and draw perspectives.

Method

Overall approach

The method is about designing at farm scale and is inspired by co-development approach developed by (Payette and Champagne, 1997), a collective learning approach, starting from the participants' real-life situations (peer work). In our case, we brought together exclusively farmers. Two major roles for farmers are defined: (i) *witness farmers,* that present technical challenge or project to sustain and ready to change for sustainable management, and (ii) *adviser farmers* who may provide expertise and knowledge to make propositions of change.

It is based on a sequence of five steps with a feedback loop between steps 1 and 3. Information from local stakeholders (for instance technicians from agriculture and water management sectors), and the description of the farming systems in the territories are involved during the step 0 (cf. Fig. 1). It is a required step because (i) it introduces the project to farmers, and (ii) it ensures a profitable cooperation among farmers.

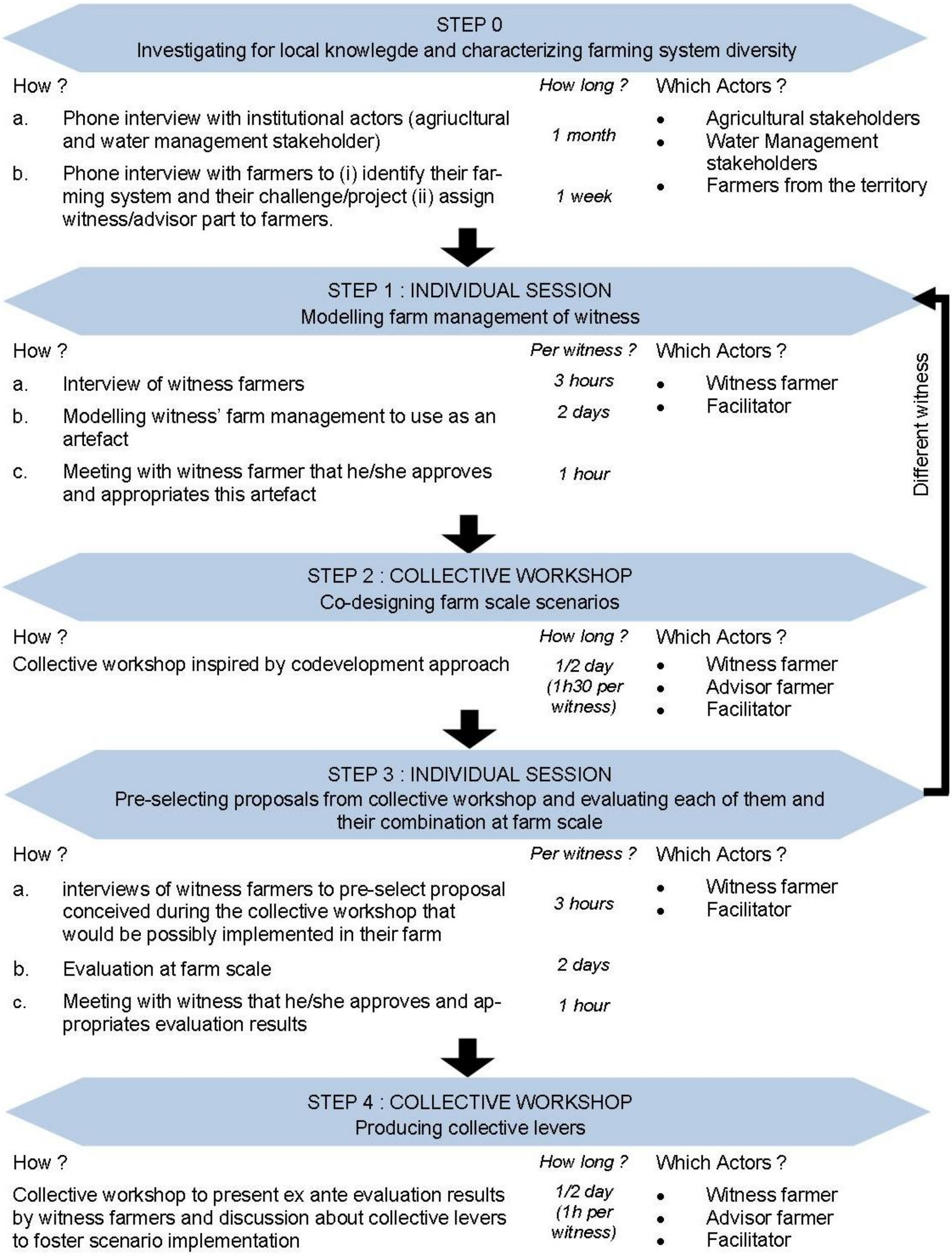

Figure 1. Five steps of participatory approach, alternating between individual sessions and collective workshops

