ELABORATING INNOVATIVE SOLUTIONS WITH EXPERTS USING A MULTICRITERIA EVALUATION TOOL. THE CASE OF SOIL BORNE DISEASE CONTROL IN MARKETGARDENING CROPPING SYSTEMS

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Résumé – Imaginer des systèmes innovants avec des professionnels agricoles en utilisant un outil d'évaluation qualitatif. Le cas du contrôle des maladies et ravageurs du sol en maraîchage sous abri. Le maraîchage sous abri est très sensible aux ravageurs et maladies telluriques. Jusqu'à présent, la productivité de ces systèmes reposait presque exclusivement sur la lutte chimique, mais des systèmes alternatifs doivent maintenant être trouvés pour des raisons environnementales, sociétales et pour la santé humaine. Plusieurs techniques culturales sont connues, mais ne permettent qu'un contrôle très partiel des maladies et ravageurs. L'objectif du projet est de construire des systèmes alternatifs avec des conseillers techniques et des agriculteurs, en augmentant l'efficacité des combinaisons de techniques déjà connues et/ou en inventant des systèmes plus innovants. Le projet se déroule en deux étapes. La première consiste à construire un outil pour évaluer la résistance/résilience des systèmes de culture aux ravageurs et pathogènes. Le second consiste à utiliser l'outil avec un groupe d'experts pour concevoir de nouveaux systèmes techniques, à l'échelle de la parcelle mais aussi de l'exploitation. Comme les connaissances scientifiques sur les effets des combinaisons de techniques sont lacunaires, les connaissances pratiques des conseillers et des agriculteurs sont également mobilisées. Le modèle support de l'évaluation est un outil multicritère qualitatif ; il est déjà disponible pour les nématodes, et en construction pour les champignons du sol. La seconde étape va consister à utiliser ce modèle avec un groupe de conseillers techniques et de producteurs, pour imaginer des systèmes techniques qui pourraient contrôler les pathogènes sur le long-terme. Les systèmes les plus prometteurs seront alors testés dans des stations expérimentales et en parcelles de producteurs. La co-construction avec des professionnels agricoles vise à imaginer des solutions qui soient à la fois performantes sur le plan pathologique et réalisables dans les exploitations agricoles. L'article illustre en quoi l'utilisation de connaissances expertes ne permet pas seulement de combler les trous de savoirs, mais aussi d'imaginer des solutions innovantes.

Mots clés : évaluation qualitative, système de culture, contrôle des pathogènes, approche participative

Abstract - Market-gardening cropping systems in protected cultivation are very sensitive to soil-borne pests and diseases. Their productivity used to rely on pesticides, but alternative systems have now to be found for environmental, societal and health reasons. Many cultural techniques are known to provide some control of soil-borne diseases, but are only partially efficient. The aim of the project is to design alternative systems with professionals, by improving the efficiency of the present techniques and/or imagining more innovative systems. The research project takes place in two steps. The first one consists in building a tool to assess the resistance or resilience of a given cropping system to soil-borne pests; the second one consists in using the tool with professionals in order to build alternative cropping and farming systems in cooperation. The model built for evaluation is a qualitative multicriteria tool. As scientific knowledge is not available for each technique or combination of techniques, empirical knowledge collected from growers and technical advisers is used to fill the gaps. The model is already built for root-knot nematodes and under construction for the other fungi.The second step will consist in using the tool with technical advisers and growers to redesign cropping systems and select the promising ones that should be put into trial in R&D stations. Co-building farming systems with stakeholders appears as an absolute necessity, to imagine solutions both efficient and acceptable for growers. The presentation will enable to discuss how combining expert and scientific knowledge may not only fill the knowledge gap, but also enable to build innovative solutions thanks to the diversity of experts' standpoints.

Keywords: qualitative evaluation, cropping system, pest control, participatory approach

INTRODUCTION

Farming systems must evolve to fit to the major economic and social changes of the next decades. This is mostly true for protected vegetable crops that face new stakes such as limiting use of chemical products to avoid pesticide residues in the food products and in ground water, while avoiding any visual symptom of pests and diseases to agree with marketing-firm requirements. Moreover, market-gardening cropping systems in protected cultivation are very intensive and are often characterized by a very low number of crops in the rotation. They are therefore very fragile as regards pests and diseases.

