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Foreword

The world today continues to produce food primarily on the basis of the principles of the Green Revolution. Most of this production thus relies on input- and resource-intensive farming systems, with obvious heavy costs to our environment. Soils, forests, water, air quality and biodiversity continue to degrade inexorably. And this drive to produce at all costs has not been completely successful because hunger remains an uncomfortable reality across the globe. And this even though we currently produce more than enough to feed everyone. At the same time as this reprehensible situation, we are witnessing a global obesity epidemic. This is an unsustainable behaviour and we need to promote a transformation in the way we produce and consume food. We need to design sustainable food systems that not only provide a healthy diet but also protect the environment.

Over the past decade, agroecology has drawn increasing interest and, according to many stakeholders, represents a strategic approach that can enable a successful transition to more sustainable farming and food systems.

It is in this context that we at the FAO organized a series of multi-stakeholder seminars on agroecology between 2014 and 2018. These events offered the various participants an update on the many facets of agroecology and highlighted its beneficial role. Arenas for animated exchanges and useful debates, these events prompted an important and significant mobilization of civil society and the research community. They provided opportunities to these actors to clearly express their expectations for strengthened institutional support for agroecology. They have thus shown how agroecology, although a concept that has always been framed scientifically since its birth almost a century ago, remains a spirited and strong approach, very dependent on the context in which it is sought to be applied. This mobilization has generated in its wake a dynamism and a great hope around agroecology and the solutions that this new agricultural model may be able to provide to the challenges reflected in the 17 Sustainable Development Goals to be achieved by 2030. To convert this dialogue on agroecology into action, an initiative for its scaling up was launched by FAO and its UN partners at the Second International Symposium on Agroecology in April 2018. We also commend France for its exemplary commitment to agroecology and for its ongoing support to FAO in this area.

The policy adopted by France in favour of agroecology is indeed exceptional because it addresses all the levers needed to promote the agroecological transition, from production to consumption, by way of a transformation of the systems of education, research and innovation. To this end, French research and development organizations are providing significant scientific and methodological support for the development of agroecology at the international level. This is why we, in early 2018, strengthened our cooperation with French research and higher-education institutes in the form of a partnership framework contract. This contract is focused on developing countries and aims to promote the agroecological transition as one solution among others for achieving food and nutrition security in the ever-lengthening shadow of climate change.

This book presents the experience of ten years of work by the Centre for International Cooperation in Agricultural Research for Development (CIRAD) and the French Development Agency (AFD). It capitalizes an extremely valuable expertise, illustrated with examples from successful initiatives in Africa, Asia and Latin America, to guide us in the transition to agroecology. The reader can benefit from CIRAD's excellent research work on leveraging biodiversity in agrosystems, the optimization of biogeochemical cycles, management at the landscape and territory scales, as well as the creation and assessment of production systems that maximize ecosystem services. The analysis jointly proposed by CIRAD and AFD also shows us how the agroecological transition cannot be limited simply to an introduction of ecological principles into agricultural systems and how it must go through a phase of organizational and institutional innovation, consisting of a comprehensive and holistic approach to the entire agricultural and food system, in order to initiate a transformation towards more sustainable production and consumption.

I am therefore delighted at release of this very useful book, whose publication is particularly timely as it will help to further FAO's reflections and actions and those of all its partners. This volume will, in this way, help advance agroecology so that this approach can be scaled up, bringing us thus closer to the realization of the plan of action for people, planet and prosperity: the 2030 Agenda for Sustainable Development and its 17 Sustainable Development Goals.

José Graziano da Silva

Director general
Food and Agriculture Organization
of the United Nations (FAO)

Contents

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Finally, we would also like to extend our thanks to Kim Agrawal for translating this book from the original French.

Introduction

Agriculture has made a recent return to international agendas in its role as a lever of development in countries of the Global South and as a major instrument for achieving several of the UN's sustainable development goals. While it is acknowledged that agriculture in these countries must meet the food and economic needs of their rural and urban populations, new priorities have been added to this agenda: preserving resources and ecosystems, promoting territorial development and employment of rural youth, responding to the demands of an increasingly globalized market, contributing to the health and well-being of the population through the quality and diversity of its products, adapting to climate change, etc. These new exigencies call for unprecedented and rapid transitions in agricultural systems in these countries.

Such transformations have to take place in a fast-changing and uncertain context, marked, on the one hand, by changes in the demographics of many countries of the Global South, accompanied by rapid urbanization, on the other, by low investments in agriculture and inadequate public services, by the globalization of trade and private investment, and the expanding reach of agro-industries, and by difficulties in the conditions of agricultural production (climatic extremes, favourable conditions for proliferation of pests, depleted and fragile soils, water shortages due to climate change, etc.).

The different forms of agriculture in the Global South have also to evolve without reproducing the impasses and negative impacts – social, nutritional and environmental – of the Green Revolution's productivist models. It is in this context that new agroecological practices are beginning to emerge. They are based on the mobilization of the ecological functionalities of agricultural systems, the optimization of natural processes, and the frugal management of resources. Agroecology cannot, however, be reduced to a set of technical practices. The agroecological approach corresponds to a paradigm shift that addresses the concerns of citizens and consumers regarding their nutrition, their health, ecosystems, equity, and social and environmental responsibility. It calls for a new way of assessing the performances of production and processing systems, and requires a different kind of logic of innovation. To go from the agricultural model promoted by the Green Revolution to that of agroecology, we have to leave behind the prescriptive 'top-down' logic of technical change, based on the implementation of standardized technical packages. We have to transition instead to a logic of innovation backed by a network of diverse actors, including, of course, the producers themselves, and one that is based on the analysis of local contexts and needs and on the development at the territorial scale of the most suitable biological, technical and institutional solutions.

The French Centre for International Cooperation in Agricultural Research for Development (CIRAD), as part of its research mission, and the French Development Agency (AFD), as part of its mandate of providing development aid to countries in the Global South, are exploring the possibilities of developing systems based on the scientific principles of agroecology. Several dozen research and development projects on the agroecological transition have been conducted by these two organizations in partnership with researchers and local entitites of the Global South in recent years, mainly in Africa, Madagascar and the Indian Ocean, in Southeast Asia, Latin America, as also in the French Overseas territories.

This book reports on some of these research and development activities, all of which are part of a general, participatory and territorialized action-research approach aimed at the co-production of a number of common goods: knowledge (scientific and endogenous knowledge), practices, partnerships (groups, networks, innovation platforms, etc.), skills (training, increase of social capital, imparting of knowledge through exchanges and learning), and, finally, innovation approaches themselves.

The book is divided into two main parts.

The first part describes nine cases studies of the implementation of agroecological systems or practices by producers, the research community and various actors of development in different production contexts in the countries of the Global South: mixed crop-livestock systems in Burkina Faso; food crops in Madagascar; cocoa cultivation in agroforestry systems in sub-Saharan Africa; nets to protect market-garden crops from pests in Africa; the agroecological transition in Laos; banana cropping systems with reduced pesticide use in the French West Indies; agroecological horticultural systems in Réunion; coffee-based agroforestry systems in Central America; and the development of coffee varieties suited to these systems. The results of these case studies make it possible to discuss the determinants of the agroecological transition, the technical and organizational solutions that have been identified, and the performances achieved by the new systems.

The eight thematic chapters of the second part consist of reflections on the implementation of the agroecological transition: the determinisms of the development of agroecology; natural regulation processes and the use of biodiversity that can be mobilized for agroecological solutions; the evaluation of the performances of these systems; agroecology and climate change; the ecologization of agriculture through the prism of collaborative innovation; market dynamics to promote the agroecological transition; and territorial mechanisms to enable the agroecological transition. The determinants of the agroecological transition and the genericity of the technical, organizational and collaborative approaches mobilized for this transition in different contexts of the countries of the Global South are presented and discussed in this half of the book.

Finally, the conclusion presents the main lessons learned from the work of CIRAD, AFD and their partners on the implementation of the agroecological transition. The discussions bear, in particular, on the ways in which the very diverse agricultural models in countries of the Global South can all be made to undergo an agroecological transition, the various trajectories that this transition can take, and the genericity of its biophysical and organizational levers. Finally, this summary reminds us of the new challenges that will have to be met and the conditions that will have to be satisfied before the agroecological transition can take place at a significant scale.

Part 1

Case studies

Chapter 1

Co-design of innovative mixed crop-livestock farming systems in the cotton zone of Burkina Faso

Éric Vall, Mélanie Blanchard, Kalifa Coulibaly, Souleymane Ouédraogo, Der Dabiré, Jean-Marie Douzet, Patrice K. Kouakou, Nadine Andrieu, Michel Havard, Eduardo Chia, Valérie Bougouma, Mahamoudou Koutou, Médina-Sheila Karambiri, Jethro-Balkewnde Delma, Ollo Sib

Producers in western Burkina Faso have to contend with high rainfall variability and very volatile agricultural prices (Cooper *et al.*, 2008). Such uncertainties have led the vast majority of them to diversify their production and practise mixed crop-livestock farming using low levels of inputs in order to ensure their food self-sufficiency while containing economic risks. Their mixed crop-livestock farming systems are based on cotton, cereals (maize, sorghum), legumes (groundnuts, cowpeas), and the rearing of cattle and small ruminants (Vall *et al.*, 2006).

Producers have, for a long time, favoured a strategy of extension of cropping areas and increase in herd sizes, as long as space is available to them to do so, both for extending cropping areas and for new pastures (Milleville and Serpantié, 1994). However, as population and, consequently, the pressure on the land increased, producers opted to implement strategies to intensify agricultural production (Ouédraogo *et al.*, 2016; Jahel *et al.*, 2017). Intensification of production is meant to enable them to maintain, or even increase, production levels to meet the growing local demand for agricultural products (Bricas *et al.*, 2016). Agricultural policies and development entities have thrown their weight behind this intensification to achieve food security and increase exports[1]. This has resulted in the decrease in fallows, the transition to continuous cultivation, overgrazing, and an increased use of synthetic inputs (Vall *et al.*, 2017). Producers have also intensified production by strengthening the association between agriculture and livestock husbandry in order to be more self-sufficient in agriculture energy, animal feed and organic manure. However, the sustained increase in agricultural and pastoral pressure on natural resources has resulted in their degradation

1. https://www.agriculture.bf (retrieved 23 March 2019).

and fragilization, leading to a decline in soil fertility (Bationo *et al.*, 2007), an impoverishment of pastures (Vall and Diallo, 2009), and a critical decline in the potential for production and regeneration of agroecosystems.

In such a context, an agroecological transition must be encouraged to diversify and increase agricultural production in a sustainable manner, while safeguarding agroecosystems. This kind of transition, however, requires profound changes in farming practices (Duru *et al.*, 2014; Tittonell, 2014) and, consequently, calls for efforts to co-design innovative farming systems with the involvement of producers to try out, assess and adapt new practices, and to provide support to producers in these changes (CIRAD, 2016). It is in this perspective that, since 2005, co-designing of innovative mixed crop-livestock farming systems was taken up in western Burkina Faso in order to analyse the interactions between vegetation, livestock herds and cropping at different scales (farm, territory), and to look for ways to optimize these interactions in order to achieve a sustainable intensification (Vall *et al.*, 2016a).

After recalling the principles of the co-design of innovative farming systems, we will present a summary of the developments observed in the mixed crop-livestock farming systems. We will then highlight examples of the design of agroecological, technical and organizational innovations, carried out at the scales of territories, farms and production systems. We will conclude by reviewing the lessons learnt from the successes and failures of such efforts.

Mechanisms for the co-design of innovative multi crop-livestock systems

Undertaken as a result of a combination of a desire for change by actors in the field and the willingness of researchers to support these actors in this effort, the co-design of innovative mixed crop-livestock farming systems aims to produce useful knowledge and to transfer knowledge and know-how required by the actors to successfully carry out their plans for change (Vall *et al.*, 2016a).

In theory, co-design relies on a multi-actor framework that includes voluntary members and partners, all adhering to an ethical framework that they have themselves created in order to protect the values and objectives negotiated at the outset. In practice, we first relied on village consultation committees (Koutou *et al.*, 2011) involving diverse producers, agricultural technicians and advisers, and researchers. Having recognized the limitations of a partnership formed by locally close entities in addressing issues raised by innovation that also depend on value-chain actors located upstream or downstream of the farms and also on actors involved in territorial governance, we established innovation platforms (Dabiré *et al.*, 2016) to broaden the partnership to include the actors of the agri-chains and local authorities.

At a functional level, co-design is also based on a progressive and iterative process involving phases of exploration, implementation of change, and assessment.

In the exploration phase, we attempt to understand the concerns and expectations of actors in the field, through farm- and territory-level diagnoses to analyse producer practices (causes, methods, performances), in order to identify ongoing changes, constraints, and the categories of local actors involved. We also explore the means employed by actors to solve problems (local knowledge and practices), and we make an inventory of the scientific knowledge available to address these problems. Computer models can be used to explore a wide range of possible future scenarios that incorporate profound changes, and to carry out *ex-ante* assessments of their effects on mixed crop-livestock farming systems through simulation, or in other words, to systematically study the feasibility of the desired options (Andrieu *et al.*, 2012). Restitution workshops help define a common representation of the initial situation and the problems to be addressed and, subsequently, to establish links between the problems and their possible causes, and finally, to propose research hypotheses and an initial list of possible solutions.

In the implementation phase of the change, we choose, from among possible innovations, those that correspond to the desired changes, and which are thus compatible with the available means. This exercise promotes reflections on the feasibility of all the innovations. Experimental protocols are then developed to compare the selected options by specifying the reciprocal commitments of the actors on the operations to be conducted. Finally, these options are tested by the producers based on their own management, and their performance is measured against the criteria defined in concert with the actors. In this step-by-step co-design approach, the producer gradually develops a new system, at the same time as he learns to use it, satisfies himself regarding its utility and benefits, and reorganizes his work and his means of production (Meynard *et al.*, 2012).

We use the assessment and appraisal phase to choose options that maximize the desired impacts while minimizing negative externalities. The *ex-post* assessment consists of verifying whether the objectives initially set were achieved or not in terms of outputs (creation of new products, new technologies, new organizations), outcomes (change in practices or modes of organization) that show actors have acquired know-how and skills and built up their capacity to innovate (changes of technical or organizational practices, etc.), and, if possible, in terms of the first impacts. A beginning of the adoption of the innovating principles legitimizes the initial hypotheses and marks the success of the effort. At this point, the actors can decide to disengage from the co-designing process. However, sometimes, when certain constraints and resources were omitted during the diagnosis, adoption does not take place. In such a situation, the process of defining the problem in the exploration phase must be reinitiated.

Changes observed in mixed crop-livestock farming systems

We analysed the changes in mixed crop-livestock farming systems based on diagnoses made in the exploration phases of the co-design work. We present below a summary of the developments observed.

On the whole, mixed crop-livestock farming systems in western Burkina Faso are still at an early stage of the agroecological transition, if we base ourselves on Tittonell's

(2014) framework for analysing this transition. They are characterized by the continued use of synthetic inputs at a moderate level, combined with the introduction of agroecological practices in a rationale of eco-efficiency or of a partial substitution of synthetic inputs by ecological processes.

Diversity and trajectories of change

The first studies showed that mixed crop-livestock farming systems are not homogeneous (Vall *et al.*, 2006). It was therefore clear that any reflection on technical changes in these systems would have to take into account this diversity to respond to the constraints of producers and the opportunities available to them. Three classes of mixed crop-livestock farming systems were identified (Table 1.1): farmers with cultivation-dominated systems, the predominant group (~ 60%) with variable farm sizes (C1, C2, C3); livestock breeders, a minority (~ 20%), with a system dominated by cattle husbandry with variable herd sizes (B1, B2) with also a cultivation of a food crop; and agro-pastoralists (AP), also in a minority (~ 20%), who cultivate large areas and own large herds.

Table 1.1. Classification of mixed crop-livestock farming systems (based on a sample of 350 farms in western Burkina Faso surveyed in 2008).

Groups	Classes	Cattle population (heads)	Cultivated area (ha)	Percentage (%)
Cultivators	C1	< 10	< 5	18
	C2		5.1-10	26
	C3		> 10.1	16
Agro-pastoralists	AP	> 10	> 7.5	20
Breeders	B1	10-29	< 7.5	5
	B2	> 30		15

We then characterized the trajectories of these different classes of mixed crop-livestock farming systems to better understand the changes taking place, and thus determine if they exhibited any aspect of an agroecological transition. This work was carried out on a sample of about 40 farms belonging to these three classes. Data was collected by retrospective surveys for three periods: the establishment of the farm, the current state of the farm, and the medium-term future envisaged by the head of the farm. The analysis was based on structural variables and relied on multivariate analysis (see Vall *et al.*, 2017, for details of the method). Figure 1.1 shows the simplified evolutionary trajectories of the different categories of mixed cropping systems.

Figure 1.1 shows that, since the establishment of their farms, all producers sought to increase cultivation acreages, herd sizes and the amount of equipment they own. It also shows that the producers intend to pursue these objectives in the future, in spite of an ever-constraining land context. As far as cultivators are concerned, it is mainly the extension of cropping acreages that dominates. In the case of

C1-2 farmers, the change is modest, even problematic in some cases, with a reduction in the meagre livestock herd. C3 farmers seem to be aiming for the current situation of agro-pastoralists. In the case of livestock breeders, the increase in livestock clearly dominates the trajectory of evolution. As for agro-pastoralists, it is clearly the extension of cropping acreages that has been the dominant driver from the time of establishment of their farms to the present, followed by the desire to increase their herd sizes in the future thanks to the capitalization of agricultural surpluses into cattle.

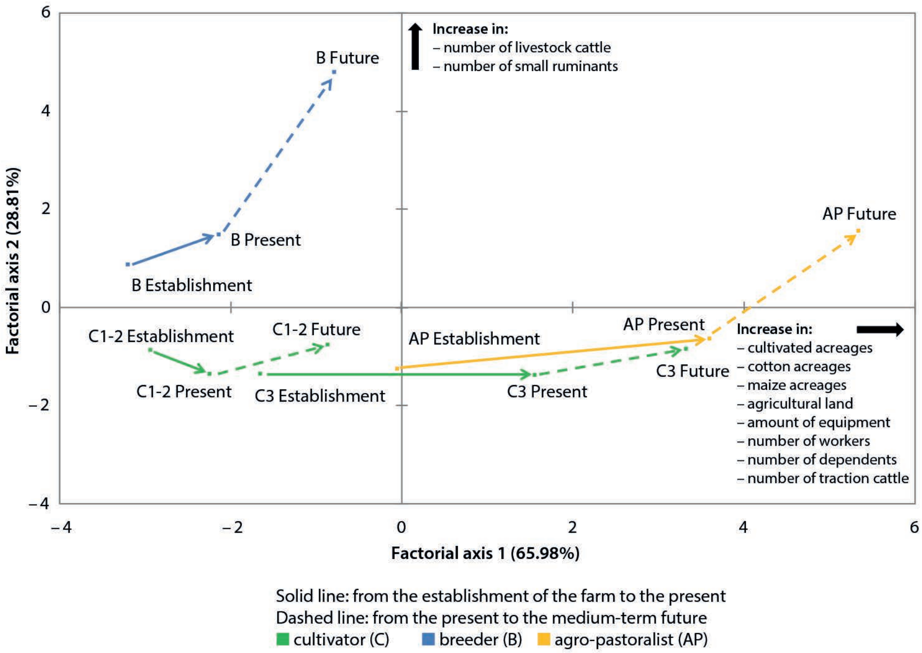

Figure 1.1 Simplified trajectories of evolution of mixed crop-livestock farming systems.
The sub-classes of C1 and C2 farmers have been merged, as have been those of the B1 and B2 livestock breeders. See Table 1.1 for more details on the characteristics of the sub-classes of mixed crop-livestock farming systems.

Evolution of agricultural practices

As far as agricultural practices are concerned, our work has shown the following developments: a trend towards crop diversification, an increased use of synthetic inputs (fertilizers, pesticides), and, at the same time, a strengthening of the association of cultivation and livestock breeding.

Producers diversify the crops they cultivate in rotations (Figure 1.2a and 1.2b) to widen their sources of income and to respond to the emergence of new markets (rice, sesame, soya, sunflower, etc.). The observed diversification does not yet reflect any agroecological practice, especially since this diversification involves pure crops and on very small crop rotation plots amidst acreages still largely dominated by cotton and maize.

