Innovation and research in organic farming: A multi-level approach to facilitate cooperation among stakeholders

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Abstract: *A wider range of stakeholders is expected to be involved in organic research. A decision-support tool is needed to define priorities and to allocate tasks among institutions. Based on research and management experience in organic research, the authors have developed a framework for experimental and research projects. The framework is based on a multi-level approach. Each level is defined according to the directness of the innovation impact on the organic systems. The projects carried out for each level were assessed over a ten-year period. Two applications are presented: analysis of crop protection strategies in horticulture and plant breeding programmes. When combined with four development models of organic farming, this multi-level analysis appears to be promising for defining research agendas.*

Keywords: *frameworks; research methodologies; crop protection; plant breeding; policy instruments.*

Introduction

During the last decade, the scope of organic food and farming (OF&F) was extended as a result of ambitious goals. Development plans were defined at various levels, from local to national (Lampkin & Stolze, 2006), as well as at the level of European institutions. They include both quantitative and qualitative objectives, and concern an increasingly broad range of stakeholders. This represents a new phase for OF&F that will be discussed in this article.

These stakeholders are primarily farmers who are encouraged to convert or develop their farms. Newcomers in the field enhance and renew organic production through projects supported by specific training and oriented by technical and economic assessments. They also relate with other farmers, whether organic (networks and associations) or not (previous experiences, relationships with neighbours, etc.). This entails a diversification of the forms of knowledge in order to provide support for projects and alleviate problems. Farmers' demands are highly varied and addressed to different partners, whether specialised or not in OF&F (Sautereau, 2009). Demands for rapid operational solutions, for example, those concerning pest and disease control, may lead to a focus on problem-solving methods such as the use of adapted plant protection products. These solutions may be convenient – at least for some farmers - and contribute to quantitative objectives, but they may not meet the expectations of other farmers (who would prefer genotypic resistance, for example) or satisfy the long-term needs of OF&F (Darnhofer et al., 2010).

At the same time, national plans aim at extending the number of stakeholders involved in OF&F development. In France, both a new development plan (Barnier, 2007) and a wide public debate (referred to in France as the "*Grenelle de l'Environnement*") have encouraged research, extension and training institutions to contribute to national development objectives for OF&F. As a result, to obtain recognition and funding for their activities, these institutions must also comply with certain requirements (e.g., contributing to the design of alternative and environmentally-friendly production methods). Likewise, various environmental stakeholders (associations, agencies, NGOs, etc.) also support OF&F for its contribution to the protection of natural resources. The range of consumers interested in OF&F has also been extended, sometimes with greater focus on product certification and origin.

OF&F development is increasingly collective and multidimensional since both farmers' trajectories and societal expectations are extremely varied. A question that often arises is whether or not this multiplication of stakeholders can sustain or counteract OF&F development. It can at least be assumed that competing development models exist: OF&F as a niche market, as a leader for future agriculture, reserved for environmentally-sensitive areas, etc. In order to address these issues, this paper proposes a framework for research and development that will: (i) enable the recognition of diversity in OF&F and its development pathways; (ii) provide guidelines for further experimental or research work; and (iii) maintain OF&F innovation capability through knowledge production and transmission.

In this paper, we first introduce a framework to address the variety of organic systems based on previous proposals in both OF&F and agroecology. We then apply it, in part, to the analysis of crop protection strategies and previous experiments in horticulture (Section 2) and more completely to plant breeding programmes (Section 3). Finally (Section 4), we discuss the relevance of the proposed framework to provide guidelines for OF&F development and its support through public policies or the private sector.

A framework to analyse OF&F diversity and development models

Several approaches have been proposed to characterise conversion to OF&F (Lamine & Bellon, 2009) and, more broadly, transition pathways towards more sustainable farming systems or agroeco-systems (Roep et al., 2003; Geels, 2004; Elzen & Wieczorek, 2005; Pretty, 2006; Geels & Schot, 2007; Gliessman, 2009)**.** Transitions are usually considered to be multi-factorial, multi-stakeholder and multi-level. With this development perspective, three levels can be distinguished in terms of individual actions and structuring paradigms (Table 1): Efficiency, Substitution and Redesign (ESR) (Hill, 1985; Hill & MacRae, 1995; Gliessman, 2004).

Table 1. Three-level approach (ESR) and examples from Hill (1985) and Gliessman (2007).

Levels	Objectives	Examples
Efficiency	**Improve input efficiency** Increase the efficiency of conventional practices in order to reduce the use and quantity of costly, scarce and environmentally-damaging inputs *But without reducing farm dependence on external inputs*	Approach widely used in agricultural research, giving rise to numerous technological developments and practices: • optimal crop or animal density • improved machinery and technology • pest monitoring to reduce pesticide use • improved timing of cultural operations • precision farming
Substitution	**Substitute chemical inputs with organic inputs and alternative practices** Replace conventional inputs and practices with environmentally-benign alternatives *At this level, the basic system structure is not greatly modified*	Approach emphasized by organic agriculture and biological agriculture research • environmentally-sound inputs • biological control • inundative biological control (releases of insectary-reared natural enemies) • symbiotic N fixation • rotations and green manures instead of mineral fertiliser • minimum tillage
Redesign	**Redesign the farm system as a functioning agroecosystem** Eliminate the causes of problems occurring in E and S (prevention) *System works on the basis of a new set of ecological processes*	Whole system transition studies on time spans beyond formal conversion • biological control by conservation • generalist beneficial insects • re-definition of problems and of subsequent means of resolution • enhancing ecological processes (recycling, self-regulation of pests and diseases)

A fourth level can be added (Gliessman, 2007) to reconsider the link that can be made between food production and local consumption. This suggests integrating the economic dimension of OF&F as well, and its relationship to the ESR model in order to account for diversity and subsequent challenges in OF&F.