The following four steps comprise a rotation between individual (cf. Fig. 1: steps 1a, 1c, 3a, 3c) and collective sessions (cf. Fig. 1: steps 2 & 4). The purpose is to create empowerment and acceptance from farmers, which are crucial for the success of decision and implementation process of agroecological practices (Newig et al., 2008). The two collective workshops allow sharing local knowledge and experiences between farmers that lead (i) to individual and collective learning, and (ii) to create room for innovation at farm scale. An artefact (cf. Fig. 2) – a model of witness' farm management – is used during the first collective workshop to support scenario design at farm scale.

Each step of the approach is illustrated in the results section thanks to the implementation on the case study. The following section presents methods and tools used during the participatory approach to design scenarios suitable for farm management. They ensured that the farming system level, including structure and strategy, is taken into account in the co-design process (Richard et al., 2018).

Methods and tools to co-design at farm scale

Farmer-based method

An effective participatory approach requires greater empowerment of farmers (Cardoso et al., 2001; Dorward et al., 2003) where they can find some discussion and experimentation spaces in which they get means to overcome the practical, cognitive and social uncertainties they face in changing their professional practices (Cerf et al., 2010). The agricultural system transition, *e.g.* toward agroecological practices, renewed the importance given to local conditions and knowledge acquired through practices in the field by the practitioner themselves (Girard, 2015). Moreover, designing farming practices addressing the environmental impacts of agriculture calls for systemic approaches, in which the farms' components are taken into account as soon as the design process begins (Dogliotti et al., 2005; Dorward et al., 2003; Joannon et al., 2006; Lefèvre et al., 2014; Prost et al., 2017). This systemic approach at farm scale requires an exclusively farmers' participation.

Modelling farm management

The design process is supported by the use of an artefact, i.e. material or abstract items created before or during a design process and constituting an interface between actors (Martin et al., 2013). This artefact is a conceptual model of the witness' farm management. This model is built through a preliminary interview and a meeting with the chosen witness farmers to understand and further represent their actual farm management (cf. Fig. 1: steps 1a. & 1c.). It includes the description of the workforce unit, the machinery resources, the agricultural surface, the land occupation and the map locating each group of plots associated to cropping systems and their interconnection (*e.g*. exchange of seeds) (cf. Fig. 2)
Witness farmers, while presenting their farm, used this model as a support of their speech. Adviser farmers, while discussing about witness' challenge and proposing suitable solutions, can use it as a support of their brainstorming. And finally, the facilitator used it as a support to have a systemic approach throughout proposals *i.e.* taking into account resources and interdependencies between cropping systems.