The aim of this project is to build sustainable cropping and farming systems for protected vegetable production in a co-design process with users. It relies on using alternative techniques such as diversified crop sequences, thermal disinfection or organic manure and optimizing their combination to enhance the natural regulatory processes in the soil. But it also goes beyond technical changes and refers to organisational and even strategic change. Following Elzen and Wieczorek (2003), we consider it as a transition situation, combining technical and societal change rather than an incremental change on technical sphere. This goal cannot be reached by using the sole scientific knowledge for two main reasons. First, systemic scientific knowledge on that subject is very poor whereas a wealth of information and knowledge is available from local practitioners, especially on the interactions betweens techniques, environment and the expression of pathogens' activity on the plants. Second, significant changes in farming systems cannot be proposed by searchers only, because they would not be adapted to farmers' constraints and farm complexity. We propose to rebuild farming systems thanks to an association between scientists and professionals; the hypothesis is that it is possible to build new agronomical knowledge based on a synergy between empirical knowledge of producers and scientific knowledge.

In the literature, building new cropping systems often relies on models. But several authors highlight that most models or decision support systems built by scientists are underused or sometimes even misused, and insist on the absolute necessity to think to the model use before its building (Cox, 1996). Among the various types of using decision support systems with actors (Mc Cown, 2002), some refers to participatory approaches, which rely on a change of paradigm, from a positivist to a constructivist one, by considering farmers as active co-developers of new technologies (Douthwaite et al., 2003). But very diverse positions are found in the literature, depending on the extent of the involvement of scientists and experts. Who build the new systems (mainly the scientists, in a balance between professionals and scientists, mainly professionals)? What is the specific role of scientists? Who chooses the evaluation criteria and who conducts the evaluation process?

Our approach relies on a combination of both 'hard' and 'soft' science, reductionist research and participatory approaches as in the Integrated Natural Resource Management approach (Douthwaite et al., 2003). The first one enables to analyse the basic biological processes, such as the effects of cultural techniques on the development of pathogens, using scientific criteria. For that purpose, we use the knowledge produced in agronomical experimentations, in experimental fields and sometimes even more controlled conditions. The second one is embedded in growers' practices. It aims at analysing their knowledge (on plant diseases, on farming system management) and using it altogether with scientific knowledge to build alternative farming systems.

The project combines two complementary approaches. The first one consists in building a qualitative model to assess the effects of cropping systems on pests and diseases, based on scientific and expert knowledge. The second one consists in building alternative cropping systems with growers, using the qualitative model as an artefact to facilitate debates among growers and scientists. We therefore consider the software as a tool for establishing mutual understanding between the various actors involved, as in the interpretive paradigm proposed by McCown (2002). Putting growers in an innovative process of farming system design, helping them to formalise and test various scenarios should be more promising that the alternative farming systems themselves, because the social and learning processes initiated are more useful than the technical improvement itself.

1. A QUALITATIVE MULTICRITERIA EVALUATION MODEL

To assist growers in designing and choosing a new cropping system, knowledge of its potential for production but also to control pests and diseases is needed. The goal of the evaluation model is to provide this knowledge, starting from a description of the cropping system. Because a cropping system consists in the association of several elements (crop sequence and calendar, management techniques) which may all influence the evolution of pests and diseases in the soil, an aggregative evaluation method is needed. Cropping systems must also be evaluated along several dimensions, production and economic potential, environmental impact, pests and diseases control, calling for a multicriteria evaluation. Although the contribution of many cropping techniques to the control of soil-borne disease has been studied (see, among others, Scopa et al. 2008 for solarisation, Abawi and Widmer, 2000, for cover crops, green manure, compost and tillage) little literature exists on their combined effects. Growers and advisers, however, do have some experiential knowledge on the effects of some combinations, when they use them. The evaluation model must therefore make use of both available knowledge types.