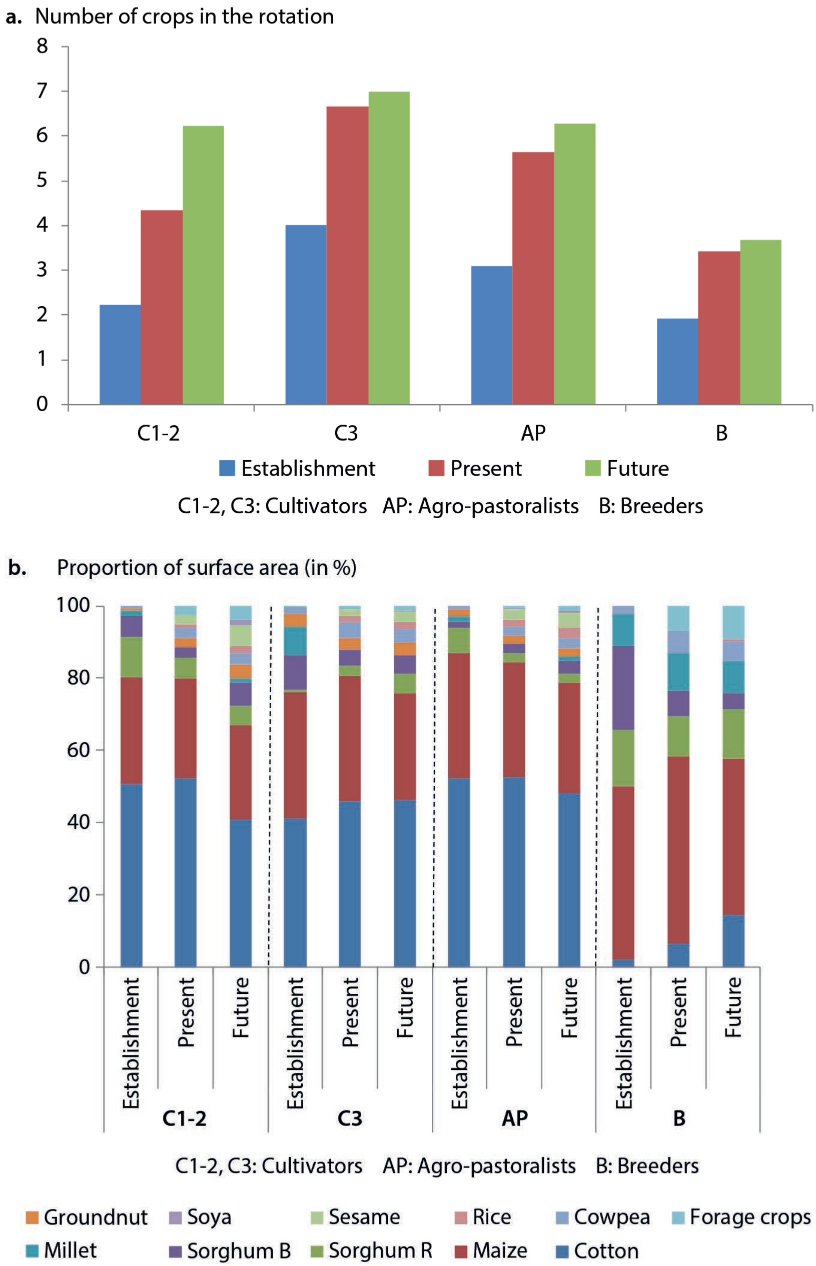

Figure 1.2. Changes in the number of crops (a), changes in crop rotations (b) according to the classes of mixed crop-livestock farming systems.

Producers rely more heavily on synthetic inputs such as mineral fertilizers (NPK and urea), herbicides and insecticides. For mineral fertilizers, this change was observed for all categories of farms. Producers who used mineral fertilizers only marginally until the 1990s increased their use substantially, initially for cotton, then for maize. They have also increased the doses, although they remain moderate compared to those in very intensive agriculture systems in developed countries. This trend towards increased dosages is clear for maize (Figure 1.3a) but has, on the other hand, decreased for cotton (Figure 1.3b); since intensive cotton has been cultivated widely for a longer period that maize, the doses were increased a long time ago. It was also observed that producers practise split applications of mineral fertilizers, something that did not occur previously. Producers started to use herbicides in the 2000s, which, today, represents a widespread practice.

Producers have increased the interaction between agriculture and livestock, and this trend is seen in all farm categories. They began adopting animal traction to extend cultivated acreages, especially since the mid-1980s for most of them. Today, some well-to-do producers, especially agro-pastoralists, have even adopted tractors. Producers have also significantly increased their production of organic manure and use it extensively on maize and cotton (Figure 1.4a and 1.4b), a practice they justify by the decline in soil fertility and the increase in the price of fertilizers.

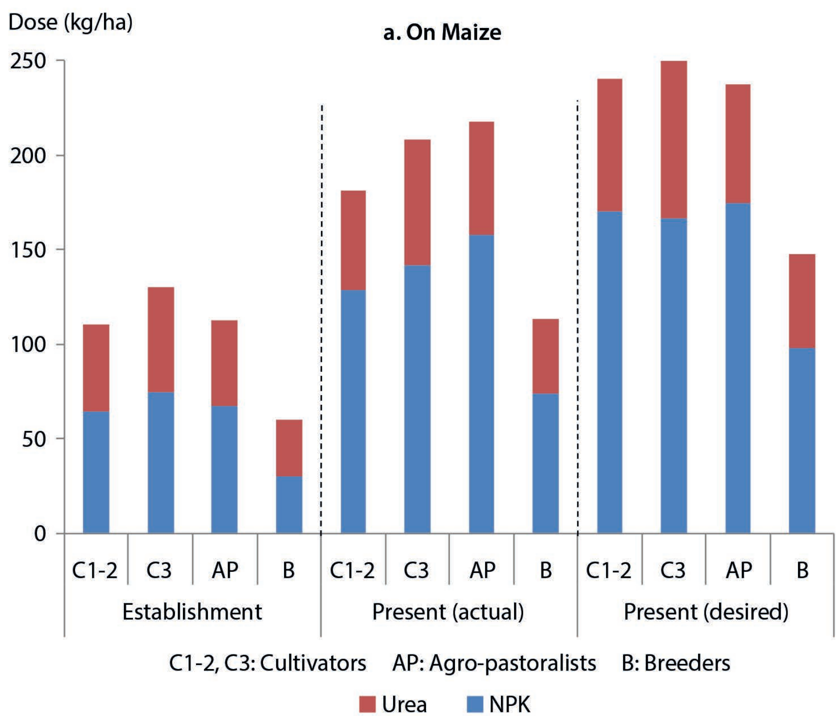

Figure 1.3a. Changes in mineral fertilizer doses on maize, between the time the crop was first grown and the present, and comparison made/desired for the current practice, according to the classes of mixed crop-livestock farming systems (see Table 1.1).

Producers have also begun to store crop residues increasingly systematically for animal feed purposes (Figure 1.5a). We have also observed the beginning of development of forage crops by a small number of livestock breeders and agro-pastoralists, who intend to increase the acreages for these crops in the future (Figure 1.5b).

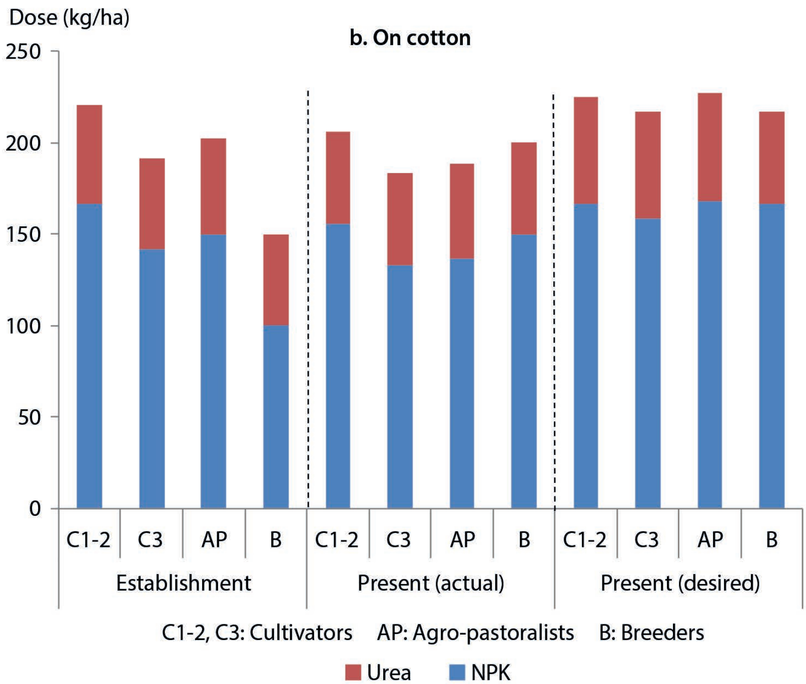

Figure 1.3b. Changes in mineral fertilizer doses on cotton, between the time the crop was first grown and the present, and comparison made/desired for the current practice, according to the classes of mixed crop-livestock farming systems (see table 1.1).

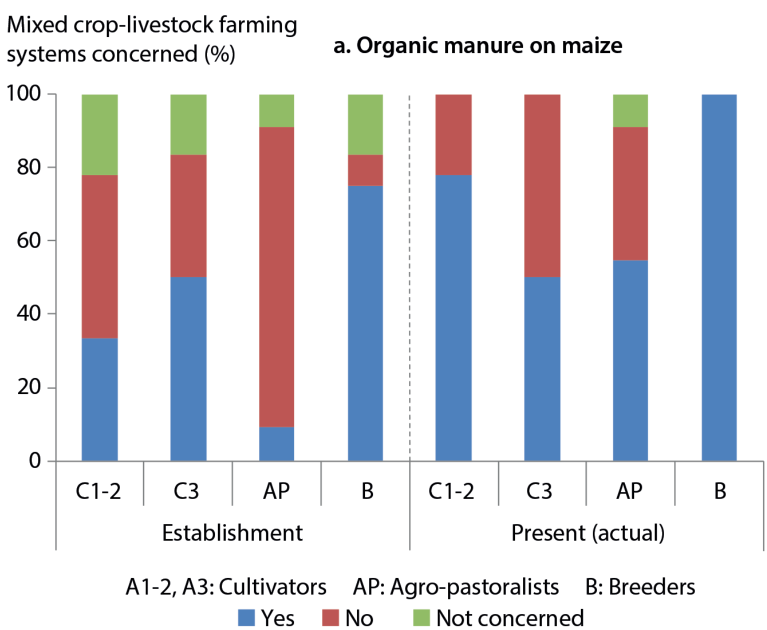

Figure 1.4a. Changes in the application of organic manure on maize, according to the classes of mixed crop-livestock farming systems (see Table 1.1).

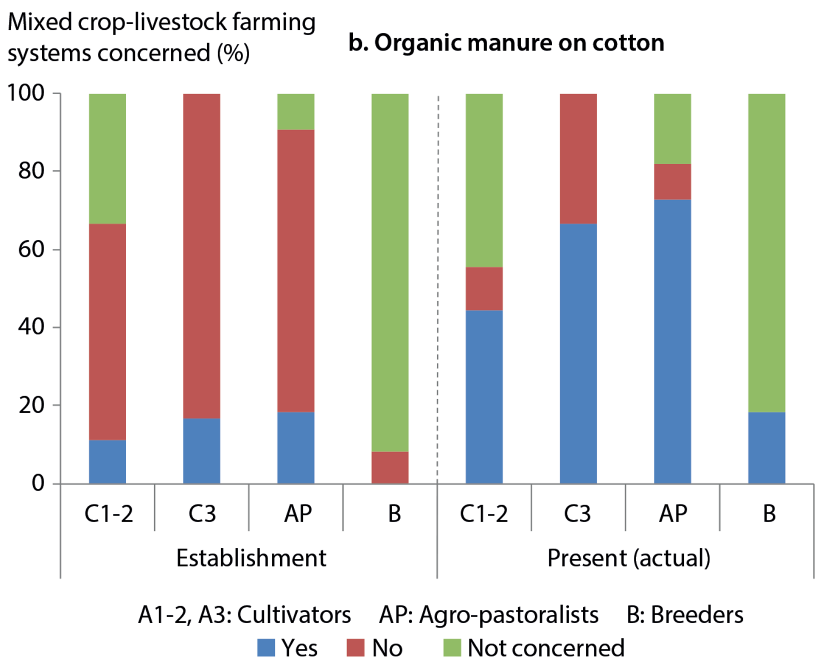

Figure 1.4b. Changes in the application of organic manure on cotton, according to the classes of mixed crop-livestock farming systems (see Table 1.1).

As concerns trees present on cultivated plots (Table 1.2), we did not find any obvious relationship between the classes of mixed crop-livestock farming systems and the types and density of trees. We did observe, however, that breeders tend to maintain a greater diversity of species.

Table 1.2. Density and types of trees in cultivated plots as measured in number of trees per hectare, according to the classes of mixed crop-livestock farming systems (sources: personal data, observations made on 40 farms).

Classes	All species	Shea (*Vitellaria paradoxa*)	Nere (*Parkia biglobosa*)	Balazan (*Faidherbia albida*)	Other species
C1-2	14 ± 5	9 ± 3	1 ± 2	1 ± 1	2 ± 2
C3	13 ± 5	8 ± 5	1 ± 1	2 ± 3	1 ± 0
AP	11 ± 4	8 ± 3	1 ± 1	1 ± 2	1 ± 1
B	14 ± 8	7 ± 9	1 ± 1	0 ± 1	6 ± 4
Avg.	13 ± 5	8 ± 6	1 ± 1	1 ± 2	3 ± 3

A still limited participation by mixed crop-livestock farming systems in the agroecological transition

In the mixed crop-livestock farming systems of western Burkina Faso, producers combine a strategy of extension of cultivated acreages and increase in the size of livestock herds with a strategy of conventional intensification (greater recourse to

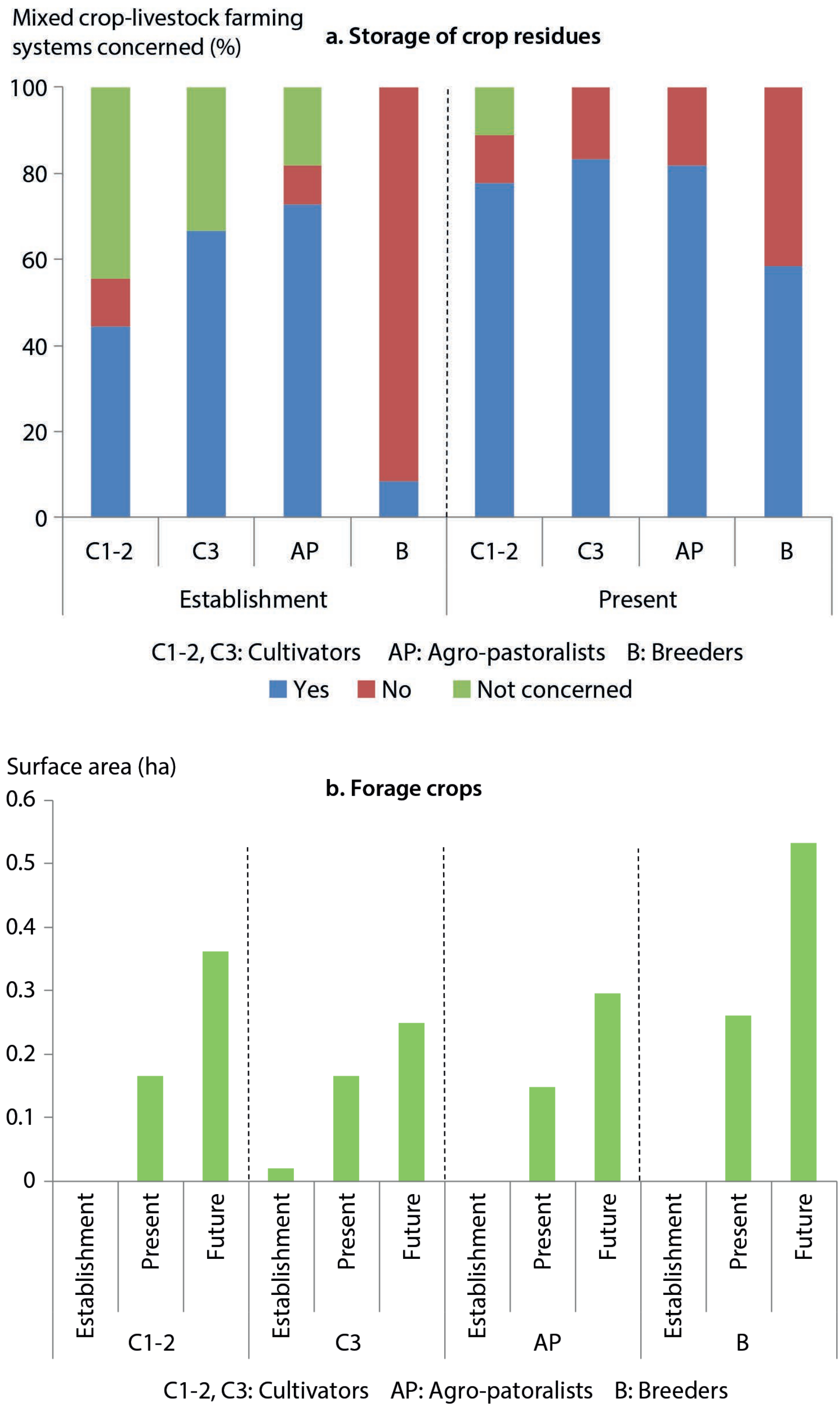

Figure 1.5. Changes in the practice of storing forage crop residues (a), forage crops (b) according to the classes of mixed crop-livestock farming systems (see Table 1.1).

synthetic fertilizers, improved seeds and agricultural equipment), coupled with an 'agroecological' intensification strategy based primarily on the combination of cultivation and livestock husbandry, and on maintaining trees in the agroecosystem. The association of cultivation and livestock husbandry is characterized by:
– extensive use of draft animals for agricultural tasks and transport;
– increase in the recycling of agricultural residues of farms, and the beginning of the cultivation of forage crops comprising of multipurpose species;
– improving the production of organic manure.

The mixed crop-livestock farming systems of western Burkina Faso have progressed little in the agroecological transition. They are at a stage at which producers continue using synthetic inputs at a moderate level, while introducing practices with an agroecological character based mainly on an association of cultivation and livestock husbandry. To support producers in undertaking a more meaningful transition, i.e. to create sustainable intensification impacts by leveraging better the possible interactions between natural vegetation, livestock herds and crops, as well as the recycling of biomass in farms and territories, we initiated the co-designing of technical and organizational innovations. The implemented approach has been systemic and multi-scale so that constraints at higher or lower levels do not inhibit change at other levels (Figure 1.6).

Co-design of innovations at the farm and territorial scales

We present a summary of this co-design work carried out to support the agroecological transition of mixed crop-livestock farming systems at different scales: territories, farms and production systems.

Co-design of rules for territorial resource management

In Burkina Faso, local authorities which were created following decentralization must renew the mechanisms for managing natural resources of their territories so as to exploit them sustainably, control competition and manage conflicts between users. Starting in 2009, changes in the land law have helped them implement local land charters. Inspired by local customs, uses and practices, but remaining in compliance with the country's laws and regulations, a charter determines, at a clearly defined scale, the specific rules for good and judicious management of territorial resources.

From 2008 to 2012, with backing of the Fertipartenaires[2] project, we supported the Koumbia commune in designing and implementing a local land charter to establish rules for the use of resources and space that are compatible with a sustainable management of resources and an agroecological transition (Vall *et al.*, 2015). Given the number of actors involved at the commune level (14 villages, 1358 km^2, 36,000 inhabitants) and beyond (province, country), a relatively complex mechanism for the representation of actors had to be implemented to establish the charter.

2. http://food-fertipartenaires.cirad.fr.

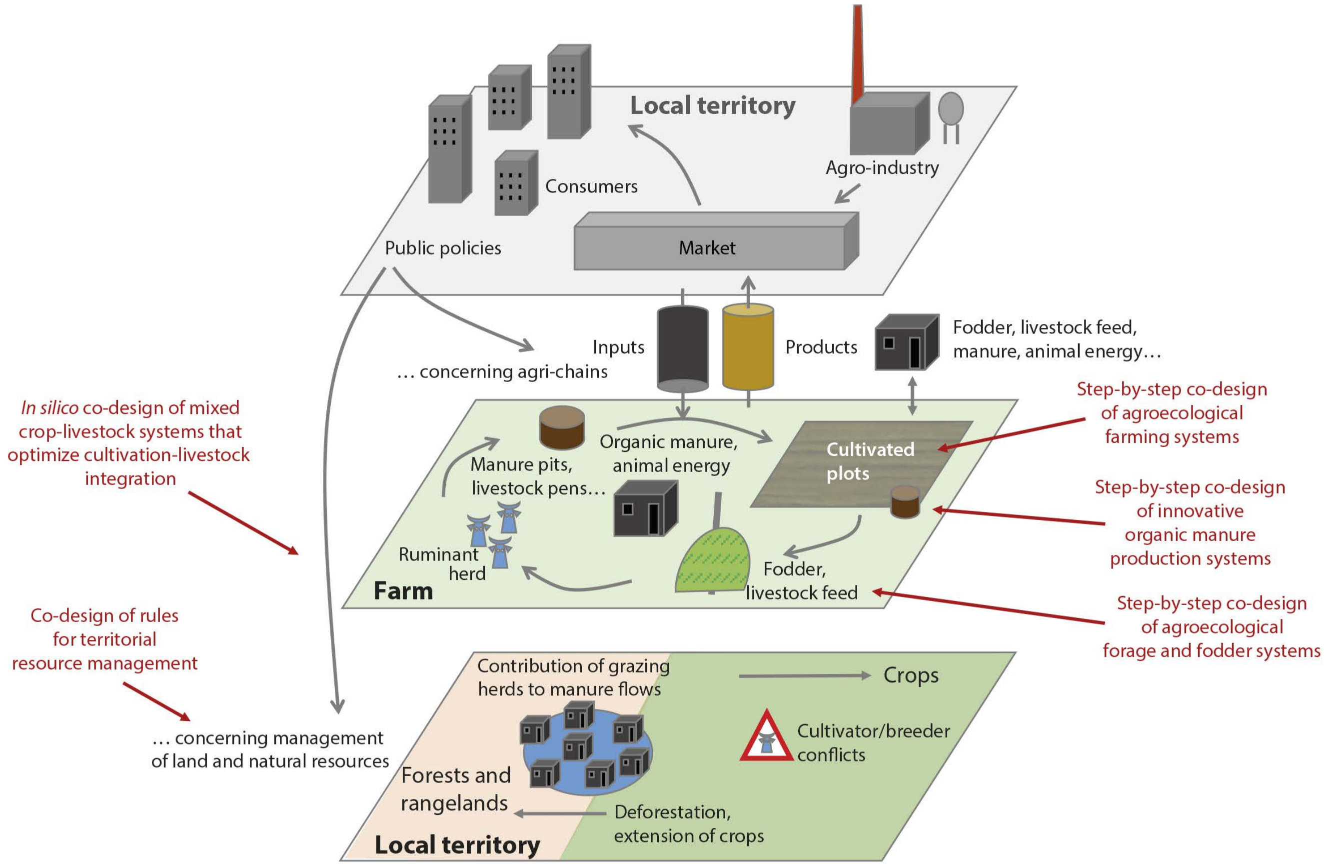

Figure 1.6. Interactions between cultivation and livestock husbandry in mixed crop-livestock farming systems in western Burkina Faso and context of co-design work carried out to support their agroecological transition.