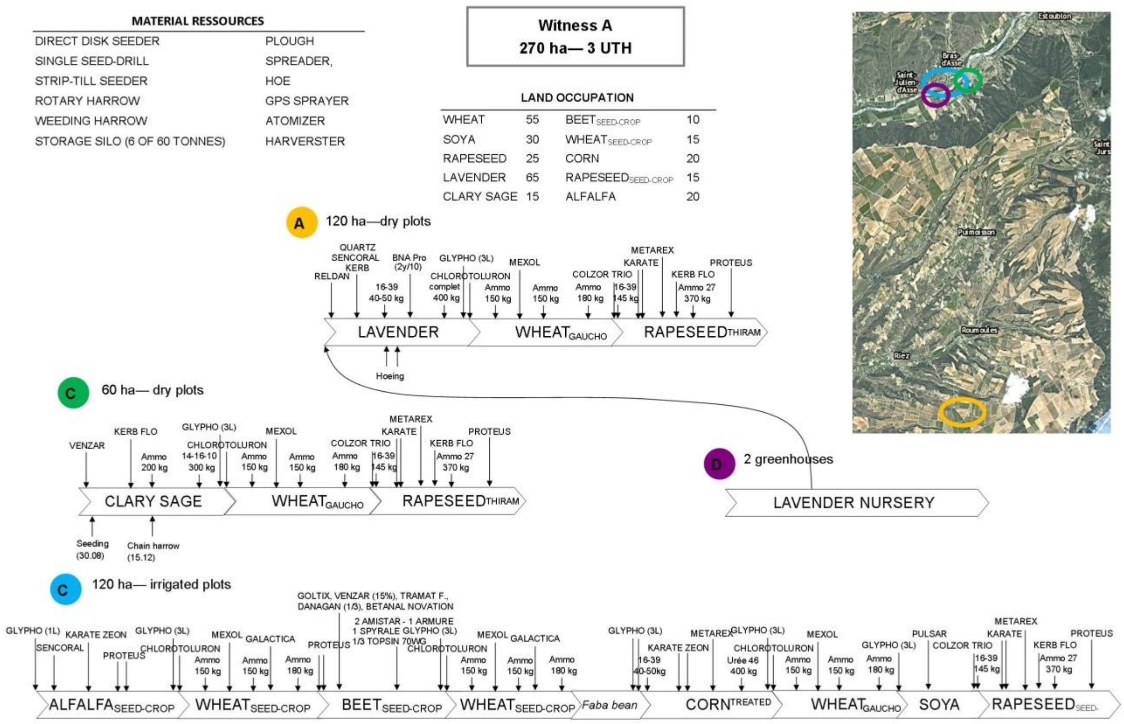

Figure 2. Artefact - model of witness A's farm management.

Evaluation at farm scale

The objective of the evaluation stage is to develop a method (i) easy to master and (ii) able to assess the suitability of proposals for farm management and their consistency to protect groundwater quality. The evaluation at farm scale is a multi-criteria assessment method designed to assess the agronomical, social and economic performances of proposals and their efficiency to reduce pressure on groundwater quality. The indicators were identified through stakeholders and farmers interviews according to their objectives (Girardin et al., 2005) (e.g. 'improving soil quality' associated with the indicator 'organic matter content'). For each proposal, we evaluated the difference of witness' farm management between the baseline and the scenario after implementation of one proposal (for instance an agroecological practice, a new cropping system) (cf. Fig. 3(a)). Then, we evaluated the difference of witness' farm management between the baseline and the final scenario after implementation of all the proposals combined in a unique scenario (cf. Fig. 3(b)).

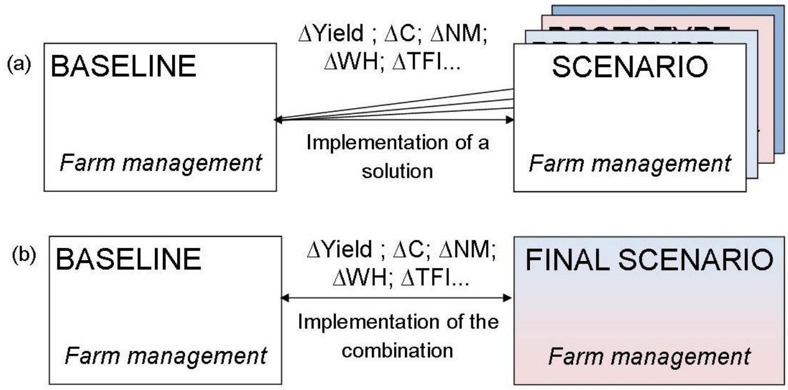

Figure 3 : Steps of *ex ante* evaluation method (a) evaluation for each implementation and (b) for the combination implementation

The agronomic dimension was represented by the yield performance and soil organic matter content (SOM). The crop yield performance was calculated through local expertise whereas SOM difference is estimated through bibliography and local references. For example, to assess the proposal "inserting faba bean in the rotation", we referred the impact of this proposal's implementation on organic matter through references from publication (scientific paper or grey literature) or reference from experts.

The economic dimension consists in two basics indicators: full costs and net margin. The differences are calculated and all the economic data (*i.e.* input prices) are collected through local references (phone call to agricultural cooperatives and economic actors).

The difference of working hours per 15 days and of their allocations through a year, between the baseline and scenarios, is an indicator of social performances.

Finally, the effect on groundwater quality's pressure is calculated by the variation of Treatment Frequency Index of active molecules (TFIam) and estimated by the amount of nitrogen potentially lixiviated difference through bibliographic and local references.

These indicators are basic and give information trends on the impact on economic, agronomic and social performances and groundwater quality pressure. These trends can be discussed, during step 4, according to local factors that affect the performances and lixiviation. The main objective of this evaluation step is to predict impact of proposals at farm scale and foster their implementation by farmers. So we must take into account the point of view and knowledge of those who are also the managers of the systems to change. The results must be realistic according to local farmers.