1.1 Qualitative multicriteria evaluation methodology

Following the analysis of Sadok *et al.* (2008), we have chosen to use a rule based, qualitative approach, because it is more adapted to sustainability evaluation and to the incorporation of farmers' and expert knowledge. The DEXi system (Žnidaršič *et al.* 2008) implements such a methodology. In this approach, the model consists of variables (called *attributes*) hierarchically linked in a tree to ultimately form the *output* (or final scoring attribute). Terminal nodes of the tree represent *inputs*. Intermediate attributes form *aggregate attributes* which result from the aggregation of input attributes and/or of lower level aggregate attributes. All attributes take symbolic values (words) and these values are aggregated according to *rules*. In this methodology, a cropping system is described by a vector of variables (crop sequence, tillage techniques, fertilisation management, soil sanitizing techniques...) which correspond to the input attributes.

1.2 Qualitative evaluation tree

The qualitative evaluation tree mainly relies on an analysis of the scientific literature, even if the description of the cropping systems takes into account the way growers implement their techniques at field level.

To clarify and organize the effects of the cropping system on pests and diseases, we have followed two rules. The first rule is to divide the effects by the way they interact with the pests or pathogens. This rule has been applied with success to build an evaluation model to assess the effect of sheltered vegetable cropping systems on root-knot nematode management (Tchamitchian *et al*., 2009). However, common soil-borne pests and diseases in these systems also include fungi (*Sclerotinia* spp, *Botrytis cinerea*). It is therefore necessary to build an evaluation model addressing this range of pathogens. Because a single technique may have contrasting effects on these pests and diseases while others may have more consistent effects, building one evaluation tree for each pest or disease and finally aggregating them should be avoided. Hence, the second rule is to group pathogens on the base of their functional responses to the different elements of the cropping system, by analogy to the *functional traits* approach used in ecology (Lavorel & Garnier 2002). The grouping may of course be different depending on the branch of the tree. For example, solarisation or steam disinfection have a lethal effect on both root-knot nematodes and fungi while crop rotation will differently affect them. To build the evaluation tree, several options are possible. The first is to start from the input attributes (terminal nodes, description of the cropping system) and to aggregate them progressively until the final and overall aggregate attribute is obtained. The advantage here is that no element of the cropping system should be left alone; the disadvantage is that combined or synergetic effects are more difficult to identify. The second option is to start from the top-most aggregate attribute and to divide it progressively into core components, until the terminal nodes are reached. The advantage is a more synthetic approach and model with an easier identification of combined effects, with the risk however that some elements of the cropping system are left because their action is not readily identified. We have chosen to follow a mixed approach combining a top-down and a bottom-up analysis. Higher aggregate attributes are identified from an analysis of the possible ways of controlling the pests and diseases, while input nodes were listed from the description of the elements of cropping systems. The challenge here is to join the two parts while avoiding redundancies and missed connexions.

According to the analysis of the different pathogens concerned (root-knot nematodes, soil-borne fungi), three rather independent means to control the soil-borne pests and diseases were identified: actions affecting the pathogen itself, actions affecting its biotic and abiotic environment and actions modifying the plant sensitivity to the pathogens. These will form the top-most aggregate attributes of the evaluation tree.

Actions affecting the pathogen

We group here the effects that alter directly the total population of the pathogens in the soil (lethal techniques for example) and the actions that alter its life cycle. The lethal actions sub-tree covers both chemical and non-chemical techniques that aim at killing part of the pathogen populations. Solarisation, biofumigation (incorporating a crop whose decomposition in the soil will produce biocidal volatile compounds), steaming are such techniques, which are described by their frequency, their application conditions and other technical details. Concerning frequency, for example, Candido *et al.* (2008) showed that yearly solarisation can control the root-knot nematode infestation on the long term while a single application has an effect limited in time. In the case of biofumigation, the choice of the crop to be incorporated in the soil (species and cultivars) modifies the intensity of the effect (Collins *et al.*, 2006; Lazzeri *et al.*, 2003). Because these techniques are not selective, no mention of the target pathogen is made here. However, their efficacy depends on the initial level of the pathogenic population, so their effect is finally weighted by a qualitative estimation of the infestation level of the plot on which the cropping system should be applied.
Altering the life cycle of the pathogens encompasses different techniques preventing the completion of that cycle. Choosing planting dates and species so that the plant infestation phase is not possible is one way, which is described in this model by *integrated* variables describing how long the cycle break is (rather than by enumerating the crops and their planting dates). However, it is not possible to group the different pathogens at once: cycle breaks for fungi seems to be more effective in winter, while for root-knot nematodes they should occur in warmer soils, when females need host plants to end their cycle and reproduce. Evaluation of the cycle is therefore made for root-knot nematodes on one hand, for fungi on the other hand and aggregated afterwards.