During the exploratory phase, transitional consultation frameworks were mobilized in each village to take stock in a participatory manner and pre-identify resource management rules. During the drafting phase, an *ad hoc* consultation framework including village representatives, elected officials and the administration made it possible to adjust and fit these rules into the legal framework, and to design a project for drafting and implementing a charter.

The Koumbia municipal council adopted the charter in 2010 (Vall *et al.*, 2015). The aim of the third phase was to set up the commissions responsible for its application, and its articles concerning the management of agricultural land, pastures, forest areas, ponds and watercourses. However, in 2012, certain decrees pertaining to the implementation of the land law had still not been published. Furthermore, the events of 2014 (the fall from power of President Blaise Compraoré on October 31) prevented the application of the charter. In fact, to date, its impact on facilitating the implementation of agroecological practices and systems has not been evaluated and remains hypothetical. The implementation of the charter has to be taken up again and pursued to achieve the expected results.

In silico co-design to optimize cultivation-livestock integration

The management of a mixed crop-livestock farming systems is relatively complex because of the diversity of its components. A change of practice in one of the components has immediate repercussions on the others. This is why the modelling of the functioning of such a system is, in theory, very useful in trying to optimize the association of cultivation and livestock husbandry and to study the impacts on it due to changes in practices. Several farm simulation tools were tested in order to renew the approaches for co-designing production systems, and to support producers in a participatory approach framework involving researchers, producers and technicians of extension services.

The first is called *Cikeda* (which means 'agricultural farm' in the Dioula language) which helps calculate the effects of various farm-level technical and organizational alternatives on resource flows (residues, organic manure, cereals) in terms of the balances of forage, minerals, cereals and on incomes (Andrieu *et al.*, 2012). The second, *Simflex* (Andrieu *et al.*, 2015), simulates the farmer's main decision rules in the face of climatic and economic hazards. The third, *optimCikeda*, is a linear optimization model that maximizes the income of the farm when confronted with constraints.

These tools informed the strategic and tactical reflections of 6 and 18 producers respectively representing the three classes of mixed crop-livestock farming systems and who were participating in projects (Sempore *et al.*, 2015a, 2015b). In the first case (strategic reflections), the aim was to analyse, with six producers, the benefits of a new production activity, such as a cattle fattening unit. In the second case (tactical reflections), it was more a question of planning the activities to be carried out during the next cropping season (acreages of different crops, organic fertilizer inputs, amount of animal feed to be produced). These different tools helped build up the knowledge on integrating cultivation and livestock husbandry of all the producers who experimented with simulation tools, with *Cikeda* being perceived as the best of the three by the farmers due to its simplicity in representing the farm. An assessment of practices was also undertaken in the year following the use of the different tools, and showed an increase of more than 20% in the amount of compost produced, and in the introduction of fattening units and fodder crops by 80% of producers. More livestock-specific modelling tools were also developed and then used to design innovative livestock breeding units (Delma *et al.*, 2016).

Step-by-step co-design of agroecological farming systems

The work of co-designing agroecological farming systems had two objectives: first, to promote cropping systems based on conservation agriculture (no tillage, permanent crop cover and plant diversification) to limit the loss of soil fertility; and, on the other hand, to create associated cropping systems – mainly leguminous cereals – to diversify and increase security of production, while benefiting from the nitrogen supplied to the system by the leguminous plants.

Cropping systems based on conservation agriculture were tested for several years in farmers' fields with sorghum associated with pigeon pea (*Cajanus cajan*), followed by maize associated with cowpea (*Vigna unguiculata*). At the end of four years the results were as follows: yield of 2889 kg/ha maize grain and carbon stocks of 10.73 tonnes C/ha in the superficial horizon (5 cm) on conservation agricultural plots as against 2605 kg/ha and 6.35 tonnes C/ha respectively on conventional plots (Sanon, 2017; Coulibaly *et al.*, 2018). To date, however, few farmers have adopted these systems. This is due to persisting and significant technical difficulties (weed control, lack of knowledge on pigeon pea) or organizational and cultural ones (hard to retain residues on the plots). However, producers did evince interest in improving the fertility of degraded plots.

For associated crops in conventional systems, the main systems tested consisted of maize associated with various multipurpose legumes (food for human consumption, fodder, soil cover). Coulibaly *et al.* (2012) showed that the maize/cowpea association saved 30% of the cultivated area compared with pure maize and cowpea, and that the maize/mucuna combination (*Mucuna rajada*) saved 26% of the cultivated area in terms of the system's overall production. However, with the mechanization of weeding in cotton-growing areas, it is difficult to implement associations without an arrangement allowing intercropping, which largely explains the lack of adoption of intercropping, or even its disappearance when producers resort to herbicides. New research is planned to adapt the systems to ensure a more viable reintroduction of legumes in this new context.

Step-by-step co-design of agroecological forage and fodder systems

To cope with the reduction of grazing pastures and also the problems of accessibility and price of livestock feed on the market, which curb projects to expand breeding programmes on farms (purchase of draft animals, production of milk or cattle fattening) (Delma *et al.*, 2016), we assisted producers in the design and implementation of forage and fodder production and storage techniques.

An initial part of the work, carried out on a large scale (several hundred test plots on farms), concerned the production of forage legumes (*Mucuna deeringiana*, *Vigna* *unguiculata*, *Cajanus cajan*, etc.; Ouattara *et al.*, 2016). The producers tended to focus more on *V. unguiculata* for its multi-use character (food, fodder, fertility) and its good quality haulms (Gomgnimbou *et al.*, 2017), and on *M. deeringiana*, which is easy and economical to cultivate (2 to 4 tonnes of dry matter [DM] haulm per hectare).

Another part of the work concerned the establishment of very dense (20,000 plants/ha) fodder plantations of *Leucaena leucocephala* and *Morus alba,* also known as 'shrubby fodder banks' (Ollo *et al.*, 2016). The fodder banks enter into the production stage following the establishment period (12 months). While the initial results showed that production (4 to 10 tonnes DM/ha) fell short of the output targeted by farmers (15 to 20 tonnes DM/ha), the first fodder banks withstood the dry season, fires and termites, which makes them potentially very beneficial.

For the moment, the adoption of forage, annual and tree crops remains limited, and grazing, storage of residues and the purchase of feed remain the preferred options for breeders. However, this work resulted in some unexpected and promising outcomes, such as the creation of a mini-dairy by Fulani women in Koumbia, and the launch of a seed production activity of *M. deeringiana* by Kourouma farmers. These outcomes indicate a probable empowering effect of the co-design, and highlight the benefits of expanding the mechanisms of design to upstream and downstream actors of the value chain in order to better address the issues of sustainability and feasibility of innovations.

Step-by-step co-design of innovative organic manure production systems

The bulk of the manure production in western Burkina Faso takes place near habitation areas where animals are kept (Diarisso *et al.*, 2016). The transportation of litter and manure thus represents a significant workload and constitutes a real obstacle to the production of organic manure, especially since the extension of cultivated acreages leads to ever-increasing distances to be covered. We proposed to producers that they should decentralize the production of organic manure to the field itself by modifying the production methods in order to reduce this transportation constraint (Blanchard *et al.*, 2017; Benagabou *et al.*, 2017).

The objective was to produce good quality manure in the field itself with a minimum of labour and external inputs. Work carried out on a large scale (more than 1000 pits) between 2005 and 2012 helped design an organic manure production model in cemented pits in the field. They were filled at the end of the dry season (~ 20% animal waste, 80% agricultural residues), with a supply of rainwater, needed no shredding or turning over, and were emptied after 12 months, producing a yield of about 50%, a production of 150 kg DM/m^3, a composition of about 10 g C/100 g, and a carbon/nitrogen ratio of about 20 (Blanchard *et al.*, 2014).

The assessment carried out in 2015 of the impact of this work confirmed the adoption of this technique, and highlighted an early impact on the production of organic manure (increase of 7 tonnes per farm), on maize yield (+786 kg/ha), and, in the farmers' opinion, on improving soil fertility and on increasing their incomes and their food security (Vall *et al.*, 2016b). The increase in, and improvement of, agroecological manure production are topics that are still of interest to producers. Today, practices continue to develop with the installation of bio-digesters and fertilizer trials based on shea caterpillar droppings (Coulibaly *et al.*, 2016).

Conclusions

This work of co-design of innovative systems has helped transform local farming systems and support producers in an agroecological transition.

They produced two principal categories of outputs: potential agroecological innovations; and analyses of ongoing processes of change. Both types of results have been the subject of scientific and technical publications.

The developments observed show that mixed crop-livestock farming systems in western Burkina Faso are still at an early stage of the agroecological transition. Producers maintain the use of synthetic inputs at a moderate level, while introducing agroecological practices based mainly on strengthening the association of cultivation with livestock husbandry.

The results of the co-design work have also contributed to changes in practices in mixed crop-livestock farming systems. However, the level of adoption of agroecological practices has varied, based on the type of innovation proposed. When innovations were made part of transformations already underway, adoption and early impacts were observed more rapidly. This was true for innovations involving the strengthening of associations between cultivation and livestock husbandry, e.g. manure pits in the field. In contrast, the adoption of innovations that flowed counter to the intensification models favoured by development entities is still very limited, e.g. mulch-based cropping systems, or even intercropping. Unexpected changes were also observed in the activities of some actors involved in the co-design process, e.g. the setting up of a mini-dairy, bio-digesters, hay-lofts and marketing of *Mucuna* seeds. These changes illustrate an empowering effect of co-design through the extension of the action in a different direction, chosen by the actors in the field themselves.

The successes and failures of this work of co-design of innovative mixed crop-livestock farming systems have also led us to propose a few recommendations to make co-design more effective and to accelerate the agroecological transition:
- taking the time to properly study and understand the dynamics of changes underway to fine tune the proposals of innovation to the producers' constraints and objectives;
- preparing the co-design of innovative farming systems through studies of agroecological processes that can be mobilized at different scales and planning actions to support change in order to consolidate results;
- taking into account the adaptation of rules to manage territorial resources when co-designing innovative farming systems;
- including key value-chain actors and those involved in territorial management into co-design mechanisms such as innovation platforms;
- combining little-known innovations of actors in the field with ongoing innovations to increase their interest and to involve them.

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Chapter 2

Agroecology in Madagascar: from the plant to the landscape

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Introduction

Context and problem

The Vakinankaratra region, located at the centre of the island of Madagascar, straddles two biogeographic zones that present stark physical and human differences: the highlands and the Middle West area (Figure 2.1). Research and development teams located in Antsirabe have been working for over 30 years to extend support for a sustainable intensification of agricultural production in the region. Various agro-ecological solutions have been explored for this purpose in order to make the best possible use of the available natural resources and in an effort to maintain coherence between farms in all their diversity. More or less complex innovations, sometimes combining different options, were envisaged depending on the context.

The average altitude of the highlands of Vakinankaratra is 1400 m, and the mean annual rainfall there is 1300 mm. Human settlement in this area dates back more than 2000 years, resulting in a high population density (over 120 inhabitants/km^2). The farms here are characterized by small surface areas (0.5 ha on an average), labour-intensive farming systems, a very low level of use of inputs, and the cultivation, when possible, of an off-season crop in irrigated areas. Irrigated areas and rainfed farming areas on the *tanety*[1] (hillsides) are already occupied. Cultivation systems in the developed lowlands are based on irrigated rainy season rice, with rice yields of about 3 t/ha, followed in the off-season by market gardening (potato, tomato, carrot) and/or fodder in the case of dairy farmers. The main productions of the farming systems in the *tanety* include rainfed rice (in expansion), maize, sweet potato, beans,

1. *Tanety*: rainfed farming (solely dependent on rainfall for its water supply) practised on the slopes and hilltops.

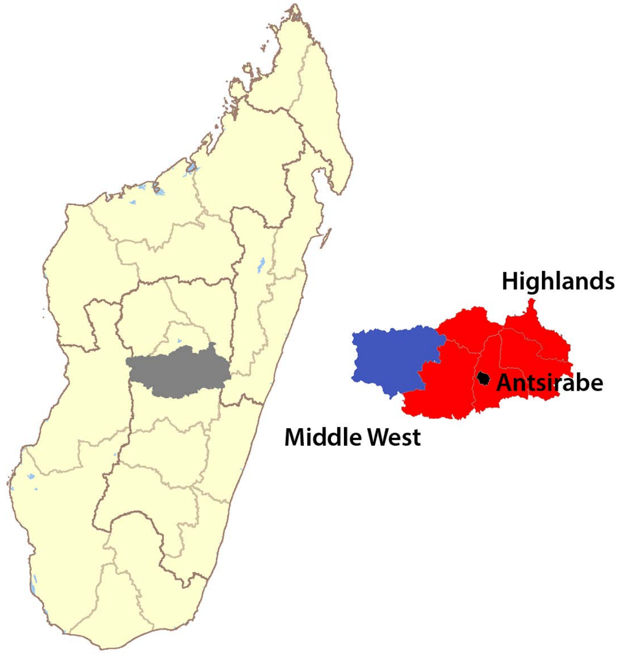


Figure 2.1. Location of the highlands and Middle West area in the Vakinankaratra region, Madagascar (from a Wikipedia map – Privatemajory CC BY-SA).

Bambara groundnut (*Vigna subterranea*), cassava, potato and peanut. In the context of a growing population, rainfed rice has become an extremely important component of the overall rice production that forms the staple of the Malagasy diet. The increase in the production of rainfed rice is the result of the adoption of a Nepali variety that is particularly suited to local conditions, as also of varieties originating from local research institutions (Penot *et al.*, 2016; Raboin *et al.*, 2014). Crop-livestock integration is widespread and manure remains the primary source of fertilization for crops. Livestock husbandry also provides a local opportunity to leverage plant resources and increase revenues. The problem faced by farmers with limited arable land is their inability to increase land productivity because they have very limited access to conventional intensification methods (fertilizer, mechanization, pesticides), and this in a fragile environment and with fairly steep slopes.

Madagascar's Middle West is at a lower altitude, of around 800 m. While the chemical fertility of soils is low (desaturated ferralitic soils) their structure is good. The climate is tropical with a rainfall of 1000 to 1500 mm/year spread over four to five months. These are areas that have only recently been settled (in the 1960s), and thus have a lower population density (30 to 40 inhabitants/km^2) and surface areas of the farms are bigger than in the highlands (Penot *et al.*, 2016). It is an agricultural frontier that is still undergoing a process of stabilization. The main crops are rainfed rice, maize and cassava on the *tanety*, and irrigated rice in the lowlands. Livestock farming is widespread because of the extensive natural pastures that exist relatively close to the major markets of the highlands. In this region too, the lowlands were cultivated first, even though their surface areas are smaller, and it is only now that the farmers are forced to cultivate the *tanety* with increasing regularity. However, as far as rainfed farming is concerned, the Middle West is characterized by the presence of a parasitic plant that is harmful to cereals: *Striga asiatica*. The rice varieties and cultivation systems that are being developed are thus intended, in addition to adapting to low fertility, to reduce the incidence of *S. asiatica*.

Actors and their roles

Malagasy development entities and CIRAD have been working together for close to 35 years to meet the challenges described above. Tafa, an NGO created in 1995, was thus assigned the objective of proposing an alternative to the soil tillage-based intensification model that was being promoted in Madagascar at that time. Based on initial experiments conducted in 1991 at the Andranomanelatra site (Antsirabe region) and with the support of L. Séguy of CIRAD, this NGO designed new farming systems based on conservation agriculture, and encouraged their dissemination by way of a number of demonstration plots spread over the country's main agroecological regions. The work of promoting conservation agriculture was extended across the country through the creation in 2002 of the Direct Seeding Group of Madagascar (GSDM), in association with other national and international partners (Compagnie Bas-Rhône Languedoc [BRL], Agrisud, Research and Technology Exchange Group [GRET]). Other technological solutions were also gradually incorporated into their extension work (agroforestry, vermicomposting). AFD supported these activities through various national projects and international programmes. In particular, from 2006 to 2012, it supported the development programme 'Irrigation and Watershed Management Project', whose aim was to increase the income of farmers in a sustainable manner, while conserving the environment through, *inter alia*, the promotion of agroecology. In parallel with these development-oriented actions, FOFIFA (National Center for Applied Research on Rural Development, Madagascar), the University of Antananarivo and CIRAD created a group towards the end of 2001 called 'Sustainable Farming and Rice Cropping Systems' to ensure agronomic and economic support for increasing the area under rainfed rice cultivation. This group's efforts were focused on two major innovations: on the one hand, the creation and dissemination of high-altitude rainfed rice varieties developed by the varietal-breeding programme launched by FOFIFA and CIRAD in the mid-1980s; and on the other, the creation and assessment of cropping systems based on conservation agriculture, disseminated by the NGO Tafa and CIRAD since the early 1990s. This Franco-Malagasy research group has progressed through different types of scientific collaboration, gradually broadening its research themes and its sphere of partnerships. Consequently, in 2013, the current mechanism for research in partnership 'Highland Production Systems and Sustainability' also brought in the French Institute of Research for Development (IRD), Fifamanor and AfricaRiceCenter.

Conceptual framework

Wezel *et al.* (2014) propose a classification of agroecological innovations according to the mechanisms they use and the extent of change required: increase in efficiency, substitution of external inputs, and redesign of systems. In the highlands and Middle West areas, the farmers' use of inputs is low. Consquently, the solutions proposed are based not so much on mechanisms of substitution as on increased efficiency and the redesign of systems.

We will first present two examples of an increase in efficiency at the scale of the plant, by showing how varietal breeding was focused on varieties that are naturally resistant to a fungal disease (blast), by better utilizing soil nitrogen and producing additional plant biomass, and thus becoming more competitive against weeds. We will also present an example of an increase in efficiency, at the intermediate scale of the livestock system, through the process of making manure, thus boosting nutrient recycling and increasing crop yields. We will see how an increase in efficiency can impact the farm. We will then present examples of how soil and crop management could be redesigned at the scale of cropping systems, based on new rainfed rice varieties and on conservation agriculture. The latter is an example of a more profound agroecological transformation from a systemic point of view and from the point of view of the mechanisms mobilized.

Two innovations based on an increase in efficiency

Varietal breeding adapted to low soil fertility and diseases

Plants that are better adapted to low fertility and diseases

The FOFIFA-CIRAD genetic improvement programme for high-altitude rainfed rice was launched in 1984 (Raboin *et al.*, 2013). Its aim is to breed varieties adapted to the biophysical environment of the highlands (cold, disease pressures, low fertility) as well the socio-economic context of farms (limited capacity to buy chemical inputs). In these cold altitudes, a strong correlation was observed between the vegetative development of rainfed rice varieties, measured in terms of leaf area index, and grain yield (Figure 2.2). A correlation was also shown between grain yield and length of the cycle. Under conditions of no mineral fertilization, the long-cycle and fast-developing varieties accumulate more nitrogen from mineralization over time, resulting in a higher yield. However, the cycle cannot be stretched indefinitely as the risk of cold and sterility increases as the rainy season draws to a close. Moreover, farmers are happy with relatively early varieties to shorten the duration of the lean season. Finally, this rapid development allows rice to offer more competition to weeds (Figure 2.2, Raboin *et al.*, 2014). It is also necessary to select varieties that are resistant to blast, a very common fungal disease which, in the worst case, can result in the loss of the entire crop (Pennisi, 2010), and against which chemical control is too expensive. To this end, epidemiological conditions favourable to the disease must be retained in the breeding process by applying nitrogen fertilizers and using sensitive varieties as border crops to attract pest. The border crops promote a local infestation of blast in order to subject the newly bred varieties to a strong disease pressure. It was therefore necessary to find a compromise to reconcile a selection for 'low input' conditions and for a trait that is resistant to blast. The use of inputs was greatly reduced during genealogical selection. In addition, the breeding selection stages, in which yield is assessed (varietal trials), were split between two levels of fertilization: with or without the use of chemical inputs.