Table 1. Description of indicators evaluated by calculation or estimated through bibliographic and local references to have an *ex ante* assessment of each proposal implementation

OBJECTIVE		INDICATOR OR VARIABLES		UNIT	THRESHOLD
AGRONOMIC	Improving yield	Yield spread by crops difference	$\Delta Y = yield_{scenario} - yield_{baseline}$	kg/ha	<0 : inconsistent (decreasing the yield) >0 : consistent (increasing the yield)
	Improving or protecting soil quality	Soil Organic matter (SOM) content difference	Bibliographic and local references	NU	<0 : inconsistent (decreasing OM content) >0 : consistent (increasing OM content)
ECONOMIC	Decreasing costs (C)	Operational (CO) and mechanization (CMMO) charges difference	$\Delta C = (CO+CMMO)_{scenario} - (CO+ CMMO)_{baseline}$	€	<0 : consistent (decreasing charges) >0 : inconsistent (increasing charges)
	Increasing net margin	Net margin (NM) difference	$\Delta NM = [(yield * price) – C]_{scenario} - [(yield * price) – C]_{baseline}$	€	<0 : inconsistent (decreasing NM) >0 : consistent (increasing NM)
SOCIAL	Reducing working hour	Working hour (WH) difference per fortnight	$\Delta T = WH_{scenario} - WH_{baseline}$	Hour/ fortnight	<0 : consistent (reducing WH) >0 : inconsistent (increasing WH)
	Better spreading of working hour	Competition of working hour between agricultural activities	Working calendar	hour	
GROUNDWATER QUALITY	Decreasing pesticides use	Treatment Frequency Index of active molecules difference	$\Delta TFIma = TFIma_{scenario} - TFIma_{baseline}$	NU	<0 : consistent (decreasing TFIma) >0 : inconsistent (increasing pesticides use)
	Decreasing amount of nitrogen lixiviated	Amount of Nitrogen potentially lixiviated difference	Bibliographic and local references	NU	<0 : consistent (decreasing nitrogen potentially lixiviated) >0 : inconsistent (increasing nitrogen potentially lixiviated)

Case studies

The case study area is located in south-east of France around Oraison (43°54'N; 5°55'E). The agricultural surface of the five witness farmers are located within two shallow aquifers presenting quality issue related to farming activities with nitrates and pesticides pollution.

The selected farmers were chosen from the French DEPHY farm network because they had already ambitions to decrease pesticides use and to change their farming system towards more environmental friendly systems. It seemed also easier to commit them for attending to the participatory process. There were eleven farmers who were mostly arable cash crop growers, as only one had sheep breeding. Six farmers were practicing conservation agriculture, three were managing conventional systems with shallow tillage and two were certified in organic farming. Altogether, they have a common objective to protect and improve soil quality monitored thanks to SOM. They grew beet and rapeseed that are high-value crops. The main crops of the cropping systems were durum wheat, corn and soybean. Nevertheless, each farmer had specific cropping systems tailored to their farm constraints, as they had different access to water resources for irrigation.