Most publications or public policies implicitly consider OF&F as a relatively homogeneous entity. For example, OF&F performances, technical bottlenecks, consumption or supply chain issues are often studied and discussed as a whole. Many variables could be relevant to account for this diversity. However, two comprehensive axes can be identified (Sylvander et al., 2006; Desclaux et al., 2009), as shown in Fig.1.

- The vertical axis opposes basic compliance with OF&F standards to system redesign. It is consistent with the ESR model previously introduced.
- They can be implemented on farms as well as within processing or even marketing firms (Fig. 1).

The horizontal axis refers to governance patterns, whether they are individual or collective (Sylvander & Kristenssen, 2004). Four models, considered as "polar" ideotypes, are therefore determined.

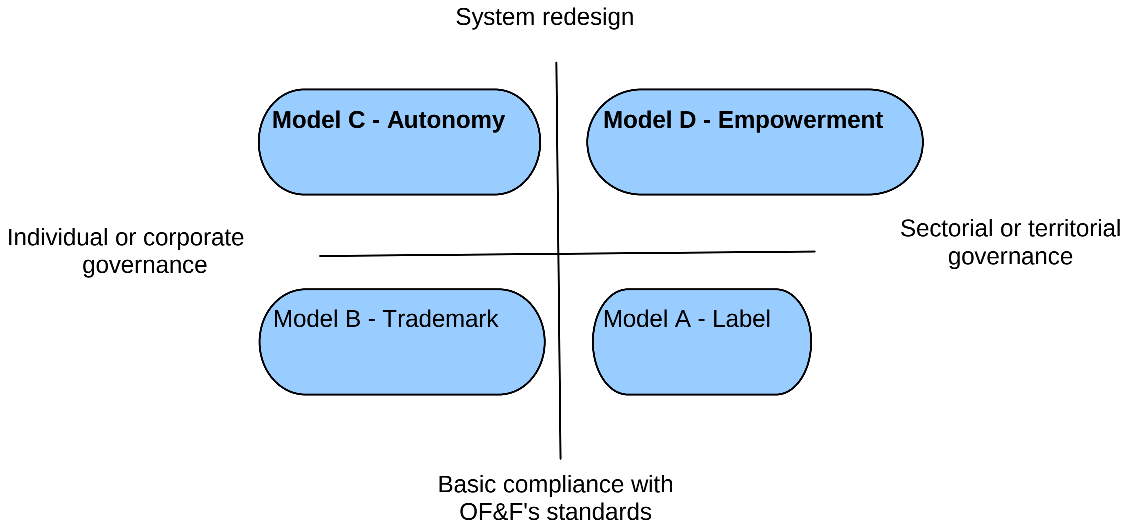

Figure 1. Four models to reflect organic farming diversity (Sylvander et al., 2006; Desclaux et al., 2009).

These four theoretical models (A to D) account for the empirical diversity. They can be described as follows:

Model A (Label): consists of farmers integrated in downstream, non-specialised firms (including cooperatives). They entered the OF&F sector to solve technical problems through input substitution and to market organic products for a small part of the turnover, selling mostly to wholesalers, large processors and/or supermarkets. The EU organic label provides added value to products in long supply chains.

Model B (Trademark): same kind of farmers as model A, who entered in the OF&F for opportunistic reasons and who also want to solve technical problems through input substitution and efficiency. They often have non-specialised farms (mixed OF/non OF) and create their own outlets (direct selling, local markets, etc.).

Model C (Autonomy): consists of experienced and skilled farmers, specialised in OF, with a high degree of education in agronomy, that use direct marketing or that have non-contractual relationships with small processing firms or supermarkets, small and medium-sized specialised companies, which also belong to this model. They usually operate on an individual or corporate basis.

Model D (Empowerment): same kind of farmers as above in terms of skills, but more committed to associative work (collective selling points, use of agricultural equipment, etc.) or to territorial networks. They may also be involved in regional or national markets. This choice enables them to focus on system design and management approaches, eliminating the root causes of many problems.

As a result, we propose a framework based on the ESR approach as applied to technical management, and complement this approach with the integration of socio-economic relationships.

Applying and adapting the ESR approach to crop protection and experiments in horticulture

When applied to crop protection in horticulture, the ESR approach can be illustrated by the following pyramid that describes pest management strategies (Fig. 2) and that includes a retrospective analysis of experiments conducted by a French research group.