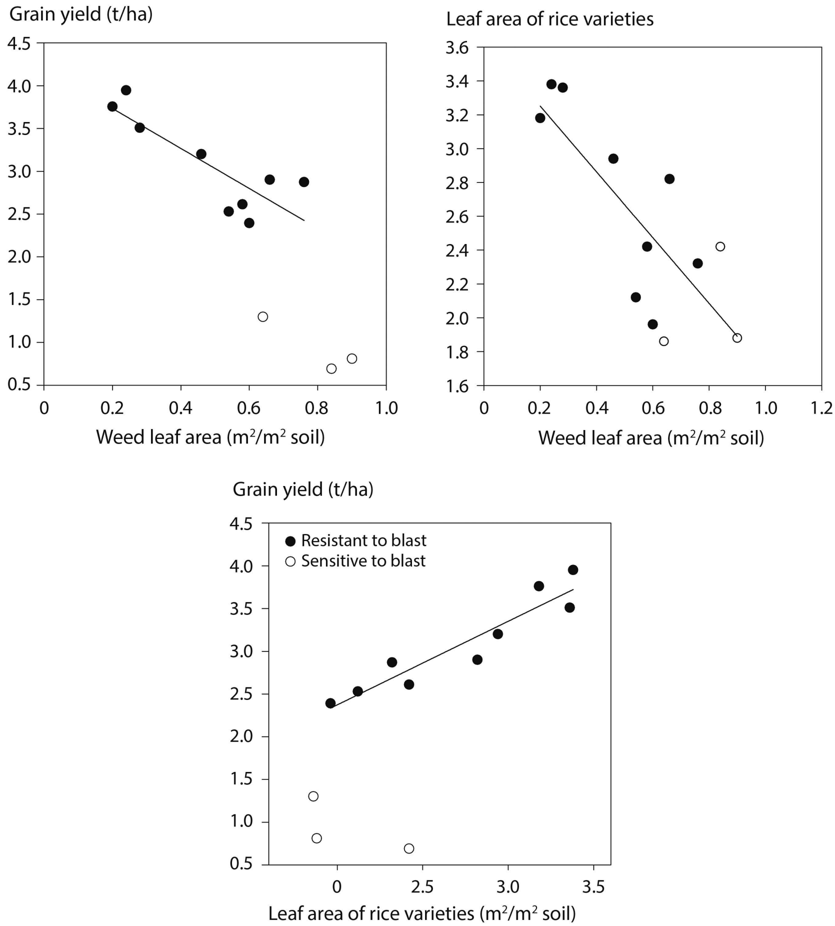


Figure 2.2. Relationship between grain yield, leaf area of weeds and leaf area of the varieties observed at an altitude of 1650 m, for a sample group of 12 rainfed rice varieties (Raboin *et al.*, 2014).

Consequences on production systems and the landscape

More than 20 varieties of upland rainfed rice have been proposed by the research community to farmers since 1994. The expansion of the cultivation area of rainfed rice to altitudes greater than 1800 m was rapid, due largely to the introduction of suitable varieties that allowed cultivation at these higher altitudes. Thus, between 2005 and 2011, the percentage of farms located above 1250 m cultivating rainfed rice in Vakinankaratra jumped from 32% to 71% (Raboin *et al.*, 2014). Improved efficiency at the scale of the rice plant resulted in changes in cropping systems on farms, and a change visible at the landscape scale. A participatory assessment of the impact of upland rainfed rice was conducted in 2015. It highlighted these rice varieties' importance in farm strategies that prioritized food security. These varieties had a significant impact on improving self-sufficiency in rice cultivation (the lean season was reduced by 3.7 months in the 112 farms surveyed) and on the well-being of farming households in the Vakinankaratra region (Breumier *et al.*, 2018).

Reduction in nutrient losses at the farm scale

Technical changes in the livestock farming system

The use of livestock manure to maintain the fertility of cultivated soils is the primary method of fertilization used by farmers. However, the fertilization value of manure varies significantly between farms. Measurements on 60 farms showed that the nitrogen content of manure could vary from 0.6% to 2.6% (Salgado *et al.*, 2014). Malagasy researchers associated with CIRAD have studied the main sources of variability in its quality, and measured the impact of improved manure on crop yields.

Based on these observations, three types of technical recommendations for improving the quality of manure have emerged: the addition of rice straw to excrement, the paving of barn floors to limit infiltration losses, and adequate management and protection of the stored manure until it is applied to the field.

Management and storage methods strongly influence the manure's nitrogen content (Andriarimalala *et al.*, 2013). It is important that vegetable matter rich in carbon (straw, dead leaves, small branches) are placed at the bottom of the pile, and matter rich in nitrogen (fresh leaves, peels and, in particular, animal residues such as excreta, slurry, etc.) is placed on top. This technique promotes degradation by microorganisms which use nitrogen from the upper layers to rapidly decompose the carbon-rich portion in the lower layers (Rabenandro *et al.*, 2009). In addition, it is preferable to place the manure in pits with a roof cover (Figure 2.3) as this helps limit nutrient losses by leaching during rains or by volatilization due to high temperatures (Salgado *et al.*, 2012).

The impact on cropping systems

The quantities of organic manure that farmers have is often insufficient for their cultivable area and requirements. Consequently, they choose to fertilize first the crops that bring in the maximum revenue per hectare. This, most often, turns out to be off-season market gardening in the rice fields. Rainfed plots (*tanety*), the least fertile, are therefore the least fertilized. Reducing nutrient losses by improving the manure production process is thus a preferred path to enhance the limited resources of the farm. Thus, a study in 2014 and 2015 compared the use of improved manure with that of conventional manure on the yield of rainfed rice in two adjacent plots on farms of 19 farmers (Figure 2.4). In both years, the yield of rainfed rice was higher by about 1 t/ha with the improved manure. In this case, improved manure was approximately twice as rich in nutrients, with 26 g N/kg DM (nitrogen per kilogram of dry matter) and 5.5 g P/kg DM (phosphorus per kilogram of dry matter) as against 13 g N/kg DM and 3.6 g P/kg DM respectively for conventional manure.

The impact at the farm scale is still little studied

Research on the socio-economic impact of manure improvement has shown that the adoption of these practices does not translate into a significant increase in the cost of manure production, despite the investments and the additional labour necessary.

The purpose of increasing the efficiency of manure utilization is to increase crop production, while deriving as much value as possible from farm resources by reducing nutrient losses at the scale of the production system. From the farmers' point of view,

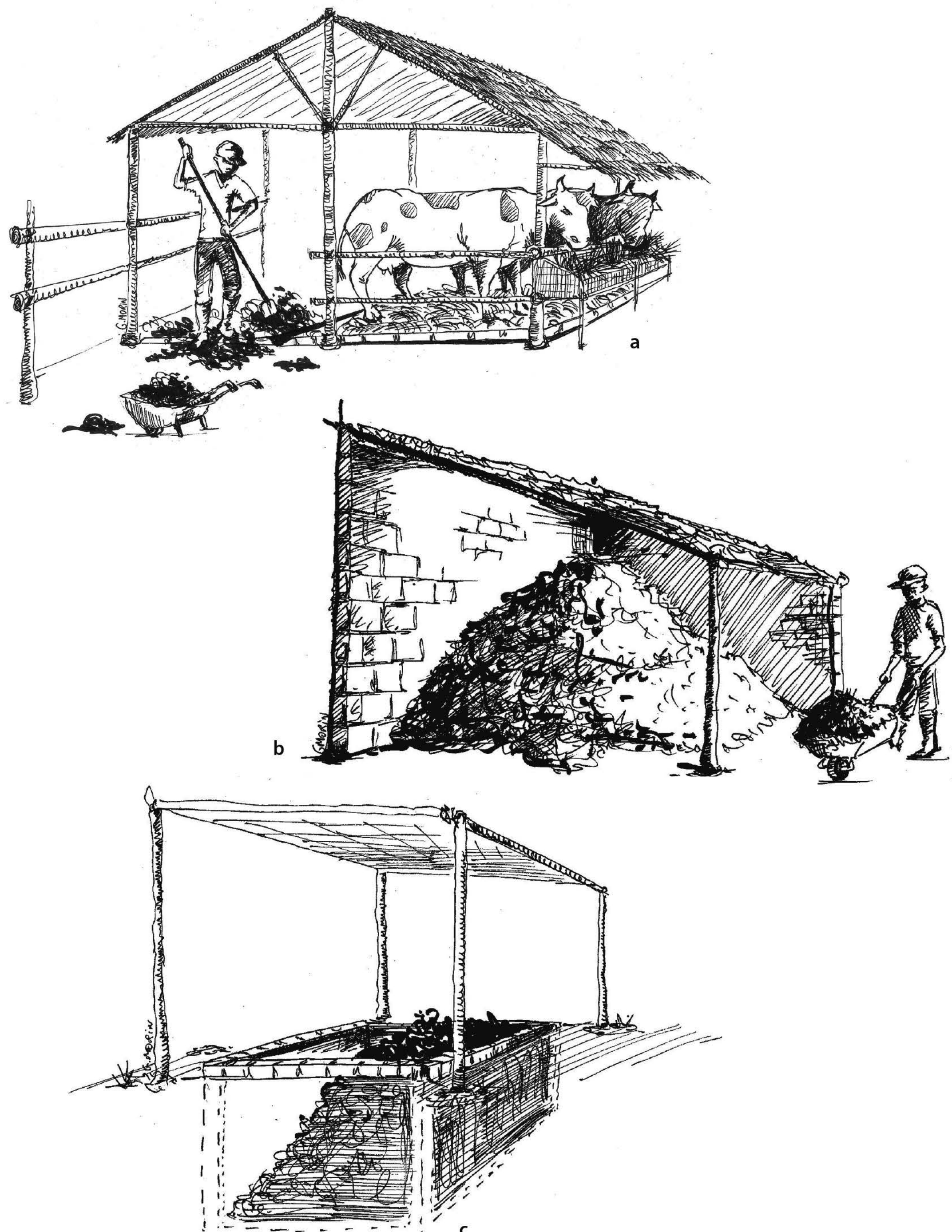


Figure 2.3. Practices to improve manure: animals in a covered enclosure (a); mixing manure with other sources of organic matter from the farm (b); manure covered with a roof and placed in a pit (c). Salgado *et al.* (2012), drawings by G. Morin.

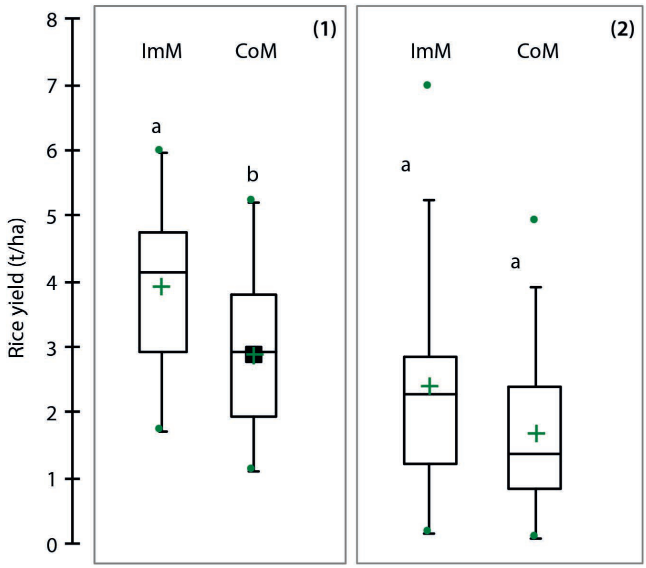


Figure 2.4. Grain yield for rainfed rice in 2014 (1) and 2015 (2) based on the type of manure used (Rasolofo, 2017).

ImM: improved manure; CoM: conventional manure. The letters correspond to the difference of treatments in a year, Tukey HSD test plots, α = 0.05. N = 19 plots per year, variety 'Chhomrong Dhan', same source of improved manure for all plots.

this technical solution does not preclude the use of mineral fertilizers. Most of them are aware of the synergistic effects between mineral fertilizers and organic manures. They thus favour ecological intensification solutions, as defined by Griffon (2013), by combining agroecological solutions and mineral inputs. However, like other agroecological practices, the trade-off is that this solution requires more labour and technical skills, with consequences on the organization of the time invested, either in developing manure production areas, or in learning. The motivations that convince producers to make this investment need to be studied further.

Innovations based on the redesign of systems

We present two examples of the redesign of cropping systems, first through intra-specific diversification (mixture of varieties) to fight a rice disease at different scales, and then through supraspecific diversification (different plant species) associated with changes in tillage management (conservation agriculture) to improve soil fertility and pest control (weeds).

Mixtures of varieties to control blast

At the plot scale

Blast, which has long been at the centre of the breeding programme for rainfed rice, is caused by the pathogenic fungus *Magnaporthe oryzae* (Ou, 1985). The symptoms first appear on the leaves, which reduces the leaf area available for photosynthesis, and then spread to the peduncle where necrosis prevents grain filling (Figure 2.5a). The first rainfed rice varieties adapted for high altitudes were quickly attacked, while the later varieties, now bred specifically to withstand blast pressure, are much more tolerant. The pathogen, however, adapts very quickly, and the risks of circumvention of plant resistance remain high.

Several approaches have been explored to limit blast pressure on rainfed rice and to delay the risk of circumvention of the resistance of new varieties. The first is the varieties mixture, a mechanism that has proven itself in many plant-pathogen systems. Researchers tested the impact of blast on a very sensitive variety grown as a pure crop or mixed with a resistant variety (Raboin *et al.*, 2012; Raveloson *et al.*, 2016; Figure 2.5b). Mixing led to a significant reduction in the severity of the disease on susceptible varieties. The deployment of this type of mixture could promote the continued cultivation of certain sensitive varieties that are particularly popular with consumers, even in the case of disease pressure. The effects of mixing varieties on the dynamics of epidemics result from several mechanisms: a dilution effect, a physical barrier to the spread of spores among sensitive plants, and induced resistance that comes from interactions between plants.

Figure 2.5a. Typical symptom of panicle blast (sterile panicle). © Mathilde Sester/CIRAD.

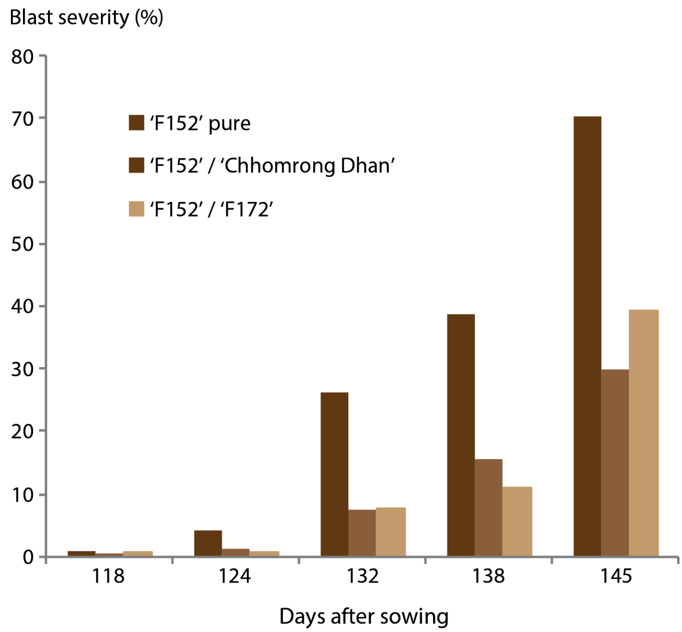


Figure 2.5b. Change in the percentage of grains attacked by blast for the F152 (susceptible) variety cultivated as a pure crop or as a mixed crop (one row of sensitive plants for four rows of resistant plants) with the varieties 'Chhomrong Dhan' (tolerant) or F172 (resistant), in 2012.

Varietal mixtures, much like the use of selected varieties, allow farmers to continue growing rainfed rice without having to use fungicides to control blast.

At the landscape scale

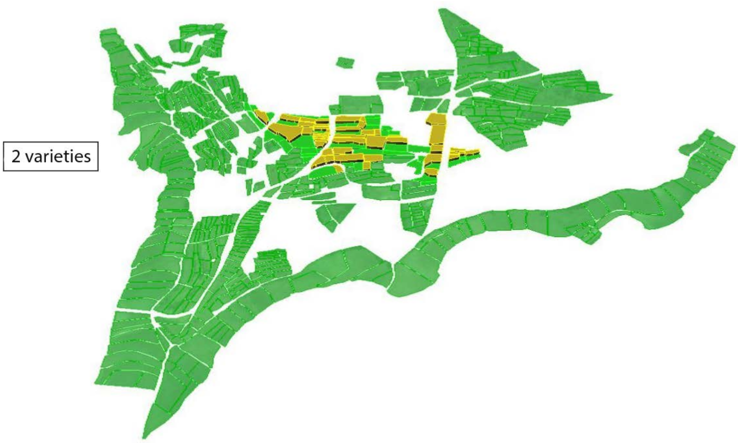
Blast pressure on rainfed crops has greatly decreased in rural conditions since the massive dissemination of a tolerant variety ('Chhomrong Dhan'). However, this situation can quickly become threatened if the pathogen adapts to this variety. A model was programmed in the Ocelet language (Degenne and Lo Seen, 2016) to determine the impact of the agronomic management of each plot and the varietal diversity at the landscape scale on the risk of propagation of the disease (Raveloson *et al.*, 2016; Sester *et al.*, 2016). This model makes it possible to compare a cultivated landscape with one or two varieties of rainfed rice (example of the results after five years of simulation is shown in Figure 2.6). The number of plots affected and the severity of the disease increase much more rapidly if only one variety is grown uniformly in the landscape.

Such studies show that agroecological pest management methods often involve solutions at scales beyond that of the mere plant we are trying to protect.

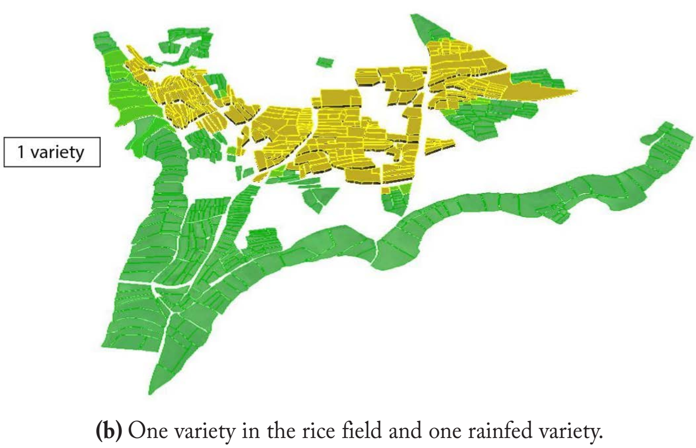
Soil management and interspecific diversification: conservation agriculture

Following the expansion of rainfed cultivation on hills in the highlands region, alternative farming systems based on conservation agriculture (based on three principles:

no-tillage, organic mulch, crop rotation) were recommended to reduce erosion and improve the sustainability of these cropping systems (Husson *et al.*, 2013). Conservation agriculture is a systemic alternative, in line with agroecology, in that it aims to increase production by mobilizing several agroecological functions of cover crops and the biomass produced (Ranaivoson *et al.*, 2017), as also to reduce the negative impacts of cultivation on soils by stopping their disturbance through mechanical tillage. Conservation agriculture and mulch-based direct-seeding system are terms that encompass a large range of farming systems with varied performances. In the highlands, the results in terms of erosion reduction are quite clear. For example, an experiment carried out from 2004 to 2009 showed that the average carbon, nitrogen and phosphorus erosion losses in tillage systems were respectively 336, 26 and 7 kg/ha/year, as compared to 6.35, 0.53 and 0.14 kg/ha/year in a conservation agriculture system (Razafindramanana *et al.*, 2017).



(a) One variety in the rice field and two rainfed varieties.



(b) One variety in the rice field and one rainfed variety.

Figure 2.6. Simulations of five years of blast outbreak on a Malagasy agricultural landscape in which rice is grown on all the plots each year. The initial infestation is identical in both cases. The height of the coloured blocks is proportional to the level of attack by the disease.

Mixed results for rainfed rice yields

An experiment was set up in 2004 in Andranomanelatra, on the highlands (1640 m), to assess the performance in grain yield and biomass production of conservation agriculture systems practised in a biennial rotation with rainfed rice. These systems have evolved over time, as shown in Figure 2.7.a, towards a production with greater biomass due to a rotation with rice (the proposed maize-based systems associated with a legume was retained here). Rice yields, lower in mulch-based systems than in systems that includes tillage for the first few years, became comparable from the sixth year onwards (Figure 2.7.b).