Results and discussion about a methodological illustration

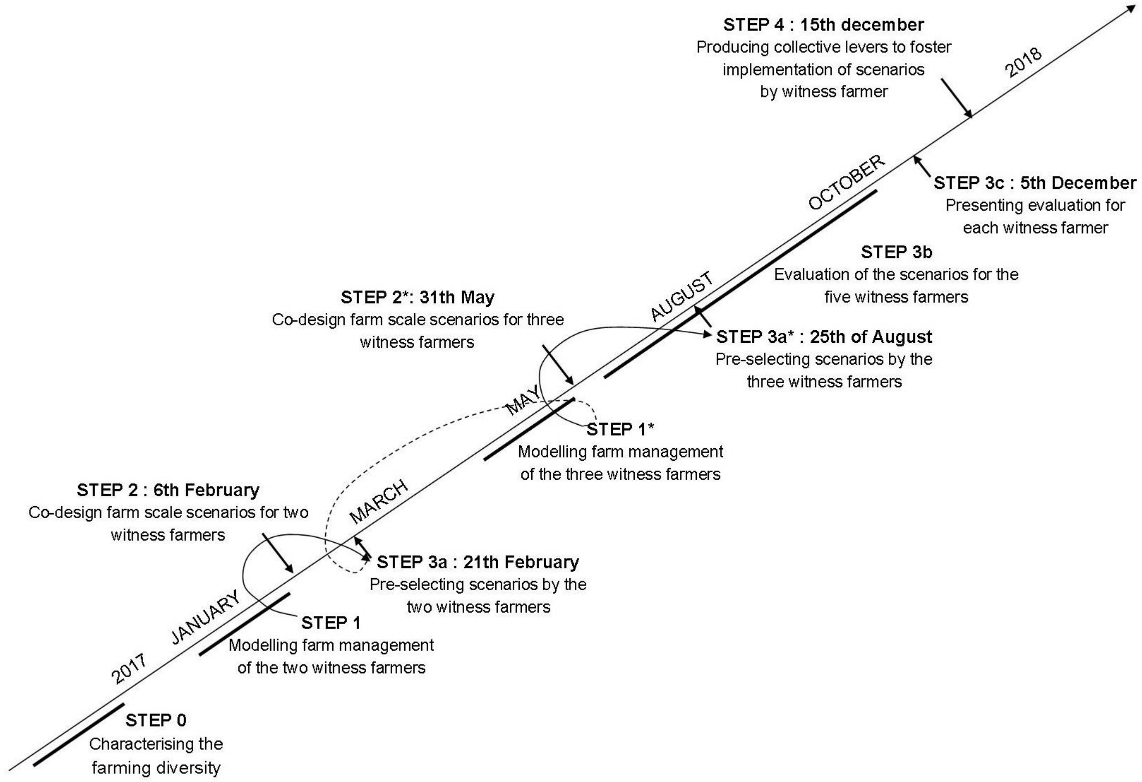

Figure 4. Timescale of the participatory approach's steps with the first and second* loops with witness farmers

Step 0: Collaboration with local stakeholders and identification of farmer candidates

This step was to contact stakeholders of water management to have information about the groundwater quality in the department and have the content of action programs developed. Then we contacted agricultural stakeholders to know about farming system diversity in the department to identify farmers who might be interested and willing to participate in the process and those who might have some challenge or project to develop and willing to be witness farmers. In this case study, we piloted the participatory process with the local coordinator of the French DEPHY farm network as co-facilitators to get legitimacy and facilitate farmers' participation.

Thanks to the local information, farmers were called in order to (i) introduce the project in collaboration with DEPHY network (ii) present the first collective workshop proceedings and (iii) plan a date of the collective workshop. For pre-selected witness farmers, we asked for their participation as witnesses and if agreed, we scheduled an individual interview.

This preliminary step has been useful to identify and work with a dynamic group of farmers, willing to change their farming systems. This context was thus favorable to develop this participatory project with exclusively farmers. This collaboration with the local Agricultural Chamber was helpful to have legitimacy for local farmers. We can wonder if without this local "gatekeeper" (Remenyi, 2012) we could have engaged farmers in this process.

Step 1: Modelling witnesses' farm management

This step involves three distinct stages. The first one was to interview witness farmers, before the collective workshop. We interviewed five farmers with a semi-structured interview to let them express their own farm management (Blanchet and Gotman, 2010). We combined this approach with fields mapping, because this method has proved to facilitate the dialogue with farmers on their field management (Saqalli et al., 2009). The objective of this interview was to record the farm management of witness farmers, i.e. their structure (practices, rotation, cropping systems, human and material resources and socio-economic environment) and their main objectives. They were conducted in face-to-face, two weeks before the collective workshop, and recorded before transcription. Collected data were useful to represent witnesses' farm management reality (cf. Fig. 2). This artefact construction was the second stage. For each witness farmers, two days of work were sufficient. Then, the third stage was to meet the witness farmers for validating the artefact and to take active ownership of this artefact by the witness farmers during the workshop.

We could wonder if the representation we made of their farm management depicts the way they saw their farm. That's why we believe that the artefact and the validation by the farmer was crucial.

Step 2: Co-development workshop

The second step was to run a collective workshop inspired by co-development methods (Payette and Champagne, 1997). Each witness farmer presents his challenge or project to realise. For each witness farmer, 'adviser' farmers shared their own experiences and knowledge for making proposals to their problematic or project. As we identified five witness farmers, we ran two co-development workshops, respectively on the 6th February 2017 and the 31st May 2017, that were recorded before transcription (cf. Fig 4). During the first one, two groups were formed, each including one witness farmer and three or four 'adviser' farmers. During the second one, there were also two groups with respectively one witness together with three adviser farmers and alternately two witness farmers (who presented one after the other) followed by three advisers (cf. Fig. 4).