Crop protection strategies can be ranked from the most direct (localised and short-term effect, top of the pyramid), to the more indirect ones (using the whole agroecosystem and affecting the long-term, bottom of the pyramid). The pyramid also shows that the more indirect the strategies are, the more means there are available (Pfiffner, 2005) and the closer they are to organic principles (Darnhofer et al., 2010). The pyramid includes four steps in pest management (Wyss et al., 2005): (i) use of cultural practices compatible with natural processes such as crop location and rotation, soil management, non-transgenic host plant resistance, etc.; (ii) management of vegetation to enhance the impact of natural enemies and exert direct effects on pest populations; (iii) inundative and inoculative releases of biological control agents; (iv) suppressive tactics as a last resort, with the use of approved insecticides of biological and mineral origin, and use of mating disruption. In this approach, cropping system design is prioritised before input substitution and efficiency.

As compared with the ESR approach, the bottom of the pyramid - with indirect means - is similar to Redesign (R), whereas its top is close to Substitution (biological control) and Efficiency. It shows a graduation from a reductionist or factorial approach (top-down on this diagram) to a holistic one (Hubert, 2002; Lammerts van Bueren et al., 2003). It also reflects a dynamic process: indirect, preventive methods are of the highest priority and have to be considered early in transition processes, followed by more direct and curative measures only if preventive measures are not sufficient.

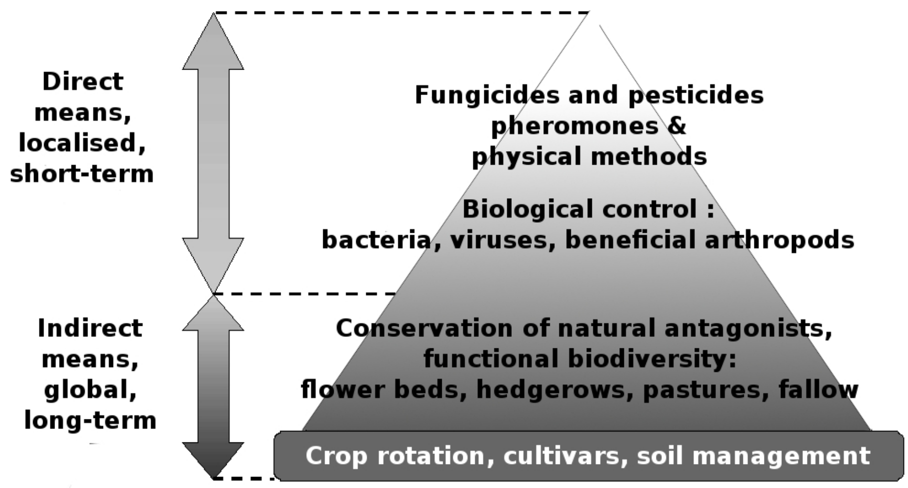

Figure 2. Pyramid of targeted pest regulation (Pfiffner, 2005; Wyss et al., 2005).

With this pyramid diagram, it is clear that several crop protection strategies from different levels can be encountered within the same farming system. In fact, inside a farm, and especially an organic one, we can consider that the three levels may co-exist at the same time. For example, a farmer can reduce the use of copper in crop protection, substitute pyrethrum for rotenone, and enhance functional biodiversity. Favouring system redesign to limit pest damage with the subsequent redefinition of economic thresholds does not impede direct protection when necessary, e.g., in the event of pest outbreaks.

The proposed framework was completed with the previous pyramid and then used to analyse horticultural experiments. The Organic Farming Research Group (GRAB) was created by organic farmers. It has been conducting experiments in the area of organic crop production for the past 30 years. From the above multi-level approaches, the group has developed an analysis grid of its past actions in the organic fruit and vegetable innovation sector (Le Pichon et al., 2009). The experiments were therefore analysed according to the direct impact of the strategy on crop protection. Three levels were used (Table 2), following the ESR approach. The aim of this grid is to build a simple and shared management tool for the experiments, within the perspective of a global organic approach.

Table 2. A multi-level grid analysis of GRAB experiments (Le Pichon et al., 2009)

Direct means (Efficiency and Direct Substitution)	- Dose reduction (Cu) or substitution (Pyrethrum *vs.* Rotenone) - Natural product application (clay, phytotherapy) - Mechanical protection (insect-proof net, biodegradable mulch) - Biological control
Indirect means (Indirect Substitution)	- Addition of partial effects methods, crop management - Inoculum limitation - Functional biodiversity
System approach (Redesign)	- Crop management redesign (cultivar choice, implantation) - Soil fertility management (pest sensitivity, crop location) - Global biodynamic approach, at the farm or agroecosystem level

The number (Fig. 3) and the cost (Fig. 4) of experiments carried out by level were then monitored over nine years. Experiments at each of the levels showed effective results. However, the limits encountered led to an increase in GRAB research at the global approach level of the system.