A more detailed study of some systems (2005 to 2007) showed that establishing a crop was more difficult in conservation agriculture, with slower root growth, and led to a reduced development of rice and of nitrogen uptake (Dusserre *et al.*, 2012). However, under the same conditions, these systems have demonstrated their ability to provide more nitrogen, which, however, is not utilized by the crop (Rakotoarisoa *et al.*, 2010).

Contradictory effects on blast

The dynamics of blast epidemics were studied in conservation agriculture systems in the highlands. Monitoring in conventional systems has shown that the epidemic develops more rapidly following the first signs of leaf attack. At the time of the harvest, the percentage of empty grains due to the disease is generally lower in conservation agriculture due to different nitrogen assimilation (Dusserre *et al.*, 2017; Sester *et al.*, 2014). However, the lower stand density of rice in conservation agriculture, compared to that in a tillage system, could also be the cause of this difference in outbreaks. In addition, the practice of leaving rice straw on the fields in conservation agriculture systems runs counter to the preventive measures to be taken in case of the occurrence of the disease. Indeed, studies by CIRAD and FOFIFA have shown that straw can serve as a reservoir of blast spores for up to 18 months after the harvest (Raveloson *et al.*, 2018). This is an example of a trade-off that farmers have to accept when practising agroecology. The research community has to better quantify these contradictory effects in order to inform decision-making by development agencies, policymakers, administrative authorities and farmers.

A practice still little adopted on the highlands

The lack of quick and clear results on crop yields, the competition for residues, and the increased technical skills required for systems in conservation agriculture result in few farmers practising it in the highlands (Hartog *et al.*, 2011; Randrianarison *et al.*, 2007). While the overall working time is reduced in conservation agriculture due to the elimination of manual tillage, it is not sufficient to offset other technical problems, particularly those related to the effectiveness of various associated cover crops. In addition, most farmers do not have the necessary financial capacity to set up these systems, which are initially very intensive, as advocated by their proponents (Cavellier de Cuverville *et al.*, 2010). The time required for a return on investment is often too long.

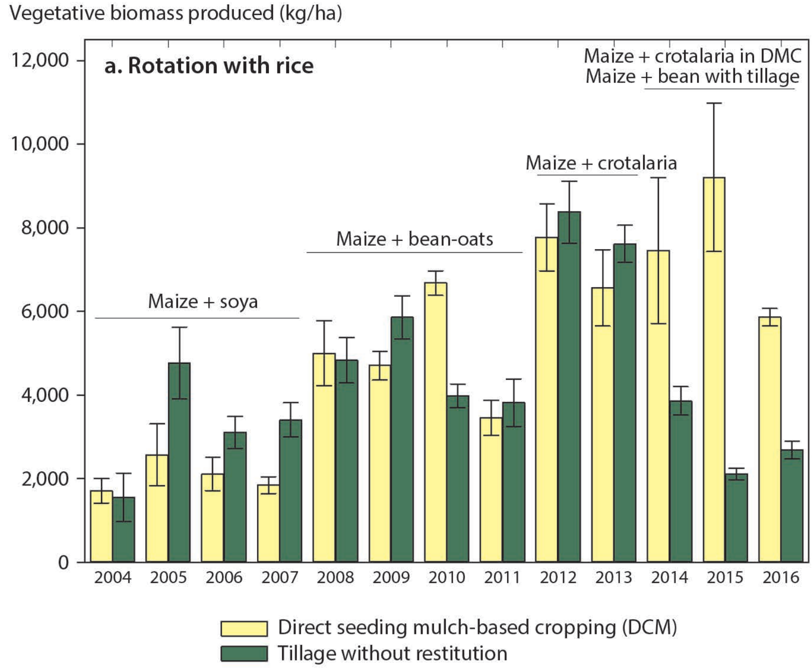


Figure 2.7a. Change in biomass production of crops in rotation with rainfed rice as recorded during the Andranomanelatra experiment from 2004 to 2016 (unpublished data).

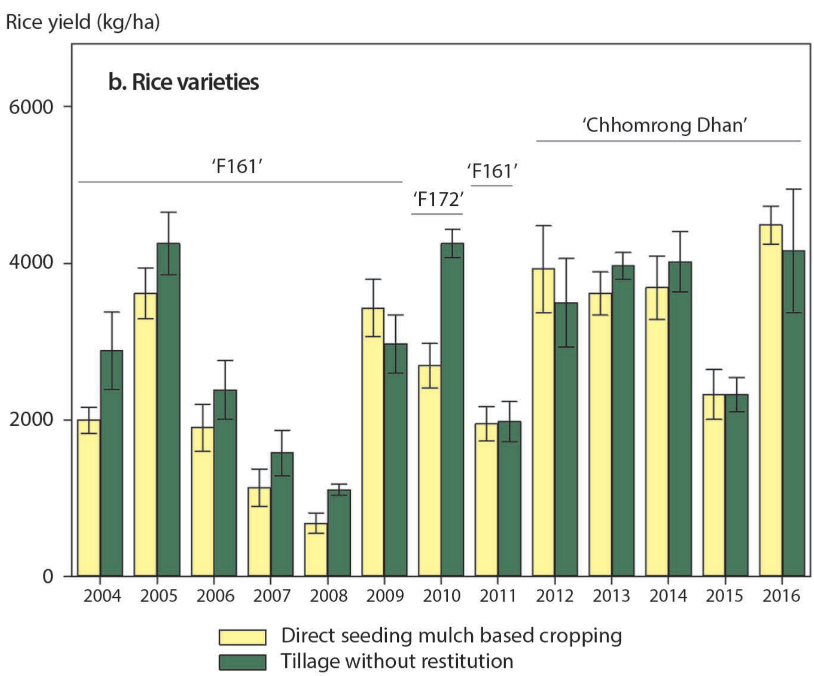


Figure 2.7b. Change in rainfed rice production for the Andranomanelatra experiment from 2004 to 2016 (unpublished data).

A cohort analysis (Randrianarison *et al.*, 2007) of the dissemination of techniques in conservation agriculture around the Tafa station revealed the main reasons for abandonment:

– the improvement of the soil water balance is not critical in the highland environment;

– production costs related to the adoption of these systems are too high during the installation phase;

– after the fifth year of adoption, the reasons for abandonment mentioned by farmers are generally economic ones (an insignificant increase in yields and in gross margin per hectare for producers and a low return on investment) or social ones (difficulty in managing cattle roaming and grazing and great difficulty in organizing producers into associations or cooperatives).

A broader study in the intervention areas of the project 'Irrigation and Watershed Management in the South-East Highlands' (BVPI/SE-HP) showed the same constraints for the same effects (Hartog *et al.*, 2011), with a proven and long-standing reliance on the effectiveness of tillage that is not matched by the expected effects of conservation agriculture with no-tillage conditions. Thus, the majority of farmers assume soils will be compacted after five years of conservation agriculture. The strategies of local farmers are clearly driven by short-term concerns of food self-sufficiency and a rapid conversion of any possible production surpluses into economic benefits, whereas conservation agriculture requires a judicious management of resources and a projection of production over the long term. For example, there is no space for improved non-productive fallows. The cold temperatures in the dry season, the lack of a locally adapted service plant and the absences of increase in yields (when mineral fertilizer is not used) have clearly limited the interest in conservation agriculture. The few farmers who have adopted these systems are the ones who are better off, for whom technical and social constraints are less restricting (Hartog *et al.*, 2011). These sets of constraints are similar to those found elsewhere in Africa for this type of system (Corbeels *et al.*, 2014).

Better agronomic results in the Middle West

More recently, studies were conducted in the Middle West area for a more detailed understanding of the dynamics of soil nitrogen in mulch-based cropping systems, and the impact of different types of crop residues on rice. First, a short-term experiment on the rainfed rice/*Stylosanthes guianensis* rotation, showed that even though *S. guianensis* is capable of fixing large amounts of atmospheric nitrogen and generating significant biomass, the end release of nitrogen to rice was low in the initial years of cultivation (only 5% to 8% of the nitrogen originating from the *S. guianensis* mulch was used by the rice, according to Zemek *et al.* [2018]). On the other hand, in an older set-up, in two-year-old rural farming systems based on rainfed rice and 4- to 10-year-old *S. guianensis* (Figure 2.8), the yield of rice was improved in mulch-based systems after a *S. guianensis* crop. However, this conservation agriculture system requires additional work, especially during sowing, due to the presence of a thick groundcover (8 t/ha DM on average).

While *S. guianensis* was introduced for its ability to quickly colonize poor soils, it also possesses the capability of controlling the outbreak of striga, a characteristic plant parasite of this region, on rice and maize crops. In 2015, harvests in seven partner

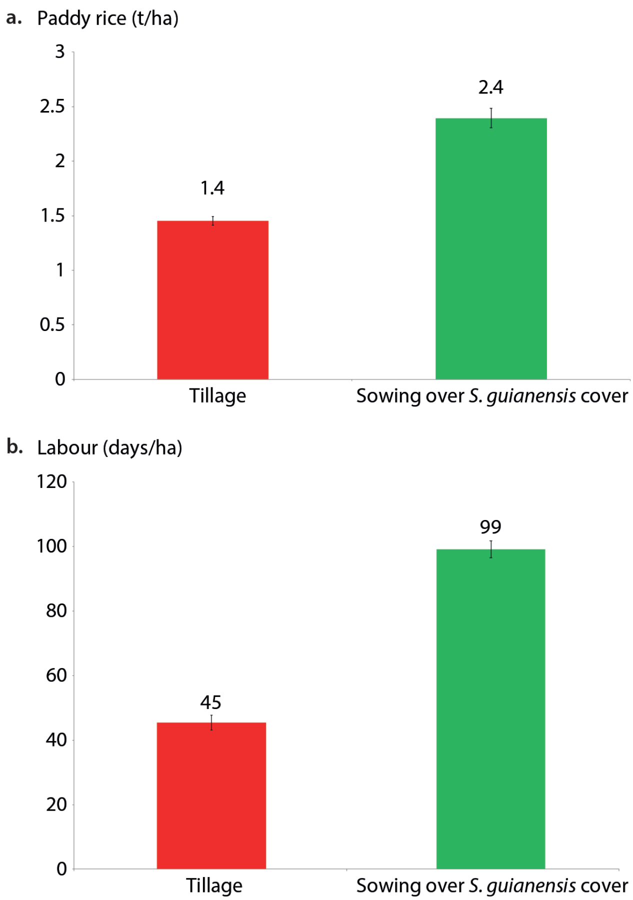


Figure 2.8.a. Comparison of farm yields for rice cultivation based on tillage (24 plots) with those based on conservation agriculture with a cover of *S. guianensis* (19 plots), 2016 and 2017 harvests (Autfray *et al.*, 2018). b. Comparison of working time in a farm for rice cultivation based on tillage (24 plots) with those based on conservation agriculture with a cover of *S. guianensis* (19 plots), 2016 and 2017 harvests (Autfray *et al.*, 2018).

farms have shown that the yield of the B22 variety, highly valued but very sensitive to striga, was similar (1.8 t/ha on average) when grown in rotation with *S. guianensis* to that of the Nerica4 variety, which was newly introduced and is resistant to striga. On an average, in an experiment conducted over four consecutive years with tillage, the rate of infestation of B22, as compared to Nerica4, was about ten times higher, resulting in lower yields. However, the infestation rate, compared in the same period, dropped from 2.1 to 0.4 plants/m^2 in a system that included *S. guianensis*, and from 3.4 to 0.3 plants/m^2 for maize (Randrianjafizanaka *et al.*, 2018).

The beginning of adoption in the Middle West

The history of the dissemination of mulch-covered cropping systems around Ivory in the Middle West area since 1998 shows that farmers find it hard to adopt conservation agriculture in a sustained manner without the continuous support of technical experts.

Two studies in the Ankazomoriotra and Vinany communes, in a mid-altitude zone (900-1100 m) (Quiennec *et al.*, 2013), helped characterize farms, identify a typology, and measure the adoption of conservation agriculture systems (five years after their introduction), based on farm type and size. Observations since 2005 in the area of operation of the development actor FAFIALA have shown that the very smallest farmers who adopt conservation agriculture systems obtain a net agricultural income that is lower than from traditional systems. On the other hand, farmers with a medium to large agricultural areas (bigger than 5 ha) manage to increase their cultivated areas by adopting conservation agriculture systems (due to the reduction of fallow time) and thus increase their net agricultural income. In all, out of 1318 ha monitored by the AFD-funded project 'Irrigation and Watershed Management in the South-East Highlands' (BVPI/SE-HP), conservation agriculture was practised on 450 ha of them in 2011 (Penot *et al.*, 2011). Surveys also revealed that conservation agriculture systems proved effective against the adverse effects of striga, allowing for rotations focused primarily on cereals. On the other hand, the working time saw a significant increase in systems based on *Stylosanthes* spp. Studies for modelling revenue (Charentenay and Penot, 2012) showed a small positive impact on incomes (an extra 10 to 19% over five years), as the results of adopting conservation agriculture are only felt in the medium term, following the stabilization of production, without any significant increase in yields. Such a shift in paradigm and farmer strategy from the short to the medium term cannot be achieved in less than six years. While conservation agriculture is still challenging and unsuitable for the highlands in a very specific land and social context, it does constitute a potential alternative for sustainable agricultural development in the Middle West area due to the diversity of the systems proposed and the possibility of maintaining cereal cultivation despite the presence of striga.

What changes does agroecology entail in research work?

This work on agroecological solutions, which has spanned many years, has led researchers to work in a different way, especially as concerns interactions with farmers.

Participatory breeding

Participatory breeding consists of a closer involvement of small farmers in the creation, selection and dissemination of plants, in conjunction with a continuous dialogue or exchange between farmers and researchers. To fine-tune rainfed rice varieties to the farmers' needs, part of the breeding work must be done on their plots with their participation (Photo 2.1). This is especially true for farms with little intensification and therefore particularly subject to the heterogeneity of environmental conditions. This is why a participatory varietal assessment network is created every year in partnership with different actors, who have changed over time (farmer organizations, NGOs, projects, research or training institutions). The rainfed rice breeding programme is also evolving towards a greater involvement of farmers by increasingly involving them earlier in the breeding process, including in the experimental station phases. It is through this approach that four new lines have been identified as more efficient and more appreciated than the control plants corresponding to the two targeted ecology types.

Photo 2.1. Participatory assessment of new rainfed rice lines by women farmer groups in the Middle West area in 2015. The participatory approach allows, for example, the taking into account of the preferences of choices according to gender in the breeding process. © Kirsten Vom Brocke/CIRAD.

Innovation platform

In the Middle West area of Vakinankaratra, the Stradiv[2] research project is testing new approaches to a participatory design of cropping systems, based on a permanent link between activities carried out on reference farms and those of the experimental mechanism in nearby Ivory. This site integrates the breeding of rainfed rice, various thematic experiments and a technical reference base for imparting training to the Direct Seeding Group of Madagascar (GSDM). Thematic diagnoses of constraints and performance monitoring of different plots are continuously carried out on the reference farms. The selection of innovative systems is first undertaken with a specific experimental mechanism allowing a joint assessment by researchers and farmers of a large number of strip-plot modalities. Subsequently, the cropping systems are implemented by farmers in reference farms for an economic assessment and integration at the farm scale. This approach helps combine local and scientific knowledge on practices and technical models, in order to quickly select, over time and space, the best arrangements and methods of crop management (Autfray *et al.*, 2018).

Assessment at the farm scale and management of trade-offs

As we have shown in the preceding examples, farmers may be forced to make trade-offs between different objectives in their agroecological practices. For example, allowing the rice straw to remain on the field can help control soil erosion but, at the same time,

2. *System approach for the TRAnsition to bio-DIVersified agroecosystems, from process analysis to multi-scale co-conception with actors*, project funded by the Agropolis Foundation.

will reduce the amount of high-quality manure produced and could lead to continued fungal disease pressure. It is therefore important to assess the technical options from every angle. For example, Rasolofo (2017) studied the performance of three cropping systems in terms of productivity, potential to maintain soil carbon content, and the possibility of recycling aboveground biomass as a forage resource. Figure 2.9 shows the impact of the off-plot export of 0 to 100% of residues on potential milk production from these residues and the amount of nitrogen returning to the soil from the residues left behind. We can observe that milk production can be increased substantially without significantly compromising the return of soil nitrogen by plant residues. Indeed, a part of the nitrogen returned is from roots which, in any case, remain in the soil even if the entire aboveground biomass is used. The recommendations must take into account the constraints and objectives of the farmers in terms of production and maintenance of fertility, which differ depending on the types of farms.

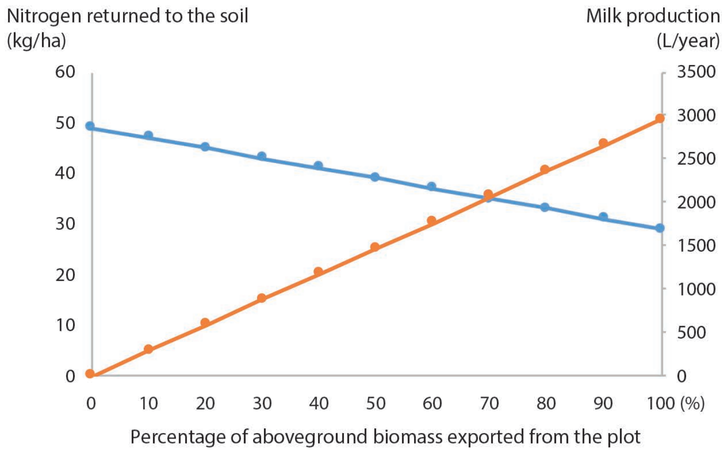


Figure 2.9. Simulation of the amount of nitrogen from crop residues returned to the soil (left axis) and the amount of milk (right axis) that can be produced, by using 0 to 100% (x) of the aboveground plant biomass from a rainfed rice/maize + bean rotation system (Rasolofo, 2017).

Conclusion

More than 30 years of research and development on agroecology in Vakinankaratra has resulted in varying degrees of adoption of innovations developed by researchers jointly with farmers. In particular, there exist differences within the region that can be explained, in part, by the performance of cropping systems, the pressure on residues, and the agronomic, economic and social problems confronting farmers.

The practice of conservation agriculture involves quite profound changes, not only in cropping systems, but also in production systems: land allocation, labour distribution. In addition, in a context in which farmers lack easy access to technical references, the adoption of these new complex systems represents a significant risk of technical failure. Thus, many farmers with difficult economic conditions are reluctant to make drastic changes to their production system because of the risks such changes pose for their food and economic security. In this context, it is the simplest and least risky innovations that are adopted first by farmers. Consequently, new rainfed rice varieties, whether imported or locally selected, are adopted very rapid. These varieties have the advantage of being eminently suitable for already existing cropping systems that use little or no mineral fertilizer or herbicide. They offer an opportunity to increase production of rice and contribute to the region's food security without having to resort to complicated techniques.

As of now, there has been no major redesign of production systems in Vakinankaratra driven by research on agroecology. Nevertheless, as we have seen, by creating new tools that structure interactions with local actors in a participatory approach, more complex components of 'agroecological systems' are gradually being adopted: varieties, improvement in the efficiency of nutrient recycling, cultivation of service plants to control striga and/or produce fodder, etc. Farmers in Vakinankaratra benefit from a range of technical options that they are beginning to implement. It can therefore be expected that the intensification of production systems will gradually become a reality, and that it will happen through the mobilization of a significant number of the ecologically intensive options now available to the farmer and not on the basis of conventional intensification solutions (chemical inputs, mechanization, etc.), which are, in any case, still inaccessible to many small producers in these regions. However, it will be necessary to continue working with local actors to intensively and efficiently support the innovation process around these alternatives.

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Chapter 3

Agroforestry: diversified practices for the agroecological transition of African cacao farming

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Since the 1960s, the cultivation of cacao (*Theobroma cacao* L.) in Africa has experienced unprecedented growth. The area under cacao cultivation in Africa, 3.3 million hectares in 1961, now stands at 6.5 million hectares. During the same period, African cocoa production has more than trebled, from 865,000 tonnes (Braudeau, 1969) to 3 million tonnes (FAOStat, 2017), confirming Africa's predominant position, and that of Côte d'Ivoire and Ghana in particular, in world cacao farming. Between them, these two West African countries account for 70% of the world cocoa supply (ICCO, 2017). In the coming years, world chocolate consumption is expected to increase sharply due to rising living standards in several very populated emerging countries (India, China and Brazil in particular). This trend could lead to problems for the global cocoa market arising from a possible supply-demand mismatch for this agricultural commodity (ICCO, 2017). Therefore, it is likely that the dynamics of cacao cultivation observed over the past 50 years, especially in Côte d'Ivoire and Ghana, will spread to other African countries in the humid tropics having soil and climate conditions favourable to cacao farming. Indeed, African family farming has already proven its ability to adjust its cocoa production to match demand.