We present here the example of one witness (farmer A) to show the outputs of such workshops. His farm management is presented on Figure 2. At the beginning, as co-facilitators, we welcomed farmers and introduced the context of groundwater quality protection. These farmers from DEPHY network had the same strategy (soil quality protection, decreasing costs and maintaining production), so we gathered farmers by their farming system. Witness A worked with three adviser farmers. He first presented his farm components (cropping systems, machinery, materials…) and introduced his challenge: 'reducing inputs'. The adviser farmers asked questions of clarification. Once they agreed about his challenge to reduce his inputs, they began to discuss and propose solutions: the consultation stage started. During *consultation*, the role of the facilitator was:

i. To allow discussion between adviser farmers but refocusing if necessary
ii. To write down, in green on the artefact, the proposals (cf. Fig. 5)
iii. To keep a holistic approach when a proposal was made, i.e. make adviser farmers describe every material and human resources implied by the proposal.
iv. To take note of the lock out expressed by witness farmers

For witness A, various solutions have been proposed (cf. Fig. 5) and can be sorted according to their strategies that are consistent with the challenge of decreasing inputs:

1. Protecting and improving soil quality: implementing inter-row frost-sensitive cover crop between lavender in the cropping system A (cf. Fig. 5) and cultivating rapeseed associated in the cropping system B either with vetch (inspired by the experience of one adviser farmer), or a mix of barley and rye to control slugs or alfalfa (because the crop is already cultivated on the farm and on-farm seeds are thus available).

2. Improving treatment efficiency: applying low-volume treatment and substituting chemical pesticides with biological ones (e.g. METAREX® to IRONMAX®) in the cropping systems A, B & C (cf. Fig. 5) and treating alfalfa with castor meal, natural pesticides or rodenator machine to protect from wireworms.

3. Lengthening the rotation: implementing faba bean crop between wheat in the cropping system A & B (cf. Fig. 5) to control rye development and implementing a mixed cover crop of rye and hairy vetch in the cropping system A (cf. Fig. 5).

4. Decreasing costs: harvesting farm-saved seed of wheat and rapeseed crops in the cropping systems A & B (cf. Fig. 5).

All the proposals could be qualified as agroecological practices (Wezel et al., 2014). This result shows that the method tailored individual proposals predicated by collective expertise. However, the exclusive farmers' participation caused knowledge gaps. However, these farmers were already engaged in farming system change, most of them were looking for information from internet, scientific journals, forum, etc… and experimented in their field. In our case, one adviser was providing a lot of proposals, as he has been experimenting many practices (*e.g.* Farm-saved seeds, implementing cover crop in the rotation…) for ten years.