Actions affecting biotic and abiotic environment of the pathogen

Soil-borne pathogens are part of an ecosystem and as such their evolution is interrelated to that of the other living organisms of the soil and to the physical and chemical environment provided by the soil, but also of the aerial microclimate for the fungi once they have infected a plant. Brussaard *et al.* (2007) have listed the different agricultural management practices that affect the soil and their effects on the soil microbial and fauna activities. The most beneficial practices encompass organic amendments, green manure, fertilisation, tillage and crop rotation and sequences. Concerning green manure, compost and amendments, two effects are identified. The first is a modification of the trophic conditions for the pathogens, the second is a modification of the biotic communities present in the soil. There are however little evidence that modifying the competitions in the soil modifies its infestation level by fungi like Sclerotinia *spp*. or Botrytis, while this appears more promising in the case of root-knot nematodes (van der Putten *et al*. 2006). Modifications of the abiotic conditions in the soil mainly refers to irrigation and mulching, changing the humidity and temperature in the soil.

Actions modifying the plant sensitivity to the pathogens
There are some evidences that the plant nutrient state, controlled by the fertilisation practices, modifies its susceptibility to infection by pathogen (Hoffland *et al.* 2000). These evidences refer mostly to plant-fungi interactions, while no available literature report evidences for modifications of the nematode-plant interactions due to the plant nutrient status.

From the literature review, two main problems were identified. First, inconsistent results are indentified on the effects of some techniques such as organic amendment or tillage techniques on disease control. Second, there is a lack of knowledge as regards combination of techniques (such as combining organic amendment and solarisation).

1.3 Multicriteria evaluation model

The previous part focuses on the description of the evaluation of the potential of a given cropping system to control root-knot nematodes and soil-borne fungi. The final grade is qualitative (good, fair, low and no-control). When a non satisfying grade is obtained, the method used for aggregation allows to identify which sub-tree is responsible for this grade, pointing at which group of elements should be improved to obtain a more satisfying score. Based on a preliminary work (Salles 2007), a model for the evaluation of the environmental impact of the vegetable cropping systems is under design using the same methodology and reusing the input attributes when possible. This will allow, in the future, to combine environmental and sanitary dimensions in the evaluation.

2. A DESIGN PROCESS INVOLVING USERS

The second step of the project, designing alternative cropping and farming systems, is the step where growers and technical advisers are most involved.

2.1 From an increase in technical efficiency to system re-design

Among the techniques previously described, few enable to limit soil borne disease without altering crop sequence management or crop successions (except steam disinfestations). Even green manure or solarization locks up a greenhouse for 2 to 4 months, and therefore modifies the organization of human labour and crop sequence. The slightest change may consist in improving the efficiency of these already used techniques, by improving the processes (dates of application, practical modalities), or their combination (as an example combining biofumigation and plastic mulch so as to boost biocidal compounds production). The production systems analyzed rely on a very limited species diversity: lettuce crops in winter and *Cucurbitaceae* and *Solanaceae* crops in summer. Changing crop rotations for pathological reasons implies to introduce new species in the crop sequence either to reduce the frequency of very sensitive crops or to introduce species having biocide effects (such as *Brassicaceae* and *Alliaceae*…). This change would not only modify the crop sequence but also implies to sell new food products and find new markets. Another way to limit soil borne pathogen development could be to rethink the crop allocation, *i.e.* the organisation of species on plots (moving one particular species from sheltered plot to open field…).

All these changes can be replaced in the ESR model proposed by Hill and Mac Rae (1995), where innovations can be classified in 3 categories depending on the intensity in change: those which enable to increase the efficiency of techniques already used (E); those which consist in substitution of one technique by another (S) and those relying on deeper changes and system redesign (R). In the case of soil borne disease, most of the changes refer to the "Redesign" modality and cannot be designed by scientists alone, otherwise they would be rejected by growers.