In order to maintain or increase cocoa production, farmers have mainly taken the route of extension of cacao farms through repeated migrations into forest areas and clearing of forest lands (Ruf, 1995). Starting in the 1970s, a large number of farmers started cultivating cacao under the open sun, rather than under forest shade, as they had been doing until then. There are several reasons for this, technical as well as social and legal (Ruf, 2011). However, even though these full-sun cacao farming systems doubled the average yield of the African cacao farm from 250 kg/ha of marketable cocoa in the 1960s to 500 kg/ha in the 1990s (FAOStat, 2017), they have become extensive due to the withdrawal of technical and financial support resulting from the liberalization of the cocoa sector. Finally, the global phenomenon of climate change could lead to a reduction in areas suitable for cacao farming in West Africa (Läderach *et al.*, 2013), and ultimately an increased vulnerability of farms whose existence depends on cultivating this cash crop.

At present, given the agronomic, social and ecological limitations of full-sun cacao farming and the challenges that confront it, an agroecological transition of African cacao farming is unavoidable, both for its own future and that of forest zones. Indeed, in Côte d'Ivoire and Ghana, the last remaining forest areas remain under threat. It is therefore urgent to protect them while supporting farmers in stabilizing existing cacao growing areas and improving their standards of living. In other countries that still have vast forest reserves and which may be tempted to embark on cacao cultivation to diversify their economies and provide income to rural populations, it is a question of limiting deforestation and reducing the negative environmental impact of cacao farming. This chapter analyses the relevance of agroforestry for an agroecological transition of African cacao farming.

The full-sun technical model called into question

Even though the cacao is believed to need shade to grow properly, it was shown in the 1960s that its productivity increases when it is fully exposed to sun light, provided with nutrients and protected from pests and diseases (Braudeau, 1969). The technical model proposed to farmers therefore focused on increasing yields through full-sun cultivation and the intensification of inputs and labour, based on the use of selected and vigorous varieties from hybrid seeds. This model also favoured the cultivation of cacaos as a monocrop or under a light and homogeneous shading, often reconstituted, with the use of synthetic inputs for phytosanitary protection and fertilization (Wood and Lass, 2001). At the same time, especially following the independence of the countries concerned, cacao cultivation became the subject of interventionism because of its economic potential, all the more pronounced due to high world cocoa prices. Farmers were aided and guided in particular through the availability of processing equipment and phytosanitary products.

In both countries, Côte d'Ivoire and Ghana, there is evidence that some farmers had practised full-sun cacao farming as far back as the 1920s and 1930s, well before the research community began recommending it. In Côte d'Ivoire, however, this practice increased sharply in the 1970s due to the massive flows of migrant farmers whose main objective was land appropriation (Ruf, 1995). These migrant farmers, who, incidentally, adopted widely distributed cocoa hybrids, were not interested in adopting intensive farm management practices once a farm was established, which would have required farm maintenance and recourse to inputs. They relied instead on 'forest rent' (soils rich in organic matter and nutrients left behind by the cleared forest cover) which, combined with rainfall quantities and patterns favourable for vigorous young cacaos, provided yields of 500-700 kg/ha (Ruf, 1995), yields which some farmers nevertheless boosted further by gradually adopting the use of pesticides recommended by agricultural extension services.

This technical model of full-sun cacao farming continues to be used by farmers as long as they continue to benefit from the high yields. However, in general, after 20 to

30 years of cultivation without sufficient mineral fertilization and adequate phytosanitary protection, the production conditions become degraded and cacao productivity collapses (Ahenkorah *et al.*, 1987; Hanak Freud *et al.*, 2000). Some farmers try to rehabilitate their cacao farms, but the technical difficulties and the additional costs to do so are prohibitive, forcing them to abandon their cacao farms to create new ones elsewhere, on new forest clearings. Other farmers convert their cacao farms to rubber or oil palm plantations, which are crops that are more easily cultivated than cacao on degraded soils (Ruf, 1995). By not providing the motivation for the rehabilitation of degraded cacao farms, the model of full-sun cacao farming therefore appears to be unsustainable. The farmers abandon their cacao plots and move to other places for planting new trees; thus, the system looks as if it is itinerant, even though cacao is a tree crop.

Forest areas have thus virtually disappeared from Côte d'Ivoire and Ghana; the Ivorian forest area decreased from 13 to 3 million hectares between 1960 and 1990 (Hanak-Freud *et al.*, 2000). The 2000s saw further acceleration of the disappearance of the remaining Ivorian classified forests and national parks (Higonnet *et al.*, 2017). The same is true in Ghana where it is estimated that 80% of forest areas have disappeared since the introduction of cacao cultivation to the country (Cleaver, 1992).

For cacao farmers – 95% of them have cacao acreages ranging from 1 to 10 ha (Rafflegeau *et al.*, 2015) –, the challenge is therefore to reinvent sustainable models of cacao farming that are also agronomically efficient. The objective is to guarantee them decent living conditions in a context that is uncertain in economic terms (fluctuation in world cocoa prices: between 2000 and 3500 US$/t over the last decade; high taxes; and/or weak public support) as well as in climatic terms (disrupted seasons, rising temperatures and shifting of areas suitable for cacao farming), with a minimum of environmental impacts.

In parallel with this dominant history of cacao farming, in some areas, farmers have been practising agroforestry cacao farming for a long time or have been moving towards more agroforestry-oriented practices.

Agroforestry systems: farmers' agroecological practices already in use

In fact, many African cacao farmers are developing and managing systems in which, unlike the full-sun model, the cacao is associated with other perennial, forest and fruit species with multiple uses. These systems are found in most cocoa producing countries, including Côte d'Ivoire, Ghana, Nigeria and Cameroon. These agroforestry systems, often called traditional, are highly diverse and demonstrate the farmers' capacity for adaptation and innovation. Recent studies have shown that these systems have several benefits, including for the farmers themselves. Five of these benefits can be mentioned.

Multiple productions help meet the cocoa producers' requirements

In comparison to full-sun monocrop cacao cultivation, the first advantage of agroforestry systems, whether they are simple (two or three components: cacao-rubber association, cacao-fruit trees association or cacao-oil palm associations) or more complex, is the diversification of products. In Côte d'Ivoire (Herzog and Bachman, 1992; Adou Yao *et al.*, 2016), Ghana (Ruf *et al.*, 2006) and Cameroon (Jagoret *et al.*, 2014a), many species are associated with cocoa, such as *Persea americana* (avocado), *Elaeis guineensis* (oil palm), *Dacryodes edulis* (African plum), *Cola nitida* (kola) and *Ricinodendron heudelootii* (njansang), each of which provides an edible product: fruits, young leaves (sauce preparation), seeds (condiments, oil), and sap (palm wine). Other, mainly forest, species have a commercial value (*Terminalia superba* and *Milicia excelsa* for example for the supply of timber) and/or medicinal value because some of their organs (leaves, bark, root, wood) are used to treat various ailments (*Cola cordifolia*, *Alstonia boonei*, *Rauvolfia vomitoria* for example). These various species provide products that are both self-consumed and sold by rural households, two functions that can represent, as demonstrated in Cameroon, up to 56% of the usage value attributed by farmers to the various ligneous species present in their cacao farms (Jagoret *et al.*, 2014a).

By being more diversified than full-sun cacao farms, and by separating the species according to a spatial structuring (by surface and by height) that limits interspecific competitions, cocoa agroforestry systems are economically less risky. In Côte d'Ivoire, the association of rubber trees in cacao farms, still embryonic in the 2010s, can allow farmers to limit risks in an unstable context of high volatility of cocoa prices, while allowing them to derive value from their lands and make farming remunerative while awaiting the entry into production of rubber trees (Snoeck *et al.*, 2013). Jaza *et al.* (2015) have estimated that the introduction of three local fruit species into cacao farms in central Cameroon – African plum (*Dacryodes edulis*), the wild mango (*Irvingia gabonensis*) and the njansang (*Ricinodendron heudelotii*) – can generate substantial additional income compared to full-sun cacao cultivation. The different species associated with cacaos can also offer sequential productions that are spaced out over the year. Thus, in central Cameroon, the species of trees interplanted with cacaos allow farmers to harvest different fruits (avocados, mangos, kola nuts, African plums, palm nuts for oil production) in a staggered manner during periods when cacaos do not produce (Figure 3.1). At the same time, forest species and oil palms can provide farmers with timber and palm wine around the year, or even be host at certain times of the year to caterpillars that are consumed by local populations (Photo 3.1).

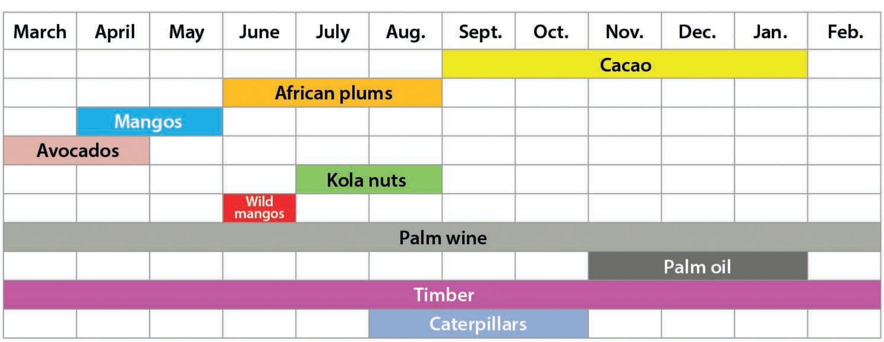

Figure 3.1. Periods of harvest of different products provided by the cocoa agroforestry systems of central Cameroon.

Photo 3.1. *Petersianthus macrocarpus* (Essia) is the host plant for *Imbrasia ertli*, a caterpillar species consumed by the populations of central Cameroon. © Patrick Jagoret.

Higher cocoa production than it appears

In cocoa agroforestry systems, marketable-cocoa yields can be similar to, or even higher than, those obtained in full-sun cacao farms when farmers are unable to apply the appropriate quantities of required pesticides and chemical fertilizers (Figure 3.2, green circle), even in older cacao farms that have significantly exceeded the threshold beyond which reconversion or rehabilitation is often recommended (Figure 3.2, blue circle). This is especially the case in central Cameroon, where the majority of the cocoa is produced from complex agroforestry systems. A study of observed yields, estimated from counts of pods made in dedicated studies, has shown that average yields are of 596 kg/ha, but they can reach up to 2 tonnes/ha in some areas (Bisseleua *et al.*, 2009; Jagoret *et al.*, 2017a; Saj *et al.*, 2017a). These yields were observed in plots in which an average of 1500 cacao trees per hectare are grown with 190 fruit or forest trees, thus demonstrating that it is possible to grow cacao in such systems while achieving higher levels of yields than commonly believed. Saj *et al.* (2017a) further found that the cocoa yields in these complex systems depend on competition with associated trees. In particular below a certain level of presence of trees, long-term cocoa production, i.e. beyond 40 years, does not seem assured. A sufficient density of shade trees is thus necessary to maintain the long-term performance of cocoa agroforestry systems.

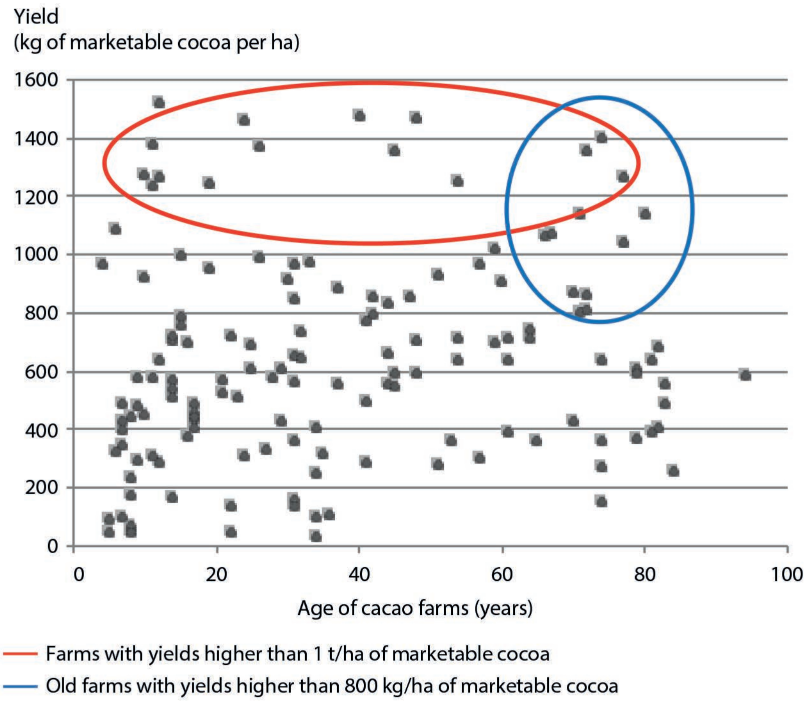

Figure 3.2. Yields of marketable cocoa observed in 144 agroforestry cacao farms in central Cameroon (Ngomedzap, Bokito and Zima areas).

Technical management without the use of synthetic fertilizers

Cocoa yields of complex agroforestry cacao farms can be maintained at satisfactory levels without recourse to fertilizers, provided that good agricultural practices are applied (Jagoret *et al.*, 2011). In central Cameroon, the soil organic matter content below cacaos is around 4.1 to 4.7% (Duguma *et al.*, 2001), whereas the level required for good cocoa growth is 3.5% (Braudeau, 1969). Snoeck *et al.* (2010) have shown that appropriate tree management in cacao farms allows farmers to correct the depressive effect due to the planting of cacaos on cleared forest plots, and to return after 25 years to a level of organic matter under cacao trees similar to that of the original forest. In the absence of fertilization, trees play an important role in restoring soil fertility by helping recycle organic matter and nutrients, which also improves the soil's cation exchange capacity. Also, in central Cameroon, the ability of agroforestry practices to maintain or even to restore soil fertility has also been observed by Jagoret *et al.* (2012) in agroforestry cacao farms installed on what was previously savannah, with the soil organic matter content increasing significantly with age, from 1.7% in young cacao farms to 3.1% after 40 years. Over the long term, as far as fertility is concerned, the type of associated tree appears to be as important as the soil pedological origin (Snoeck and Dubos, 2018). Unlike for fruit trees, cacao fruiting is independent of the vegetative growth. Its nitrogen requirements are therefore low because nitrogen contributes more to its vegetative growth than to its fruiting. A nitrogen supply will favour long branches that bend easily. Consequently, to increase production, it is better to reduce the vegetative growth which will promote flowering (Snoeck *et al.*, 2016). The association with legumes is thus often sufficient to meet the cacao tree's nitrogen requirements (Nygren and Leblanc, 2009).

In cocoa agroforestry systems, the biological activity promotes water infiltration, the incorporation of organic matter into the soil, and the storage and release of surface nutrients. In addition, the permanent litter layer provides soil protection against runoff and erosion. Rousseau *et al.* (2012) have shown that the richness of the macro-fauna of cocoa soils is not significantly different from that of the neighbouring forest and is greater than that of the neighbouring savannah or cultivated soils. This result confirms the observations made in Cameroon on the microbial activity of soils under young and adult cacaos in the forest and in the savannah (Snoeck *et al.*, 2010). In Ghana, favourable effects of shade trees on soil fertility and the nutritional status of cacaos (increased cation exchange capacity and higher nitrogen level) have also been demonstrated (Isaac *et al.*, 2007; Blaser *et al.*, 2017).

Higher carbon storage levels in agroforestry than in full-sun cacao

The more diversified and complex the cocoa agroforestry system, the more it seems to be able to store carbon, thanks in particular to the forest trees associated with the cacaos. In the agroforestry systems of central Cameroon, for example, the aboveground carbon stock of adult cacaos older than 15 years is, on the average, between 5 and 10 tonnes/ha (Saj *et al.*, 2013). In the most complex systems, cacaos thus represent less than 10% of the stock of the total tree biomass of these systems, whereas this stock can sometimes reach 20% in simplified agroforestry systems. Compared to neighbouring forest systems, however, the level of aboveground carbon storage of cocoa agroforestry systems remains 20 to 50% lower. It can however reach up to 180 tonnes/ha in certain areas (Saj *et al.*, 2013, 2017b). Also, in Cameroon, it has been shown that, in the cocoa agroforestry systems set up in savannah, the aboveground carbon stock can reach, after 60 years, the same level as that obtained in cocoa agro-forestry systems created after clearing the forest (Nijmeijer *et al.*, 2018). These authors have estimated that the surface soil carbon content has increased from 6.5 to 9.5‰ per year for more than 60 years (Nijmeijer *et al.*, 2018).

In Ghana, in cacao farms established after forest clearing, significant decreases in surface soil carbon content (- 49%) have been observed, with no significant differ-ences in tree cover levels at the plot scale. Nevertheless, localized positive effects of shade trees on soil carbon (+ 20%) were observed, in comparison with areas without tree cover (Blaser *et al.*, 2017).

Flexible and resilient cacao farming systems

For farmers confronted by the volatility of world cocoa prices and increasing climatic variability, agroforestry systems display significant adaptability and flexibility in farm management that full-sun cacao farms do not. A common argument in favour of full-sun cacao farming is that it is more profitable for a farmer to manage a mono-specific cocoa plot in a diversified farm, as such a configuration allows him to select crops for which investment in inputs and labour will be profitable. However, given the time lag between the completion of technical operations and their effects on the cocoa yield, farmers come to know the price that their cocoa will fetch too late to take advantage of this theoretical logic. Therefore, they have already invested in inputs and labour for their cocoa plots and in the post-harvest processing of cocoa when they learn what their exact remuneration will be, often calculated on the basis of fluctuating world prices. In contrast, the cacao agroforestry farms allow to reduce this kind of risk by ensuring a remuneration of the labour and the land through the other farm productions, contributing to, as already mentioned, enhanced food security through income from sales and self-consumed production.

In Cameroon, a reconstitution *a posteriori* of trajectories of former cacao agroforestry farms has shown that their technical management can be temporarily interrupted or modified without entirely destroying the system (Jagoret *et al.*, 2014b). This makes it possible to absorb shocks by returning to the initial situation after a semi-abandonment phase (Figure 3.3) or by transforming the cacao farms to initiate a different productive project by drastically reducing, for example, the density of cacao trees. In the case of abandonment following a fall in prices or family conflicts during, for example, the inter-generational transmission of the cacao farm, the presence of other trees in the cacao farms makes it possible to slow the degradation of the cocoa stands.

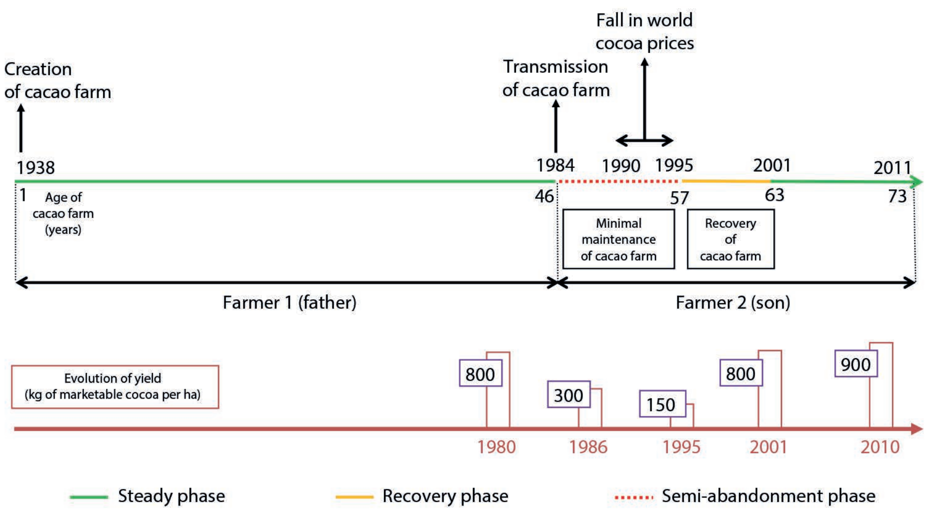

Figure 3.3. Example of the resilience of an agroforestry cacao farm in central Cameroon: the resumption by the farmer of cacao cultivation in his farm, after a management phase of at least eleven years, allowed him to restore it and return to an equivalent level of production (Jagoret *et al.*, 2014b).

Their restoration will be faster than in the case of degraded full-sun cacao plots overgrown with weeds. The biomass resulting from the growth of trees will also allow a favourable felling/replantation, by reconstitution of a 'forest rent'.

These different examples confirm that cocoa agroforestry systems can be a source of inspiration for researchers working on an agroecological transition of African cacao farming.

Modalities of supporting farmers

In Côte d'Ivoire, the trend towards agroforestry has gathered strength in recent years. Though initially not visible, spontaneous palms and fruit trees planted in full-sun cocoa plots eventually emerge above the cocoa layer. The agroforestry process is now becoming associated with the natural aging of cacaos (Schroth and Ruf, 2014). An increasing number of farmers are adopting innovative agroforestry practices to reintroduce trees into their full-sun cacao farms. Thus, Sanial (2015) showed that 30% of them plant *Ficus facensis* (*aloma* in the Baoulé language) because of its shading that is suitable for cacaos and its role in the maintenance of soil fertility. This is similar to the case of central Cameroon where many farmers retain *Ficus mucoso* and *Ceiba pentendra* (silk-cotton tree) for these same reasons (Jagoret *et al.*, 2014a).