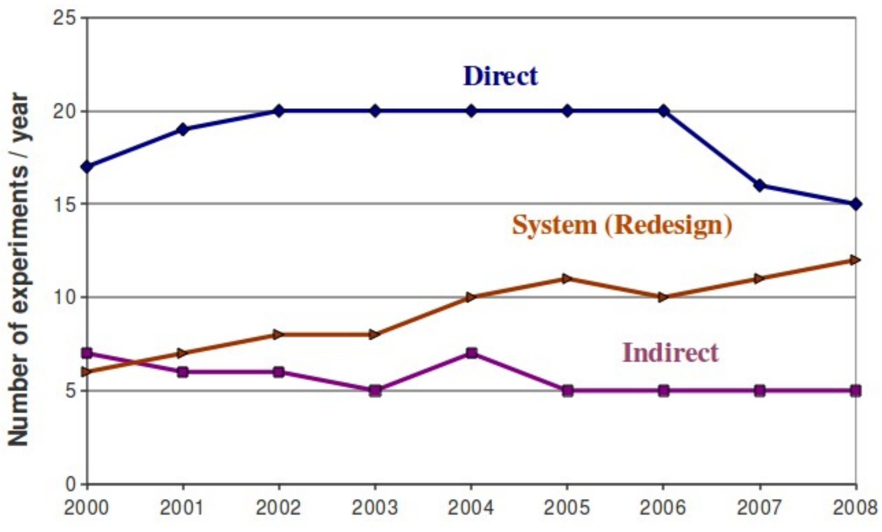

Figure 3. Number of experiments/year (2000-2008) by level (Le Pichon et al., 2009).

As for GRAB, 70% of research costs are due to wage expenses, the costs are closely linked to time spent for conducting each experiment.

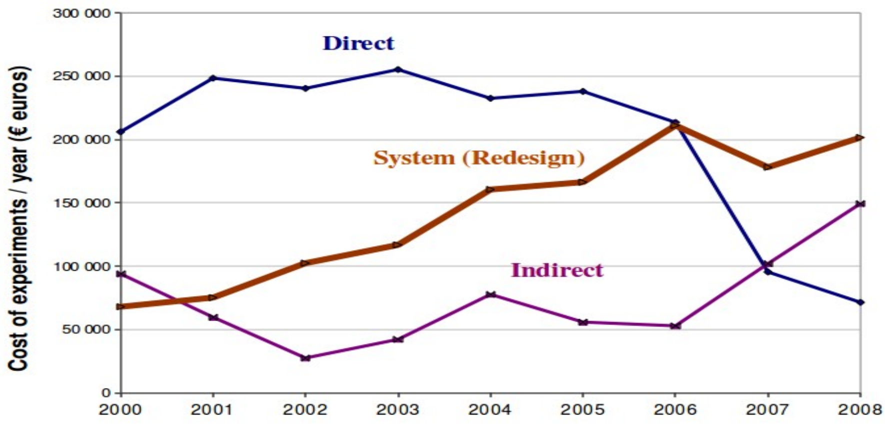

Figure 4. GRAB experiment costs/year (2000-2008) distributed by level (Le Pichon et al., 2009).

It can be deduced from both figures that the number of experiments at each level has slowly evolved over the last four years in favour of System level experiments (Fig. 3). Considering the resources devoted to each level, there is an increase in the System and Indirect levels, and a marked decrease in the Direct level (Fig. 4). This shows that the complexity of experimentation increases with the highest levels, entailing more resources (time, funding, etc.) for the same number of actions.

Thus, research in functional biodiversity (Indirect level) requires more and additional resources since the time devoted to bibliography, sampling and identification may be considerable. However, even if costs for Redesign are higher, they should also be considered as a mid-term investment and assessed on a longer time span, poorly reflected within an annual budget. In addition, conducting multi-site and multi-annual trials contributes to a better understanding of the overall functioning of the agroecosystem, which results in greater resource needs than at the direct level.

Research methodologies should also be adapted. For example, the combinations between on-farm monitoring and on-station experiments will differ according to the level in which a topic is addressed. In general, 70% of the experiments managed by GRAB are implemented in farmers' fields. Farmer participation is especially important in designing the experimental plan. Their involvement in subsequent steps (implementing and monitoring experiments; analysing and enhancing results) is even more predictable when the system level involves a mid-term commitment, which should also be supported by an ex-ante risk-assessment. A farm of the model C-type ("Autonomy") progressively implements a global approach to elect and then manage crops, activities and marketing. An organic farm of the model B-type ("Trademark") generally uses direct strategies.Although its focus is on crop protection in horticulture, this section shows that the baseline of the pyramid also refers to crop production, particularly crop sequences and management, land development and choice of cultivars (*addressed in the next section*).

Diversity of organic models and consequences for plant breeding programmes

One of the main reasons for limited organic crop production is the lack of varieties adapted to organic conditions. Although organic agriculture is well established in most European countries, breeding specifically for organic farming systems has received little attention for both economic and technical reasons (Chiffoleau and Desclaux, 2006). Organic farmers therefore plant varieties developed through conventional breeding programmes and that are not always well adapted to their organic conditions. Conventional breeding must in fact comply with DUS (Distinctness, Uniformity and Stability) and VCU (Value for Cultivation and Use) standards required for variety registration.

Conventional breeding methods do not always provide adapted responses to the huge diversity of organic environmental conditions and end-user needs. Furthermore, by focusing on a wide range of adaptability, conventional methods may lead to the loss of genetic resources and biodiversity (Le Roux et al., 2009).