2.2 Building technical specifications for system redesign

What is possible to change in cropping and farming systems? Today, most of the growers consider that they are submitted to heavy constraints and have very narrow leeway to alter their systems for pest and disease control, especially because of the economic constraints. But at the same time, the previous analysis showed that on an agronomical point of view, few simple techniques are efficient. Our aim is therefore to identify:

- Which cropping systems and which cultural techniques can be altered easily in most of the farms?
- In which types of farms the deadlocks can be broken and very innovative systems imagined that could become a showcase for other growers?

Table 1. Specifications for building cropping systems in farms. The example of two farms

Farm 1: a large farm (S=10ha), entirely covered with plastic shelters, with intensive cropping systems, selling products to a very specialised Producers' Organisation (PO). Main diseases caused by root-knot nematodes.

Sustainability component	Grower's global aim	Criteria for system redesign
Economy/Marketing	Priority to classical crops	Cropping lettuce in winter and *Solanaceae* or *Cucurbitaceae* in summer, at least on 2/3 of the sheltered area each year
	Limiting alternative crops (those for which the PO has a limited demand)	Planting < 20% surface area with alternative species
Agronomy	Intensive crop sequences	Commercial crops on 8 months/year/plot at least
	Limiting soil exhaustion	At least 1 green manure every 2 years
Pathology	Limiting dangerous pest or disease dissemination to other plots	Forbidding dissemination of nematodes if possible, but no particular action against fungi

Farm 2: medium farm (S=5 ha, 3 ha with plastic shelters and 2 with open field), selling products to national retailers, and direct consumers for a small part. Main disease problems coming from a high fungi inoculum level.

Sustainability component	Grower's global aim	Criteria for system redesign
Economy/Marketing	Balance between classical crops (sold to national retailers) and diversified crops (sold directly to consumers)	Cropping lettuce in winter and *Solanaceae* or *Cucurbitaceae* in summer at least on 1/2 of the sheltered area each year
Agronomy	Increasing organic matter	organic amendment at high rates
Pathology	Limiting the inoculum development and its expression in contaminated plots	Allowing the use of plots for non commercial crops (green manure) and/or thermal disinfestations (solarisation) for at least 2 month/year Delaying planting dates to escape disease expression

In market-gardening, technical leeway depend on global aims of the grower, production systems (Navarrete *et al.*, 2006), marketing channels (Navarrete, 2009) *etc.,* and have to be analysed on each farm or type of farm. As an example, Table 1 illustrates two examples of specifications for building cropping systems, coming from agronomical and economical analyses.

Table 1 only describes two examples, but the aim is to conduct an overall analysis at a regional scale. Experts provide their knowledge on the farm diversity. Moreover the way they describe diversity gives ideas on the possible ways of acting. It also enables to define a few pathological situations that have to be tackled (one particular pest with high level of inoculum and few control ways, or general prevention in order to avoid future contamination , …)

2.3 Building an expert group for system redesign

The first step is to set up an expert group who will participate in the co-design and choose the situations to focus on (among those indicated above). The active participation of the experts and their receptivity to innovation are key elements to ensure that the new cropping systems will be adopted. We plan to associate a wide range of actors involved in producing and selling vegetables: various growers, technical advisors, engineers in charge of experimental designs, but also commercial advisors that could help to alleviate the marketing constraints. The group is under construction. One difficulty is to look for an equilibrium among various types of actors so that each one ay express his opinion easily.

Then co-building phase will start. Regular meetings of the expert group will be organized to support the co-building. Using an iterative approach, we will try to build a few cropping systems satisfying agronomical, pathological and economical goals at the same time. Participatory approach should help to highlight controversy and understand the various stand points: specific knowledge belonging to one particular expert as regards the effects of one technique; differences in the points of view of the experts regarding the goals of cropping systems or the technical leeway of growers.