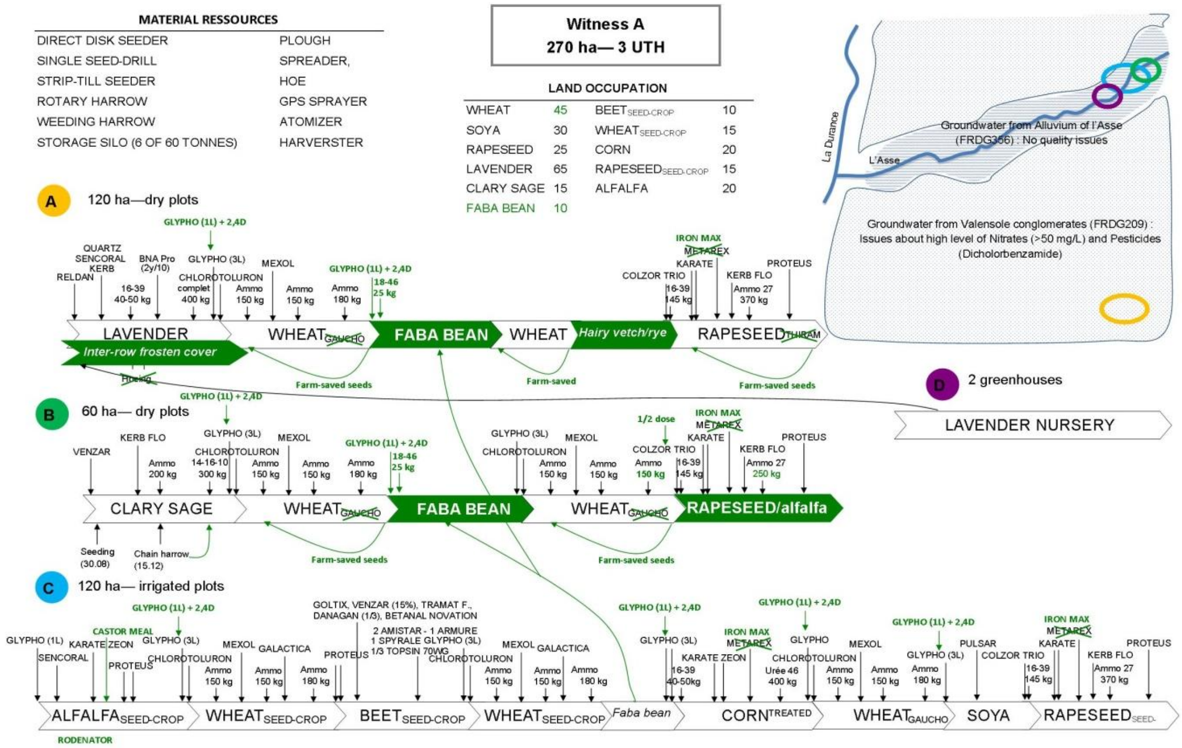

Figure 5. Illustration of the output from a co-development workshop - witness A model and the proposals made by adviser farmers (in green)

Step 3: Evaluation at farm scale

Before evaluating the proposals at farm scale, the first stage was to interview witness farmers for pre-selecting relevant proposals from the set developed during the collective workshop. We used the modified artefact (e.g. Fig. 5) for going through all the proposals made by adviser farmers. Each proposal was commented to decide whether it would be implemented or not in the witness' farm and the reasons why. In case of witness A, he did not select: (i) the rodenator proposal because it was a too expensive, (ii) the castor meal because he doubted its efficiency and (iii) the cover crop of hairy vetch and rye, because these plots were located one hour-drive from his homestead. The other proposals were pre-selected to be implemented in his farm in short and long-term. He decided to (i) keep farm-saved seeds of wheat for the next crop season and (ii) implement 5 hectares of faba bean after wheat harvest as he had some seeds left from the other cropping system (cf. Fig. 5. cropping system C).

Then, for the pre-selected proposals, we carried out an *ex-ante* evaluation. We contacted key actors as farming cooperative to have information about the input prices, research institute to have some scientific results (*e.g.* effects of inter-row cover crop in lavender on soil). We built our database on the basis of local references to assess *ex ante* performance for each proposal, and being as close as the local reality.

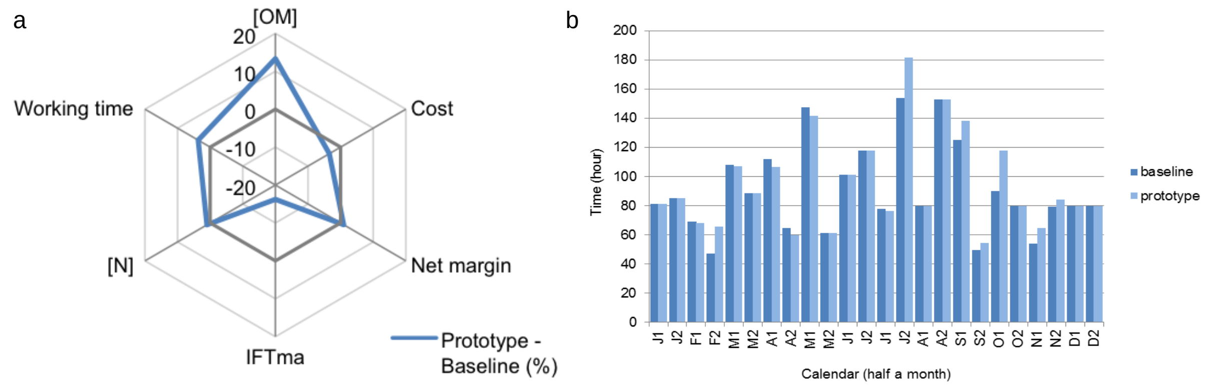

Figure 6. Evaluation performances of scenario versus baseline of witness A's farm management (a) % of difference for each indicators and (b) working hours allocation during a year