Acknowledging the diversity of organic models (A to D) also entails reconsidering breeding methods and ways of designing new varieties.

As for Model A ("LABEL"), the classic plant improvement system described as a centralised, sequential and linear process (Sperling et al., 2001), may be relevant. Five main stages (establishing objectives, creating variability, selection, evaluation and diffusion) compose the corresponding breeding programme (Sperling et al., 2001). For economic reasons, the main objective of breeding programmes is usually to develop varieties that can be widely distributed and are thus suitable for a broad range of environments (macro-contexts). The main procedure has been to standardise production conditions so as to render the crop environment as uniform as possible. Since genetic progress is defined here as being proportional to the heritability of the desired trait, breeders have aimed to maximise heritability by reducing environmental variance.

This standardisation consists of eliminating all of the limiting factors present in the biophysical environment while relying on the input supply. This approach leads the farmers to use standardised varieties targeted for long-chain market conditions that impose specific yield and technological quality, in accordance with national or international rules and regulations.

Model B ("TRADEMARK") comprises niche markets that respond to integrated value chains. The objective is no longer to ensure the wider diffusion of a varietal innovation but to control and target the diffusion of a specific final product by imposing a variety, its guidelines and exclusive rights to the harvest.

The variety might not have to be registered in the official catalogue because seeds are diffused only within specified limits such as an integrated value chain or a club. The purchase of the harvest at a guaranteed price is a major reason why the "variety x farming system" combination is accepted by farmers. The selection stage is either conducted generically by choosing from the genetic diversity or is considerably simplified by introducing the gene of technological interest into a variety to obtain, for example, a waxy maize or oleic sunflower. The logic of such a model can be extended to include the privatisation of genetic resources and their economic valorisation through the integration of an entire sector (by firms involved both in plant breeding and agroindustrial sectors). The stage of establishing objectives creates opportunities for the combination or the emergence of value chains and specific market niches.

Another form of logic is offered by Model C (AUTONOMY), characterised by a strong demand for individual rights to control the whole chain, from seed production to the marketing of the final product. All the stages of the plant breeding scheme, even the system itself, are called into question by farmers who claim autonomy in the seed sector. In this case, the farmers are typically looking for a genetic resource with patrimonial and identity characteristics, capable of becoming a ''flagship'' variety at reduced cost (a symbol of a social movement) or a ''sentry" variety' (considered by the Slow Food movement as a shield against uniform industrialised products). The variety of interest here is a designated phenotype, labelled ''local population'' or ''old variety''. The objective is an extremely localised individual adaptation — at the scale of one farm or even of one field. ''Farmers must have an enormous range of varieties at their disposal, which are as adaptable as possible: in other words, are accessible to different types of evolution, and thus neither very uniform nor very stable'' (Kastler, 2006). Irrespective of the biology of the species (self- or open-pollinated), the means range from the cultivation of populations under natural selection, to mild pressure of mass selection by dynamic management. Evaluation and diffusion are no longer based on the classical criteria that define genetic progress (e.g., yield or technological quality) but rather on consumer satisfaction.

In Model D (EMPOWERMENT), the aim is to reconcile the design of a new system for plant breeding and collective action. This model gives more equal weight to agroecological interactions (environmental aspects of sustainability) and socio-economic interactions (between stakeholders). The organisation of an emergent system of complex interactions may be facilitated by a participatory approach (Desclaux et al., 2008).

''Participatory plant breeding'' (PPB) was originally developed in developing countries. In Europe today, PPB concerns local projects for the creation of varieties adapted to environments in which organic and low-input agriculture is practised (Desclaux and Hedont, 2006). PPB is described as an approach involving all of the stakeholders of a given sector, not only in the establishment of breeding objectives, but also in the management of the breeding process and the creation of varieties (Gallais, 2006). It aims to respond to systemic issues and demands for which classic breeding (Label model) appears to be unsuited (Cecarelli et al., 2001; Almekinders and Hardon, 2006).

The reason this model is of considerable heuristic interest is that it deeply modifies the breeding stages. Each stage becomes a function that will tend to exacerbate and reveal Genotype x Environment interactions in both the agroecological and socio-economic dimensions of the environment.

These four models differ in: (i) their objectives (from yield improvement to farmer empowerment); (ii) their specific expectations with respect to genotypes (from inherited genetic resources to varieties that represent genetic, ethical and social progress); (iii) their representations of the environment (from a simple interaction between the bio-physical environment and crop management, to a complex interaction including the skills of the stakeholders, outlets, regulations, society); and (iv) the stakeholders involved. Taking this diversity into account changes the way plant improvement is considered. Between the existing analytical model (model A) and a holistic model (model D) that remains to be developed, lies the challenge of ensuring the sustainability, efficiency and acceptability of plant breeding and the resulting innovations.

We contend that there is a need for different approaches in plant breeding to improve organic farming systems and organic product quality in relation to current conventional practices and that this will differ according to the targeted markets.