New cropping systems will have to be consistent in the combination of cropping techniques and structured to fit the very case in which they will be applied. Technical specifications will be used as a guide to identify leeway. As an example, in the first case of Table 1, economic conditions forbid a high diversification in crop sequence. But as the grower is used to cultivate green manure crops to improve soil fertility, the expert group may propose to use a particular species having a nematicide effect as *Tagetes* spp., *Crotalaria* spp. or *Brassicaceous* species and/or use of nematicide oilcakes. Moreover, the diversifications species (20% of the area) could be chosen for their nematicide effects (*Alliaceae, Brassicaceae*) and as a priority planted on the most contaminated plots. Prophylaxis methods could be used to avoid nematode contamination to plots which are yet infested. This implies a reflexion on tillage organisation (order of work among plots, decontamination of tillage machinery). On the contrary, in the second case of Table 1, the expert group may look for alternative solutions by increasing species diversification and organising it on the cropping pattern. As an example, the species most sensitive to one particular fungus (*e.g.* lettuce) may be scattered on the whole farm area, sheltered or not, instead of gathering them under shelters. This would lead to adapt cultivar choice to each specific area (lettuce and winter crops under shelters; chicory and autumn crops in open field as an example). Biocide organic amendments may also be proposed.

2.4 An overall evaluation of the cropping systems

The evaluation process relies on various criteria the expert group will identify. The work will not only focus on the field scale but may open to a wider one. Indeed, to modify the crop

sequences, it may be necessary to imagine new organisations at farm level (to combine several plots, especially shelters and open field) or at supply area basin level.
We plan to combine both expert and computerised evaluation thanks to the qualitative evaluation model. The tool is built to evaluate the agronomic and pathological effects of most of the techniques (but not all of them) at plot level and on a long term scale. The use of the model for long-term analysis is crucial because some of the techniques only have cumulative effects (green manure), which are hardly impossible to evaluate by the sole expert knowledge. But as indicated by Carberry et al. (2002), using a simulator at this step implies "*that farmers, initially sceptical about models (…), satisfy themselves of the simulator's ability to adequately mimic important aspects of their production situation and system function*". That is why the qualitative model will not be considered as "the model which tell the truth", but rather as an artefact which facilitates debates.
Moreover, an expert analysis will be conducted within the group to evaluate the interest of new systems at farm level, since the evaluation tool does not tackle such scale. It will also enable to enlarge the criteria available in the model, to take into account the economic and organisational consequences of innovations.

2.5 A process for improving both scientific and expert knowledge

The process of co-building involves reciprocal exchanges and knowledge extension for both types of participants. The arguments put forward by the expert group to confirm or invalidate the conclusions obtained from the computerized evaluation are of great value for the scientists to i) improve the evaluation model and ii) identify new interactions or constraints that should be studied and better understood. Along the successive exchanges, the evaluation should finally stabilize itself and be validated by this confrontation to expert knowledge. During those same exchanges, experts will confront arguments and experiences, either on identical situations or in a more unbalanced way. When confronting arguments on closely related situations or coming from the scientific domain, they will refine and transform their own knowledge by building upon each other experiences. When being confronted to the description of new situations which they have not experienced themselves, they will broaden their knowledge which may change their rationale. They may also envision the problem from new angles, new point of views.

CONCLUSION

The goal of this study is contribute to the evolution of market gardening cropping systems and their adaptation to the new stakes they face. But the technical achievement of designing and ultimately applying the designed cropping systems on *real* farms is perhaps not the most striking achievement. The choice of a computer-aided co-building process has been made because it ensures, by the implication of growers themselves, that the designed cropping systems are feasible. It has also been made on the premises that it will create a knowledge exchange between scientists and what can be called *lay experts* (Prior 2003), the experiential knowledge gained by farmers in managing and observing their systems. The value of these knowledge exchanges is that it should enable the farmers to gain new knowledge more adapted to design than to management, while at the same time offering scientists new observations on which to work. For scientists indeed, the experiential knowledge of farmers could partially replace experimentation, but methods to elicit and moreover qualify (how case dependent it is, how certain, how precise?) this knowledge remain to be developed.
We focused for the moment on changes in the agriculture sphere, building an interactive approach with farmers and the economic and technical actors they are directly linked with. The involvement of a wider network may become a necessity, as for example consumers and/or distributors, who each specify the acceptable quality criteria of vegetables sold, or breeders who build the future cultivars. Elzen and Wieczorek (2003) even argue that

transitions must be multi-level, i.e. include changes at the micro-level (individual actions), the meso-level (structuring paradigms and rules) and the macro-level (societal and cultural characteristics and trends).

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