In addition, under the pressure of environmental lobbies and rising international awareness of deforestation and climate change, official public and private sector discourses have gravitated significantly towards 'zero deforestation' and agroforestry, even though the latter concept is not always well understood or well defined. Looking beyond discourses, we can ask what public and private initiatives are likely to favour the adoption of agroforestry practices. In Côte d'Ivoire and Ghana, recent changes in forest regulations make it possible to assign the ownership of trees to cocoa producers and, theoretically at least, fulfil a condition necessary for the success of agroforestry cacao farms and thus conducive to their expansion. Other initiatives to promote the adoption of agroforestry practices can be mentioned.

The major cocoa certification programmes

The major cocoa certification programmes are usually based on the concept of sustainable development and combine environmental and ethical standards with the adoption of agricultural practices that are supposed to increase the cocoa yield of cacao farms (Lemeilleur *et al.*, 2015). Their goal is to ensure that a number of vendor and producer commitments are honoured in order to guide the choice of a buyer, regardless of whether the latter is the end consumer or a link in the supply chain. The certification thus attests to certain practices and compliance with these commitments by a producer, who derives a benefit from the sale of his product, for example in the form of a premium. The effectiveness of certification, however, is based on a demand for certified products and financial incentives that motivate the farmer to engage in this process. It also assumes that there are principles and indicators to demonstrate compliance with the commitments made and that the certification system is controlled by an independent third party.

By design, certification is based on a product differentiation strategy that all of the actors of the sector must voluntary embrace. These commitments may be motivated by restrictive regulations or the existence of a balance of power between consumers and suppliers. Cocoa is thus the subject of several certification schemes (UTZ, RA-SAN, Organic and Fairtrade, RainForest Alliance) representing around 30% of global production, with this percentage increasing steadily. Certified cocoa seems set to become the norm across the world in the future, with most importers committed to purchasing only certified cocoa by 2020. Standardization is therefore unavoidable. But we still see, in all agricultural sectors that take this path (including cocoa), that only part of certified production is sold as such at a premium price, the rest being sold at the same price as non-certified cocoa, reflecting in this way an inconsistency between the way of consuming and environmentalist demands.

Certification systems suffer from a number of limitations. The setting up of such a mechanism assumes that the market exists and that the consumer is ready to pay the price differential for certified products. It is possible to satisfy these two prerequisites for niche markets but much less so for generic markets. The system's reliability and reputation is based on a monitoring mechanism which often has the support of producer organizations, but the compliance cost remains high despite the extra premium (between 70 and 100 FCFA/kg of cocoa for example) offered to farmers. This premium barely compensates for the costs of meeting environmental and social standards. The certification system must also be able to provide the consumer with clear and precise information so that he or she can make a responsible choice and maintain confidence in the certification system. This assumes that the consumer is assured that the specifications of the certification standards are relevant and that the products on the market actually meet these criteria. The monitoring system must therefore be effective and subject to verification at short notice.

Finally, the certification of a product requires certification of its entire supply chain, which implies prior consultation of all the actors involved in the production process. Thus, although the certification systems of major international NGOs claim an environmental objective, in Côte d'Ivoire, for example, these systems have not deterred cocoa producers from massive infiltrations into classified forests and national parks, with cocoa from classified forest even being passed off as certified cocoa (Higonnet *et al.*, 2017). We also find certified cacao farms within classified forests, which can only call into question the value of the certification, obviously flawed currently as attested by such cases (Ruf and Varlet, 2017). As for programmes for the reintroduction of forest species in full-sun cacao farms via certified cooperatives, they have a limited impact, mainly because of the low involvement of farmers in the conception of these programmes and because the species to be reintroduced are chosen without consultation with them. Some NGOs and bilateral agencies have, however, adopted participatory approaches that are able to take the wishes and initiatives of cacao farmers more into account.

The REDD+ programme

In tropical countries, 20% of greenhouse gas emissions are linked to deforestation and forest degradation (Kurdej, 2015). Since cacao farms on forest lands are driving the expansion of cacao farming, the cultivation of this crop thus appears to be a factor of deforestation, contributing significantly to greenhouse gas emissions. Conversely, it can also be an alternative to traditional slash-and-burn farming systems, contributing to a reduction of these same greenhouse gas emissions, provided that a number of preconditions are satisfied. The creation of cacao farms in areas with low carbon stocks, such as savannahs and fallows, should be favoured over the establishment of cacao farms after forest clearing, as should the maintenance of permanent forest cover or its restoration through the adoption of agroforestry practices. In doing so, it is possible to expect, in addition to any certification-related premiums, a specific derivation of value arising from the impact of this production on greenhouse gas emission levels and from its ability to contribute to their reduction. Payments for environmental services can thus contribute to the REDD+ programme (Karsenty, 2015). Such an initiative is currently being tested in northern Congo as part of a REDD+ programme that is being set up. In 2011, Côte d'Ivoire also initiated a REDD+ approach, leading to the validation of its national strategy to reduce greenhouse gas emissions. This strategy includes, *inter alia*, measures to promote sustainable cocoa production.

In Côte d'Ivoire, it is also possible to assume that the transition to agroforestry cacao farms could be based on the production of non-wood forest products mentioned above or on a better distribution of the value of wood of forest species introduced into full-sun cacao farms. This last point, however, needs clarity regarding the sharing of income from the sale of timber between sharecroppers and landowners because large-scale planting of forest trees will only take place if farmers find it very attractive. This implies moving from the extractive approach towards the 'natural' resource as practised by some loggers to a fair remuneration of the resource created by cacao farmers. Until very recently, the latter were excluded from the sharing of the value of timber: a major factor in the non-adoption of agroforestry techniques. Although the law has changed, it will take some time to become known and it remains to be seen whether this change in the legislative framework will facilitate a process of reintroduction of trees in cacao farms.

Rethinking plans for future development

It is necessary to propose new technical itineraries to farmers, adapted to the current situation of land scarcity and which offer better agronomic performance, especially in terms of cocoa production. It is matter also of promoting sustainable cacao farming systems that meet the requirements of environmental protection, biodiversity conservation, and economic and social development.

In Côte d'Ivoire, the 'Cocoa, Friend of the Forest' project, implemented in the region of Bianouan, is an operational translation of this strategy. It focuses, on the one hand, on the promotion of new technical intensification itineraries with the objective of increasing cocoa yields from 350 kg/ha of marketable cocoa to one tonne, and, on the other, on agroforestry approaches as environmental preservation techniques (maintenance of biodiversity, protection of water resources, protection of soils, prevention of pollution by pesticides and fertilizers). It also emphasizes the traceability of cocoa from the producer to the buyer through a reliable mechanism to ensure that the cocoa delivered by the cooperatives is indeed grown on cacao farms that satisfy the criteria of sustainability.

There are therefore several benefits of agroforestry, not only environmental but also economic and social. Cacao farmers have to choose, or even build, the agroforestry system that offers the best trade-offs to achieve their goals. If the farmer chooses the simplest form of agroforestry – the association of two perennial crops, such as the cocoa-rubber association in Côte d'Ivoire –, the benefit is clearly a certain economic security. If his choice is for more complex species association as in Cameroon, it is generally to respond as much to economic objectives as to environmental or even social constraints, such as the desire to build up and transmit a cocoa heritage in good condition to his heirs.

This diversity of cocoa situations poses a challenge in terms of training agricultural extension agents who provide support to cacao farmers. These agents can no longer disseminate a single technical message, be it the full-sun cacao farming model or a new agroforestry 'standard'. They have instead to consider the situation and circumstances of each farm and its plots, and find diverse and adapted technical solutions.

In fact, agronomists and agricultural extension agents have a lot to learn from – and should interact more with – cacao farmers in order to meet a number of challenges. The gradual conversion of a full-sun cacao farm or fallow into a simple or complex agroforestry cacao farm is a first challenge. The second challenge concerns the realization of the services expected by farmers from the species they choose for associating with cacaos in order to limit competition for water, light and nutrients. These choices vary widely depending on regions and communities (Jagoret *et al.*, 2014a; Sanial, 2015). The challenge of technical management is higher in the most complex cocoa agroforestry systems, which are necessarily more difficult to run and manage than simplified systems (Jagoret *et al.*, 2017b). The identification and dissemination of cocoa planting material adapted to agroforestry practices also remains a major technical challenge. Finally, the socio-technical challenge of managing trade-offs between ecosystem services in complex agroforestry systems requires the characterization of the services provided by the different species associated with cacaos.

These challenges will have to be overcome for agroforestry projects to contribute to an agroecological transition of full-sun cacao farming to agroforestry. Furthermore, this transition will likely be expensive. The State will not be able to generate the means necessary and a public-private partnership will become essential to meet these challenges of the transition to a predominantly agroforestry-based and more sustainable African cacao farming model.

Conclusion

It was family farming in Africa that turned the continent into the world's cocoa-producing powerhouse in the 20th century. However, this model of cacao cultivation has led to massive deforestation in some countries and the alternative of full-sun cacao farming has proven to be unsustainable. A true agroecological transition of African cacao farming based on agroforestry must therefore stand apart from the experiments of the introduction of imposed and poorly accepted species in cacao farms in order to meet a double challenge. On the one hand, in existing cacao farms, it is a matter of reducing the dependence on expensive chemical inputs and of rebuilding a biodiversity that is useful at the plot and terroir scale. On the other hand, for the creation of new cacao farms, it is a matter of developing technical itineraries that favour the conservation of forest species to limit deforestation, or of setting up agroforestry cacao farms on fallows or savannahs, while aiming for the longest possible economic cycle, one that is renewable and requires little capital.

The examples presented here mainly pertain to complex agroforestry systems set up and managed by some African farmers, and for the most part on family farms. These systems have provided stable yields over time, even rectifying low fertility situations due to low organic matter levels in savannah soils, while facilitating pest control and reducing the need for chemical inputs. These systems thus appear to farmers to be more sustainable, flexible and resilient for many reasons. The simpler agroforestry systems, associating only two or three species, but where a forest layer is present above the cacaos, have been less studied here, but their continuing adoption suggests that such systems also provide solutions to the problems generated by full-sun systems. These simple agroforestry systems are usually preferred more by local, urban and rural investors, who generally have greater access to capital than do family farms.

Irrespective of the agroforestry systems, rethinking plans of future development also requires the mobilization of all stakeholders of the cocoa sector so that an agroecological transition of African cacao farming based on agroforestry can grow in scope in the coming years.

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Chapter 4

Anti-insect nets to facilitate the agroecological transition in Africa

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African market gardening at an impasse

Market gardening has experienced considerable growth in sub-Saharan Africa over the last 50 years, especially on the periphery of major urban centres. While African leafy vegetables (African eggplant, amaranth, celosia, etc.) are mainly grown in rural areas, so-called 'exotic' vegetables (tomato, lettuce, carrot, cabbage, etc.) are primarily grown intensively in peri-urban market gardens or in large open fields, especially in the case of tomatoes grown at an industrial scale (Huat, 2006).

Intensive and unsuitable use of phytosanitary products

Various surveys of the phytosanitary practices of small market gardeners in sub-Saharan Africa conducted over the last 20 years have shown that, in both rural and urban areas, there is widespread reliance on intensive chemical control in order to cope with the many pests and diseases of crops (Ahouangninou *et al.*, 2011; de Bon *et al.*, 2014; Azandémè-Hounmalon *et al.*, 2015; Abtew *et al.*, 2016). These same authors also note the recourse to phytosanitary practices that put humans and their environment at risk: excessive doses of formulations and frequencies of application, frequent diversions of use (for example, phytosanitary products meant for the cotton sector), unspecific broad-spectrum pesticides (often associations of several active ingredients), manual methods of application that are not very effective and dangerous for the users (for example, use of watering cans for applying the products), spraying without protection, unsuitable irrigation practices, and/or phytosanitary applications under uncontrolled conditions (proximity to water points, during unsuitable weather, etc.) leading to risks of transfer of chemical molecules to different compartments of the environment (surface water, groundwater, atmosphere) (Diop *et al.*, 2016). A recent survey conducted in Kenya in the tomato production region reveals that, according to over 85% of 'small' producers, this field crop cannot be cultivated without weekly or bi-monthly chemical treatments given the current pressure from pests and diseases (Nguetti *et al.*, 2018).

Resistance, invasions

As a result of four to five decades of continuous use of phytosanitary products, African market gardeners find themselves at a technological deadlock: phytosanitary products are becoming less and less effective because of the selection of resistant pests such as the tomato moth *Helicoverpa armigera* (Martin *et al.*, 2002), the aphid *Aphis gossypii* (Carletto *et al.*, 2010), the whitefly *Bemisia tabaci* (Gnankiné *et al.*, 2013) and the cabbage moth *Plutella xylostella* (Agboyi *et al.*, 2016). The use of pesticides also leads to the decline in the numbers of natural enemies (predators and parasitoids) that regulate populations of local pests but which can also adapt to new pests that arrive without their natural enemies such as the oriental fruit fly *Bactrocera dorsalis* (Vayssière *et al.*, 2011), the red spider mite *Tetranychus evansi* (Azandémè-Hounmalon *et al.*, 2015) and, most recently, the tomato moth *Tuta absoluta* (Chailleux *et al.*, 2017).

The trap of the 'chemical only' solution

Small African producers face a number of constraints that lock them into the trap of an 'chemical onlyl' solution.

The private-sector advisory system encourages chemical control. In sub-Saharan Africa, technical advice to producers is dispensed by the private sector (seed companies, manufacturers and distributors of phytosanitary products). Knowledge of inputs and varieties available to small producers is therefore focused around chemical control (Nguetti *et al.*, 2018). The structural adjustment plans of the 1990s of the World Bank and the IMF led to the dismantling of extension services in the name of market liberalization and disengagement by the State. However, these advisory services are currently undergoing a reconstruction, with NGOs becoming active stakeholders.

Procurement pricing rules encourage the elimination of pests. In sub-Saharan Africa, domestic fresh fruit and vegetable markets emphasize the visual quality of products and their firmness to reduce transport and storage losses. No added value is accorded to the environmental and health quality of products. Thus, to prevent their crops from being inadequately valued, producers resort to chemical control to eliminate pests and diseases that cause pitting and/or blemishes on fruits.

The informal sector is significant in size. In most sub-Saharan African countries, the situation is often compounded by little or no regulation of the sale and use of phytosanitary products and/or of pesticide residues on or in products destined for local markets as opposed to products for export.

There is a lack of training of small producers. Under these conditions, it is difficult to promote alternative methods such as biological control. Market gardeners in sub-Saharan Africa are encouraged to follow the advice of their neighbours or their suppliers, who provide training/advice through the prism of chemical control (Nguetti *et al.*, 2018).

Nevertheless, consumer demand for healthy vegetables is starting to grow, especially in African mega-cities and, to a smaller extent, even in rural areas. In response, some supermarkets have started selling 'bio' or organic vegetables. Small markets offering local fruits and vegetables produced without pesticides have appeared in some neighbourhoods, and some producers in Abidjan, Cotonou and Nairobi have started delivering baskets of organic vegetables[1]. In rural areas, initiatives are also emerging among producer associations aware of the toxicity of chemical pesticides and the need for healthy fruit and vegetables for the sake of good health and the environment. In sub-Saharan Africa, NGOs such as Songhai, Enda Pronat and Agrisud have also been involved for several years in training producers in agroecological farming techniques.

Bottom up agroecological practices

Protecting crops through physical means

For the past 15 years, CIRAD has been experimenting with and proposing market gardening systems based on the principles of physical protection of leafy vegetable and fruit crops, in different climatic zones of West and East Africa (Nordey *et al.*, 2017). This work is being carried out in close collaboration with national research centres (INRAB, KALRO, ISRA)[2], international ones (ICIPE[3], World Vegetable Center) and universities (Abomey-Calavi, Benin; Egerton, Njoro; Péléforo-Gbon-Coulibaly, Korhogo; Felix-Houphouet-Boigny, Abidjan; Michigan State, Lansing; California, Davis) with financial support from CIRAD and USAID HIL[4]. Experiments on techniques in research stations were followed by demonstrations on producers' farms to assess together the performance of these new practices. The most promising innovation is the use of nets that provide a climate-friendly environment for cultivation while protecting crops from larger pests. Anti-insect nets were designed and adapted to agroclimatic conditions in three African countries (Benin, Senegal and Kenya). Cost/benefit analyses were then conducted to estimate the financial viability of this technology for small producers (Vidogbéna *et al.*, 2015a).

The effectiveness of nets in controlling pests

Our results have shown that the use of anti-insect nets leads to a considerable reduction in pest attacks, especially from those responsible for direct damage to the production of fruits (tomato, bean) or leaves (cabbage), such as birds, snails, caterpillars, flies and locusts (Martin *et al.*, 2006, 2015; Saidi *et al.*, 2013; Gogo *et al.*, 2014; Simon *et al.*, 2014). Depending on their mesh size, nets allow the crops to get sufficient aeration – ventilation needed to avoid a confinement of crops that would lead to fungal diseases –, even under tropical conditions. On the other hand, these nets do not completely protect crops against phloem-feeding pests such as aphids, whiteflies, thrips and phytophagous mites. They can, however, significantly reduce infestations of some whiteflies (*Trialeurodes* sp.) on tomatoes compared to crops not protected by nets (Figure 4.1). This technique has the advantage of being financially affordable and of being able to provide effective protection against certain emerging pests. This is especially the case for the tomato moth *Tuta absoluta* where the use of a physical

1. For example, see https://www.youtube.com/watch?v=Qy8WZfT0DqE (retrieved 17 February 2019).
2. Respectively National Institute of Agricultural Research of Benin, Kenya Agricultural and Livestock Research Organization, and Senegalese Institute of Agricultural Research.
3. International Centre of Insect Physiology and Ecology.
4. United States Agency for International Development – Horticulture Innovation Lab.

barrier can delay and reduce damage (Deletre *et al.*, forthcoming). To complete the protection against small pests, it is necessary, on the one hand, to optimize the natural defences of the plants cultivated under nets by ensuring the adaptation of varieties, soil quality (nutritive and microbiome resources), and water supply (micro-irrigation) and, on the other, to put in place compatible and reasoned methods of pest control.

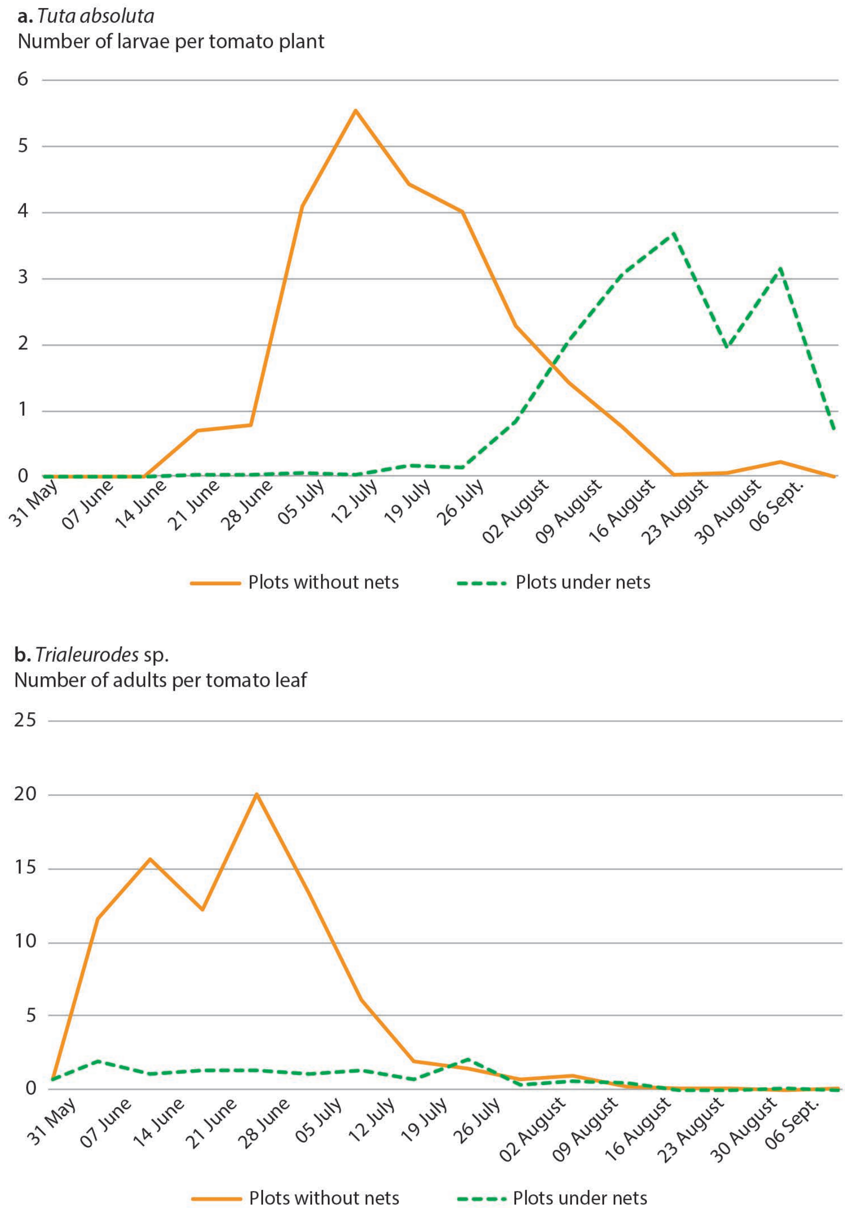

Figure 4.1. Mean number of *Tuta absoluta* (a) and whiteflies *Trialeurodes* sp. (b) per untreated tomato leaf, under nets (dashed line) and outside (solid line), in an experiment conducted in Kenya in 2017 at the Kalro research institute, Mwea.