Discussion and conclusions

Accounting for OF&F development pathways

A multidimensional reality

It is likely that there are almost as many organic farming systems as there are organic farmers. However, individuals have to adapt their specific farm situation to OF&F standards and principles. The new EU regulation (EC N° 834/2007) encourages organic production to play a dual societal role: “on the one hand, OF&F provides a specific market responding to a consumer demand for organic products and, on the other hand, it delivers public goods that contribute to the protection of the environment and animal welfare, as well as to rural development”. As a result, farmers can also interpret the way they approach and develop OF&F, since all roles are not necessarily fulfilled simultaneously. Wolfe et al. (2008) use a multidimensional perspective with broad categories, based, for each farm, on the market approach, main driver and product (Table 3). This categorisation is consistent with our four models although the agroecological driver is restricted to input management without considering redesign. In fact, marketing channels are often combined and may evolve within a single farm (Navarrete, 2009). Likewise, according to convention theory (industrial, civic, etc.), agreements between organic farmers and markets can be highly varied (Sylvander et al., 2006; Rosin & Campbell, 2009). This implies that development pathways for OF&F cannot be summarised into a unique type of agreement.

Table 3. Categorisation of farming systems and outputs (from Wolfe et al., 2008).

Market	Driver	Product
Global commodity (oriented towards large markets.)	Economics	Uniform
Regional market farming, on both large- and small-scale farms	Agroecological, with major emphasis on minimising inputs	More variable
Local market farming, mainly by small-scale farmers on mixed farms	Social, considering society as a whole	Crop, livestock, farm, landscape

An uneasily accountable diversity

Proposals to classify organic farming systems are highly varied, but they usually focus on individual situations instead of considering the relationships among categories (e.g., Lamine and Bellon, 2009). The relative importance of each level or model is a question that is still open. In spite of OF&F internal diversity, it is difficult to obtain a full picture of model distribution since their indicators (organic achievement, governance patterns) are not accessible in statistical data. Expert knowledge from extension or certifying agents can be helpful, but is usually restricted to a limited number of situations. Moreover OF&F is a dynamic sector.

Models can be viewed as complementary and not competing, thus accounting for the adaptive capacity of OF&F. Each model also involves different stakeholders, e.g., in the fields of breeding and plant or animal health. Farmers also directly contribute to guiding OF&F development through their relationships with potential converters and other farmers, for example: (i) during specific events (meetings, fairs, markets, etc.); (ii) in networks or formal groups (cooperatives, etc.); (iii) with an individual and direct support to newcomers in OF&F (sharing experiences, facilitating access to land or markets, etc.).

An accurate scale versus a readable tool

The proposed framework is not an end in itself but a support for analysis. However, the layering in levels and models should not erode readability and progress since one of our objectives is to design an analytical tool for the selection of research priorities and to stimulate debate among various stakeholders.

Classifying experiments in this multilevel approach (Table 2) can be evasive. For instance, one single tested production method can have several impacts. An experiment on fertilisation optimisation has an impact on overall plant attractiveness to pests although this is not the primary objective of the factors studied. The use of biocides, mechanical protection or release of pest antagonists were all classified in the Direct Substitution level in our framework, but they certainly have different impacts on the agroecosystem.

Moreover, the levels – originally proposed as steps (Hill, 1985) - could be reversed if we consider the organic agenda. In order to support a large number of conversions and fulfil national goals, efficiency and substitution could be prioritised (Bocquier, 2009). Conversely, various authors (Pfiffner, 2005; Zehnder et al., 2007) consider that indirect means should be implemented as soon as possible, followed by more direct and curative measures only if preventive measures are not sufficient. The Redesign approach would come first. However, when ecological infrastructures are established (hedgerows, etc.), they are not functional before several years, which would be in favour of anticipation before conversion *per se*, as suggested in Hole et al. (2005) concerning relationships between OF&F and biodiversity. Subsequently, bio-technical issues still have to be addressed, but they cannot be easily isolated from an analysis of institutional frameworks and from a vision for OF&F research that integrates new challenges for the entire organic sector (Niggli et al., 2008).

Diversification of stakeholders, partnerships and research agendas

From pioneers to the institutionalisation of OF&F

Our analytical framework showed its relevance for facilitating the selection of research actions to be conducted. After assessing past actions, it is now used to present new proposed topics at meetings of the GRAB steering committee. Producers' demands for rapidly operational solutions may in fact lead researchers to focus on Direct Substitution strategies. This tool is appropriate to ensure that priority is given to Redesign strategies or, at least, that a balance is reached among the suggested levels to deal with one particular topic. But what is the situation with other stakeholders?

Many agricultural institutions and trade organisations have long viewed OF&F as a marginal activity. New experimental stations are expected to get involved in research dedicated to organic farming. Research could probably be taken to a new level by using this framework within a whole food chain or within a territory. It would thus be possible to monitor the balance or shifts between levels and models, to allocate tasks among several experimental stations according to their skills and knowledge and to anticipate partnerships and know-how required by more global approaches. Conventional experimental stations are more likely to be requested by farmers in conversion (Label and Trademark ideotypes), and they have facilities to conduct experiments with direct inputs. They are also familiar with commercial plant breeding research methodologies. Only organic conditions are missing to implement a trial. Older stakeholders in organic research could orient their research programmes along redesign strategies, thus contributing to transitions towards sustainable agriculture (Rosemeyer, 2009; Lichtfouse et al., 2009).