For witness A, we can observe that the final scenario was quite consistent to reduce pressure on groundwater quality. It decreased around 15% of IFTma and implied no variation of applied nitrogen fertilizer rate, and potentially lixiviated (cf. Fig. 6a). We can also note that if the farmer implements the combination of proposals, he will reduce costs. Indeed, saved-farm seeds for wheat and rapeseed made him save 160€.ha^{-1} and 70€.ha^{-1} for wheat and rapeseed crops. Despite this cost decreasing, it did not increase net margin because five hectares of wheat were substituted by faba bean that had a lower net margin, with 1,9 t.ha^{-1} yield according to local references[2]. However, wheat yield is expected to increase after legume crop and reduces 9kg/ha of fertiliser amount (Schneider et al., 2010). This implementation of faba bean and inter-row cover crop is expected to increase OM content in plateau of Valensole soil from 1,2 to 1,5 % (cf. Fig 5. cropping system A). Finally, the scenario did not better allocate working hours during a year, and increased working time during July for harvesting faba bean, then during August and October for respectively seeding then mowing/crushing inter-row cover crop in lavender.

Our farm scale evaluation only gives general trend on the impact on groundwater quality. Evaluation of environmental effects of farmer practices would be better using indicators allowing expression impacts both per unit surface and product (van der Werf and Petit, 2002). For economic evaluation, it is interesting to have a global vision of the effects on costs and net margin, because it reveals the costs to implement a new crop in cropping systems. Likewise, assessing change in working time through a year can reveal competition among farming activities. However, it is essential to keep track of results at crop level to be able to explain the origin of economic and working time variation.

After proceeding to farm scale evaluations, we met, for the forth time, witness farmers. During this individual meeting, we presented the evaluation results and discussed the need to adjust the results if needed. This stage created a sense of ownership by witness farmers and ensured their involvement for the last step.

Step 4: Collective workshop

The last step was a collective workshop with exclusively farmers. The objectives were (i) to present the evaluation results of each proposal when implemented, and their combination, (ii) to discuss about collective levers to foster implementation of proposals by witness farmers, and (iii) to note which other farmers could be interested by implementing some proposals and study their potential extrapolation.

Witness A presented proposals (i) he already implemented such as 'faba bean introduction' and 'farm-saved seeds of wheat' and (ii) he might implement as it was suitable but expressed lock-in *e.g.* appropriate seeder to implement intercropping rapeseed. Among farmers, one proposed to make the seeding of faba bean and rapeseed as he had the appropriate

[2] Perspectives Agricoles, mensuel octobre 2016 « Légumineuses : des plantes aux multiples usages »

machine to succeed intercropping rapeseed. This step fostered material exchanges and practical advices, to remove local lock-ins for implementing the proposals.

For the other four witness farmers, this participatory approach has been more or less consistent. For the witness farmer B, the proposals made by other farmers have not been selected due to the inconsistency with his farm management. For witness farmers C & D, their challenges or projects were not clear at the beginning of the *consultation*. There were no consistent proposals. However, for the witness farmer E, his project was to develop agroforestry in a dry plot of 21 hectares. Many proposals have been selected to implement them for 2018 (*e.g.* planting 5 tree species, among them, 300 pistachio trees because one farmer already grew them).

Conclusion and Next Steps

According to Chantre (2016) "stakeholder participation is recognized as a prerequisite to identifying and implementing changes in agricultural practices that are both acceptable and likely to improve water quality". In our study, "stakeholder" is defined as farmer. Our approach elicits a process where farmers share their knowledge, their personal experiments and give practical suggestions. This paper shows that this farmer-based method with a systemic approach can foster involvement of farmers in a participative process, and should favour further scenario implementation to recover groundwater quality. It constitutes an interesting viable alternative to the more standard government-driven process for action program development. This approach is suitable for small catchment areas or catchments with an area of prime concern that include less than 40 farmers, because beyond, this farmer-based method makes the process longer and difficult to realize.

Compared to participatory approach developed for groundwater quality protection, scenarios from this generic method are more ambitious than implementing cover-crop in rotation (Paravano et al., 2016) and less ambitious than the conversion to organic farming (Chantre et al., 2014). However, the witness farmers have mostly implemented these individual and tailored scenarios, when they were suitable for their farm management. We can mitigate this result, as the group of farmers invested in this process was already willing to change their practices. What about farmers cultivating in catchment area and without any desire to change their farming system? The method is currently being improved and tested with another group of farmers cultivating in an area catchment with quality issue.

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