The question arises as to how to collectively share this framework. It could be used at a national level, e.g., by the French Scientific Committee dedicated to organic agriculture (CSAB), by the Technical Institute for Organic Agriculture (ITAB) or by a mixed technological network dedicated to OF&F (RMT DévAB). Better coordination among experimental sites is also required, e.g. through the creation of a network (of experimental stations) or a platform (open to users). Regardless of the option, strong public support and willingness are necessary.

Recent developments in a public research institution

In France, this framework is increasingly considered by INRA (National Institute for Agricultural Research), in research projects and expertise related to ecologically-based agriculture. In spite of pioneer studies conducted by individual researchers, INRA has also maintained a distance with OF&F. However, the political recognition of OF&F has prompted various organisations to draw up strategies to promote it. In France, this shift can be seen as of late 1997 when a mid-term development plan was designed for OF&F. INRA, for its part, announced its commitment to a research programme in late 1999, while emphasizing the need to comply with the rules governing all research activities (Bellon et al., 2000).

Basic principles and current activities were encouraged both by internal and collaborative projects, and the scientific status of organic farming research was presented in specific papers (Sylvander & Bellon, 2003; Cabaret et al., 2005; Bellon et al., 2009). Interdisciplinary and partnership-based projects were supported, considering OF&F as an agricultural “prototype”. This starting point leaves room for analytical research (in order to find solutions to bottlenecks resulting from the evolution of both practices and regulations). It is also likely to reinforce the system redesign approach (consistent with OF&F principles) and to generate hypotheses for analytical studies as well. It leads to an understanding of the processes employed in production under the constraints of regulatory standards. The basic principles of partnership-based research assume that programmes are to be developed through consultation with organic farmers’ representatives. Those principles therefore combine academic criteria and compliance with the requirements of OF&F. As a result, new calls are reoriented towards projects contributing to OF&F multi-dimensional performances and to its socio-economic development.

A new definition and assessment of performances in OF&F

Much discussion about OF&F performance focuses on its ability to “feed the world” (e.g., Kirchmann et al., 2008), with emphasis on yields and inputs. However, strategies are highly varied in OF&F: both objectives (environment, rural development, etc.) and methods (use of legumes in crop sequences, of local resources such as nutrients) are diversified. Subsequently, a wider range of performances should be considered to address combinations or likely trade-offs among performances, while improving the methods to assess them (composite indicators, data bases, etc.) as well. This would contribute to defining adapted references for up-scaling OF&F, namely with conversion in view, and to supporting the development of other organic farmers. These issues are also increasingly in the limelight at the European and international levels (Niggli et al., 2008).

Finally, this tool is also able to become a means to address the necessity of sharing agricultural issues between farmers with various degrees of participation (Bass et al., 1995), as well as with scientists and the rest of society (Chevassus-au-Louis, 2006). The two cases of plant protection and plant breeding show that consumers can play a part in redefining the way technical stakes are addressed

(Vanloqueren & Baret, 2005; Lamine, 2005; Gliessman, 2007). A first step can be to present the diversity of OF&F and the links between models, as well as the dual societal role of OF&F. Its multidimensional perspective is capable of generating a real debate among stakeholders.

Diversity of technical and knowledge requirements: the issues at stake

Regional versus horizontal OF&F development

First, the up-scaling perspectives announced in national development plans question the spatial organisation of the organic sector. The goal of combining environmental and economic efficiency would encourage organic farming. This would reduce transportation costs of commodities, ensure a greater environmental impact and enhance exchanges among farmers. However, organic farmers do not always follow a regional specialised pattern and diversify their land use. In addition, environmental performances are not similar for all compartments. As an example, management of biodiversity is not necessarily related to a high concentration of organic producers in the same area.

Resource management (e.g., nutrient cycling) calls for innovative and collective actions, involving new stakeholders such as municipalities and government agencies, as well as cooperation among farmers, whether they be organic or not. More specifically, there is a need to pursue the study of the effects of OF&F on natural enemies and pests at several spatial scales, including at the landscape level, rather than confining them to within-field or paired-field studies. This is particularly relevant to assess whether OF&F combinations with other agricultural production patterns (conventional, integrated, etc.) are disadvantageous for organic farmers. On the one hand, a high concentration of conventionally-managed orchards can be detrimental to both pests and their natural enemies; on the other hand, chemical treatments restrict the expression of ecological processes at the local or landscape level and, therefore, natural regulations that can contribute to more ecological fruit production (Ricci, 2009).

Transition dynamics and trajectories entail various knowledge-based requirements

The ESR approach (Table 1) makes it possible to differentiate farming situations, with a better understanding of the subsequent main stakes and knowledge requirements in organics. It should not be considered as a unique and linear pathway for farming system development. In OF&F, input substitution is a basic requirement since alternative production methods are advocated. It is also possible to look for greater efficiency input in OF&F (leading to SE, instead of ES), but without redesigning the system. For example, the prevalence of input substitution and efficiency does not cast doubts on monoculture or the dependency on external inputs, and drastically limits the potential solutions to the socio-economic and ecological crises facing modern agriculture.

OF&F dynamics should also be considered, taking both stakeholders and farm trajectories into account (including the associated biological processes). At the production level, four situations can be identified: (i) direct access to organic farming, often on small farms and with professional training; (ii) conversion *per se*, for experienced farmers; (iii) development of previously converted farmers; (iv) succession of organic farmers close to retirement. The way problems are addressed and possible solutions will vary accordingly, with specific needs for adapted references and support. As a matter of fact, operators do not encounter the same technical problems or the same economic constraints. At the same time, this perhaps implies that they do not have the same needs in terms of public support (technical assistance, financial support, regulations and research programmes).

The notion of a trajectory allows the consideration of conversion over a longer time period and from a wider point of view than in its official definition. Organic farmers' trajectories encompass technical trajectories, social trajectories, learning trajectories and network trajectories at the same time (Bellon et al., 2007). Compared with classical typological methods, studies involving agronomists and social scientists prove that interdisciplinary approaches are more adequate for reflecting the actual diversity of organic farming, as well as the evolutionary potential of farming systems and the transitional nature of conversion trajectories. In these socio-technical trajectories, the questions of plant protection practices, of input use and of farmers' representations of these issues, are central. In crop protection, we thus differentiate a classical approach (one pest, one solution) from proposals addressing a complex set of pests and their antagonists in fields or landscapes. The proposed framework can also help meet the needs of this diversity of farmers and to facilitate their transition towards a global management of their supporting agroecosystems. Hence, it can also contribute to the development of early converters. It also requires different forms of knowledge from producers, advisers and certifying agents (Seppanen & Helenius, 2005). Farming in compliance with nature calls for anticipation, adaptation and observation skills.

Maintaining OF&F innovation capabilities

OF&F has innovated in various domains: technical (weed control, crop protection, crop rotations and patterns, compost production), organisational (breeding methods, marketing initiatives, partnerships among farmers, research or extension workers), and environmental (reductions in the use of heavy metals, improved impact on environmental compartments). Although OF&F can still be considered as a prototype, the maintenance of innovation capabilities in OF&F will have to be considered on a new basis. Since specialised systems tend to develop - particularly in organic horticulture or viticulture – they tend to shift from the mixed crop-livestock model. Subsequently, models have to be designed with a new rationale. For example, how can we introduce organic matter into specialised systems? What land developments (ecological infrastructures, diversified agro-forestry patterns, etc.) make it possible to reduce dependence on external inputs, even if they are allowed? The following ideas can serve as guidelines for further research and development projects: (i) designing more autonomous and economically efficient systems, in keeping with OF&F principles, enhancing cooperation at the regional level; (ii) sustainable management agroecosystems that take both the health status of its living components and alternative therapeutic methods into account; (iii) improving the management of multiple qualities of organic products, (iv) reinforcing the interactions between organic farming and environment, thus securing system properties (productivity, adaptiveness, etc.). Such pathways are consistent with other proposals (Niggli et al., 2008).

In national calls for research proposals, a tension appears between two polarities: designing environmentally-friendly farming practices and systems, on the one hand (in accordance with the French *Grenelle de l'Environnement*), and contributing to a modern agricultural model with innovative techniques (genomics, GPS and information technologies, automation and robots). As a result, topics such as input reduction and improved plant and animal health management co-exist. This tension is also present in a new technology platform (TP "Organics") introduced by Niggli et al. (2008), who consider that research projects and national programmes on organic agriculture have addressed immediate technology gaps in OF&F, i.e. with a short-term perspective only. The proposed framework can also help to guide project selection and assessment of their outputs.

The roles of public policies

We introduced four models likely to represent ideotypes or poles, although several intermediate situations may occur. Such situations are highly varied and likely to represent a huge potential for OF&F development. They can be characterised in terms of distance to one or several poles (Girard et al., 2001) and not in terms of fixed categories; further research is necessary for a more in-depth understanding.

According to the models that are developing, it will be possible to infer very different types of public policies. This raises questions about possible transitions (or breaking points) among poles, and about the nature of research and development programmes relevant to specific paths. The time dimension is also crucial to link design to diversification issues. This classification is not to be considered as per se, but as a tool to design the future of public policies. Model A is consistent with a view of OF&F as a "niche". A shift on the horizontal axis will depend on farmers and market organisation, whereas a vertical shift will depend more on cross-compliance policies. Such policies can be at national or global levels, but the roles of regions and agencies (such as watershed authorities or regional parks) are increasing. The four models proposed (Fig. 1) are consistent with this dual role of OF&F: the horizontal axis reflects value chains, whereas the vertical axis is oriented towards environmental protection issues, It may seem paradoxical that these questions are not often raised in organic farming studies, perhaps because these problems are supposed to be solved, whereas they are more often central to comparative studies of conventional and organic farming (Lamine & Bellon, 2009). Promoting a sustainable agriculture and providing environmental services to the rest of society also make it necessary to strengthen the resources dedicated to interdisciplinary research.

At present, to make choices in terms of public priorities implies that these questions have been identified, analysed, debated and settled. This paper may contribute to the debate in those different areas and particularly in that of research.

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