The limitations of physical control

Physical control is generally but wrongly believed to be the only solution for controlling all pests of a crop. In reality, many insects, usually phloem-feeding ones such as whiteflies, thrips, aphids and mites, and even lepidopterans and flies, end up getting through physical barriers, regardless of the type of barrier used.

In tropical climates, nets with larger mesh sizes are required to increase natural ventilation and reduce temperatures and relative humidity under them (Nordey *et al.*, 2017). This increase in mesh size decreases the level of physical protection against phloem-feeding pests. Some species, but not all, may even proliferate there as they find safety from their natural predators (birds, ladybugs, lacewings, hoverflies) or even their parasitoids, although we have shown that an increase in mesh size could also facilitate the passage of some of these latter species (Martin *et al.*, 2015).

In Benin, for example, cabbages produced under nets are protected from caterpillar attack, but they can become heavily infested with aphids, in a similar way to tomatoes cultivated under nets, which become infested with whiteflies of the *Bemisia tabaci* species. On the other hand, in Kenya, *Trialeurodes* sp. whitefly infestations remain low under nets while they are widespread on tomato or bean crops in open fields (Figure 4.1). Since physical control is not incompatible with chemical control, producers can continue to use the latter. But since they do not want their crops damaged by insects, especially their high value-added crops, they often resort to chemical control with the usual excesses, not knowing all the species of insect pests (and the damage they cause), even less the useful species.

Other agronomic benefits of physical control

This technique is easy to understand and use. It is also relatively well-suited to tropical climates because it is possible to adjust crop shading and ventilation by choosing appropriate colour or mesh size of the net (Nordey *et al.*, 2017). Nets are also useful for protecting crops against extreme weather events such as torrential rains, squalls or droughts. Finally, the use of nets reduces evapotranspiration, and consequently reduces the plant's water needs, in addition to improving the quality of fruits, especially for the tomato, both for its marketing (firmness) and in its organoleptic qualities (better sugar/acidity balance) (Saidi *et al.*, 2013).

Technical support and favourable public policies for the dissemination of this innovation

For what economic profitability?

The economic performance of agroecological innovations can be analysed using an evidence-based policy approach, which originated from the medical sciences (Laurent *et al.*, 2009, 2012). In our case, this amounts to measuring the effectiveness of the use of anti-insect nets, then identifying the prospects for dissemination to a wider population of producers, and finally, assessing the practice's environmental impacts. The profitability analysis is therefore necessary as part of a proof-of-concept approach as well as of an approach for informing the formulation of sectoral economic policies.

It is therefore a matter of inspiring or orienting public or private agricultural policies on the basis of analyses of the economic performance of the innovations being tested. The analysis of the innovations' economic profitability at the farmer level is one of these tools, an analysis which is not solely an exercise in accounting because it is also the concrete, informed and measured representation of the economic system in which the farmer operates. Programmes to demonstrate anti-insect nets to small producers were conducted in Benin (2012-2014) and Kenya (2017-2018). In the first case, it was a matter of transferring the technology of low net-covered tunnels (Photo 4.1) to vegetable growers in southern Benin to protect cabbage crops both in the nursery and in the cultivation areas.[5] In Kenya, the aim was to assess the economic viability of high net-covered tunnels for the production of tomatoes (Photo 4.2), cabbages and green beans in rotation in different geographical zones.[6]

A composite indicator

To analyse these innovations' profitability, we have developed an indicator based on agronomic yields, producer prices and costs. This composite indicator therefore summarizes agronomic performance and market access, and accounts for the supply chains of various inputs used in agricultural production, including the labour market in the form of manpower. Profitability is thus an indicator that reflects not only a natural environment and market relationships, but also their instability and uncertainty. For example, large crop losses due to pest infestations or a surfeit of agricultural supply on agricultural markets can temporarily lower the prices paid to the producer. In both cases, the producer's income is affected.

Profitability of crops cultivated under nets

Profitability in itself is, no doubt, a useful indicator, but an analysis of the profitability compared to that of the alternatives offered to the farmer (or in comparison to his current practices) helps him decide whether he should adopt the proposed innovations. Indeed, economic performance analyses carried out in Benin not only showed that low tunnel anti-insect nets for cabbage production were profitable, but also that this profitability was on average significantly higher when compared to conventional methods, i.e. to those using insecticides (Vidogbéna *et al.*, 2015b). The analyses also showed an increase in yields in real conditions and an improvement in the quality of crops due in particular to the reduction in insecticide applications (a higher proportion of cabbages of larger size and with a better visual appearance for sales). In fact, profitability analyses have shown that nets dampen variations in yields and therefore in incomes. They thus help stabilize cash flows, reduce the volatility of production and variations in quality. This stability over time of financial resources is an important element in reducing the vulnerability of farms and improving their overall resilience. It is therefore also a means of helping the farmer acquire a long-term vision by reducing the risks he can perceive, thus allowing him to make medium-term productive investments at lower levels of risk. Indeed, the producer's decision to invest depends on his expectations, which themselves depend on, among other factors, his perception of risk and uncertainty.

5. https://www.youtube.com/watch?v=FKyJjpC4p2g (retrieved 17 February 2019).
6. https://www.youtube.com/watch?v=Y6Ri6SuWTqk (retrieved 17 February 2019).

Obstacles to and levers for adopting nets

An innovation is adopted after a multi-phase decision-making process: from understanding of how the innovation works to deciding to test and then adopt it (or to adapt it), and, finally, to decide to continue using it over time. Programmes to demonstrate anti-insect nets to small producers in Benin and Kenya were based on *ex ante* approaches, i.e. approaches that anticipated farmers' reactions instead of analysing

Photo 4.1. Cabbage cultivation under low tunnels covered with nets in Benin. © Thibaud Martin / CIRAD.

Photo 4.2. Organic tomato cultivation system under a high tunnel in Kenya. © Thibaud Martin / CIRAD.

them *ex post*. We found that small producers in Benin were ambivalent about adopting this innovation for protecting their cabbage crops despite a higher predicted profitability than with current practices (Vidogbéna *et al.*, 2016). While a small proportion of producers expressed an immediate interest in adopting this technique (18%), half of them refused to do so and the rest were relatively ambivalent. The farmers who refused to adopt the technique did so because of a perception of abnormally high labour costs. In fact, this result was also predictable. The profitability of an innovation is necessary but not sufficient for its adoption (Rogers, 2003). The required quantitative data must be supported by qualitative and dynamic analyses based on the prospective recipients' perceptions. Aside from evaluating the technology itself, the farmer must also evaluate the context in which this evaluation takes place, i.e., as we have seen, the agronomic context (an area vulnerable to attacks from pests, for example), access to the market and to inputs. Finally, the farmers' perception of the technology itself has to be considered: its comparative advantage, its complexity, its ability to be tried out, and the visibility of the results obtained (Rogers, 2003). Significant variations in this perception should be recorded according to the level of technicality and experience of the farmer in using nets (Vidogbéna *et al.*, 2015b, 2016). Furthermore, the results of *ex ante* analyses of adoption should not obscure the fact that adoption – and more precisely dissemination – is a dynamic process. Indeed, those who refuse to adopt the technique today will perhaps be the adopters or even the pioneers of tomorrow.

Profitability analysis for informing the formulation of targeted policies

A detailed breakdown of the economic performance obtained by a profitability analysis not only reveals favourable production conditions but also helps formulate hypotheses for targeted public or private support policies. In the case of Kenya and green beans, for example, Figure 4.2 breaks down, for eight farmers, the cost/benefit ratio of commercial production in the case of a fully subsidized net and in the case of a non-subsidized net. The red zone represents the breakeven point. This figure shows,

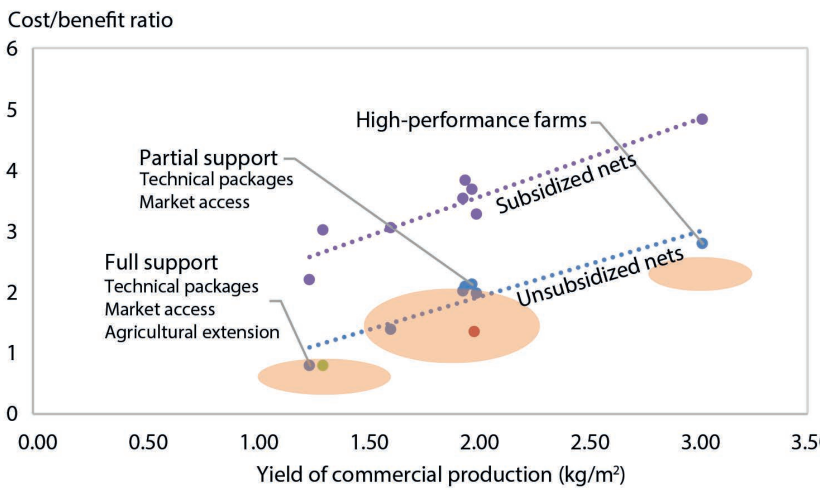

Figure 4.2. Cost/benefit ratio of commercial production in the case of a fully subsidized net and in the case of an unsubsidized net for eight producers in Kenya (Mujuka *et al.*, forthcoming).

on the one hand, contrasting production situations and, on the other, the possible impacts of a subsidy for insect nets and, consequently, the importance of agricultural policies targeted on the basis of farm type.

Contrasting production conditions

As far as situations of commercial production are concerned, it was observed that the farmers monitored in Kenya had a contrasting production experiences. Theoretically, there should be a direct relationship between yield – irrespective of its exact value – and the cost/benefit ratio for commercial production. However, many factors, biotic and abiotic, can affect yields and thus the cost/benefit ratio. In the case of the eight farmers, we observed, for example, a case in which the yield was affected by a plot maintenance contract not respected by an exporter. We also observed low green bean farmgate prices due, in particular, to an election period (departure of foreigners) but also low prices in general. We also observed the importance of good technical mastery and of having high-quality and adapted seed varieties to boost yields. In some cases, agroclimatic zones affect production conditions and trigger chains of causality: an unsuitable environment leads to excessive use of synthetic inputs, which is often inefficient and leads to economic losses.

We have identified three broad groups of farmers: subsistence farmers, farmers in the general mean, and a single pioneer/enterprising farmer. In this breakup, for example, the use of nets is not economically viable for subsistence farms. Indeed, for them, the break-even point is less than 1.

Towards targeted support policies

A typology of the economic performance of innovations under real-world conditions, i.e. made by collecting and grouping all the constraints that affect the farmer's decision-making and the economic performance of the proposed innovations, is also part of evidence-based policy approaches. For formulating support policies, information is necessary that is based on real facts and pertaining to the intended recipients of the innovations, the farmers. We have been able to show some examples of hypotheses of targeted support policies based on observations made in the field. In the case of subsidized anti-insect nets, there would be an automatic improvement in the profitability of all farms. The nets for subsistence farms would break even. As far as targeted agricultural policies are concerned, the dissemination strategy can be either commercial, with the cost of the technology being borne by the farmer, or public, i.e. with the cost covered by a government subsidy in the form of direct aid. Segmented market access strategies could also improve prices or the sharing of added value (short circuits, supermarket contracts, niche markets, etc.). In this connection, pricing policies linked to compliance with various norms and standards would make it possible to offset the costs of implementing quality initiatives. The analysis of economic performance based on profitability analyses of innovations also makes it possible to identify appropriate insurance policies for climatic hazards and economic risk. The issue comes therefore down to studying the economic relationships between the formal sector and the informal sector in which farms operate (de Bon *et al.*, 2014). Finally, adapted agricultural extension policies could improve the appropriation of innovations.

All of these targeted support policies will indirectly impact the profitability analyses of the use of nets. And this impact could furthermore be differentiated according to the agricultural populations: a relatively small population of dynamic farmers running farms well endowed with productive capital; a population of farmers with moderate amounts of capital; and a population of farmers with little productive capital and whose primary goal is food security.

The relationship between support policies and profitability are therefore crucial. To reiterate, targeted agricultural policies for subsistence farms could, for example, consist of subsidizing productive equipment, facilitating the marketing of production through controlled procurement prices, and supporting producers through extension services.

What environmental impacts?

One of the expected benefits of the use of nets is a lower environmental impact of the cropping systems concerned, especially per unit production, due to the high resulting yields, lower use of pesticides and more efficient water use. A life cycle analysis of tomato cultivation in peri-urban market gardens in Benin has revealed that poorly managed agricultural practices (excessive use of pesticides, fertilization and irrigation) associated with generally low yields inevitably lead to very high environmental impacts per unit produced (Perrin *et al.*, 2015; Perrin *et al.*, 2017). With regard to cropping systems with nets, the fundamental question is therefore whether the better yields expected and the lower use of inputs (water and pesticides in particular) will offset the environmental impacts associated with production, transportation and the end of life of the nets themselves. What is the actual contribution of these nets to the overall performance given that the real agronomic performance of these systems is very dependent on the abilities of the producers to manage their cropping systems and on their production constraints? Indeed, we have observed that the use of nets does not necessarily mean lowered use of pesticides. Life cycle analyses carried out on unheated and under-cover market gardening systems have shown the importance of not only the infrastructure and its lifespan, but also of its end-of-life management (Payen *et al.*, 2015; Boulard *et al.*, 2011; Martínez-Blanco *et al.*, 2011; Torrellas *et al.*, 2012).

Extending the life of synthetic materials, recycling them or using organic materials are some of the possible solutions to reduce the environmental impacts of under-cover systems. Management of infrastructure waste is also crucial in the environmental impacts of these systems, especially the rate of recycling of plastics, made more difficult, and thus more expensive, by the possible presence of impurities (soil, pesticides). The energy recovery of plastic waste is an interesting alternative to recycling, with the calorific value of polyethylene, for example, being equivalent to that of diesel. On the whole, the eco-efficiency of under-net cropping systems depends on the levels of use of all kinds of inputs (fertilizers, pesticides, water, soil, energy, nets and other equipment) and on their yields, while remaining very dependent on the abilities of the producers and their pedoclimatic production constraints, the latter mainly determined by their location in Africa. The eco-efficiency also depends on the level of mastery of the technology by the producer which will allow him to reduce the negative impacts of cultivation under cover compared to cultivation in the open field. The combination of an optimal mastery of the technique of the use of nets – through training imparted to the producers – with the choice of regions of production best suited to this technology should make it possible to reduce the environmental impacts of market garden production in sub-Saharan Africa. A synergy of action between experts and researchers in the disciplines of agronomy, economics, socio-technical analysis and the environmental assessment of systems will be necessary to achieve an optimal coherence and the best representation possible of these joint approaches. An example of this synergy can currently be found in two ongoing projects on the continent: ANR-Eco-Plus in Kenya (2017-2020) and HortiNet in Côte-d'Ivoire (2018-2021).

Conclusion

Our first observations in Benin and Kenya suggest that the physical control of insects through the use of nets leads to profound changes.

It promotes a reduction in pesticide use. Tested on the farm, the nets decrease, as expected, the prevalence of worms and caterpillars that directly attack fruits and leaves. And since, in the majority of cases, producers apply pesticides based on an observation of the prevalence of pests and the damage caused by them (damaged fruits or perforated leaves), the protection provided by the nets leads them to reduce the frequency of phytosanitary treatments significantly.

It also allows farmers to assess the benefits of using nets. After all, weren't nets first used in Europe on the initiative of the farmers themselves? By cultivating under nets, the farmers discover that it is possible to produce more with a reduced use of phytosanitary products and to overcome the challenge and the problems posed by the building up of resistance to insecticides. In Kenya, the dissemination of the innovation is facilitated by a cool high-plateau climate and thus by the greenhouse effect of the nets, which is beneficial to yields. In Benin, the dissemination will probably be slower because of the humid climate, which limits yields, and the lack of distribution networks for nets.

The dissemination and adoption of nets also facilitates the networking of actors. In Kenya, net-distribution projects have thus contributed to bringing together stakeholders with an interest in organic agriculture (WhatsApp group). On the one hand, a number of pioneers have emerged, and have become role models for groups of farmers who want to get involved. On the other, links have been created between these groups of farmers and innovative companies specializing in the supply of biological protection tools.

Finally, this initiative has allowed the formulation of targeted policies for a transition to agroecological farming. Very often, the transition to organic farming or agroecology is perceived by farmers to be a risky gamble. However, the confined cultivation environment provided by nets makes non-chemical methods of crop protection more efficient and less uncertain. The nets thus become a lever of transition towards these sustainable cultivation methods. Support policies targeted by producer type thus make eminent sense.

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Chapter 5

Accompanying the actors of the agroecological transition in Laos

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The drivers of the agroecological transition in Laos

In Laos, the agrarian transition is characterized by rapid changes in agricultural production systems. Since the early 2000s, a transition has been taking place, away from subsistence agriculture, primarily based on rice cultivation, forest gathering and extensive livestock farming, and towards market-oriented agricultural production systems, with a significant and rapid increase in crops grown for export (Figure 5.1) to neighbouring countries, mainly China, Thailand and Vietnam. This transition has been facilitated by the implementation of successive public policies to limit the use of shifting cultivation and to modernize agriculture (Box 5.1), and by the result of the country becoming a member of the Association of Southeast Asian Nations (ASEAN) in 1997.

The rapid expansion of cash crops cultivation has undoubtedly led to an overall reduction in poverty but it has also weakened farming communities (75% of the total population of Laos), with growing inequalities between producers, a sharp rise in indebtedness, and an increased vulnerability of these communities. Increasing climatic hazards are now combined with growing economic risks (more frequent situations of local commercial monopolies, production contracts with terms and prices that are not respected, strong interannual price variations, etc.).

Furthermore, while these policies have encouraged the reduction of slash-and-burn practices and the adoption of more intensive farming practices, they have also disrupted the traditional methods of managing soil fertility, based on long fallows, and, ultimately, undermined the sustainability of farming systems. Indeed, the technical models being promoted are based on Green Revolution principles: hybrids and improved seeds, mechanized soil tillage, and increased and increasing use of external chemical inputs (fertilizers and pesticides). These practices, however, have a negative impact on natural resources and result in the degradation of agricultural land, pollution, and biodiversity loss (Figure 5.2).

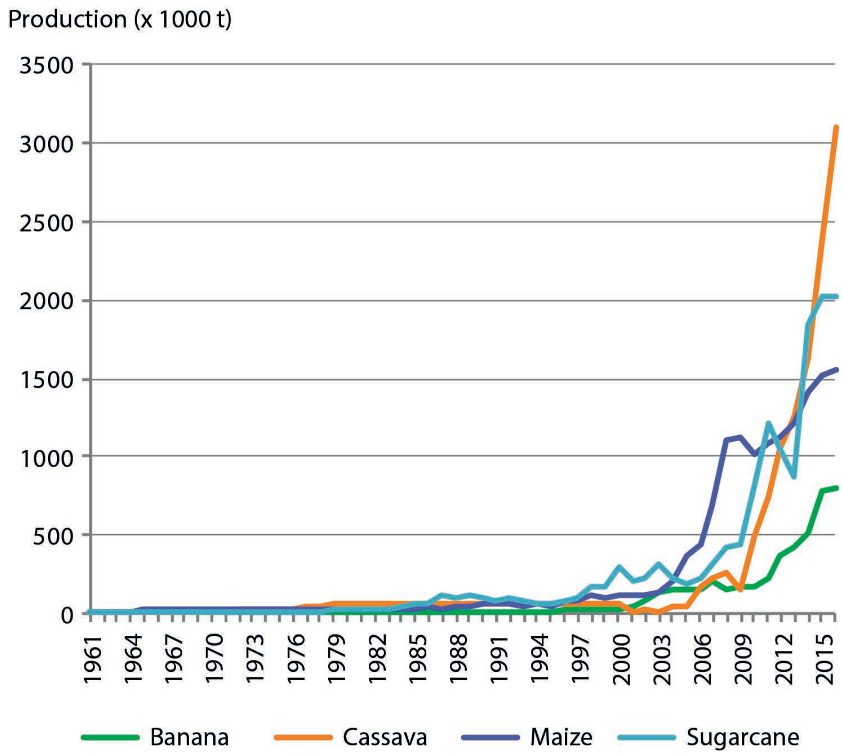

Figure 5.1. Changes in production of the main export crops in Laos over the 1961-2016 period (source: FAOstat).

Box 5.1. History of policies for limiting shifting cultivation and for modernizing agriculture in Laos

Based on Castella and Phimmasone, 2017

The 1980s

Ban (and criminalization) of shifting cultivation. This policy resulted in a massive process of resettlement of villages to more accessible areas, and an increase in agricultural pressure on land at the local level.

The 1990s

'Three-plots' land-use policy (no more than three plots in rotation per farm). Application of policies to reduce deforestation. Reducing fallow durations dramatically affected the sustainability of rotational cropping systems.

The 2000s

'Turning land into capital' policy aimed at modernizing agriculture through economic incentives that encouraged smallholder farmers to practise more intensive land management.

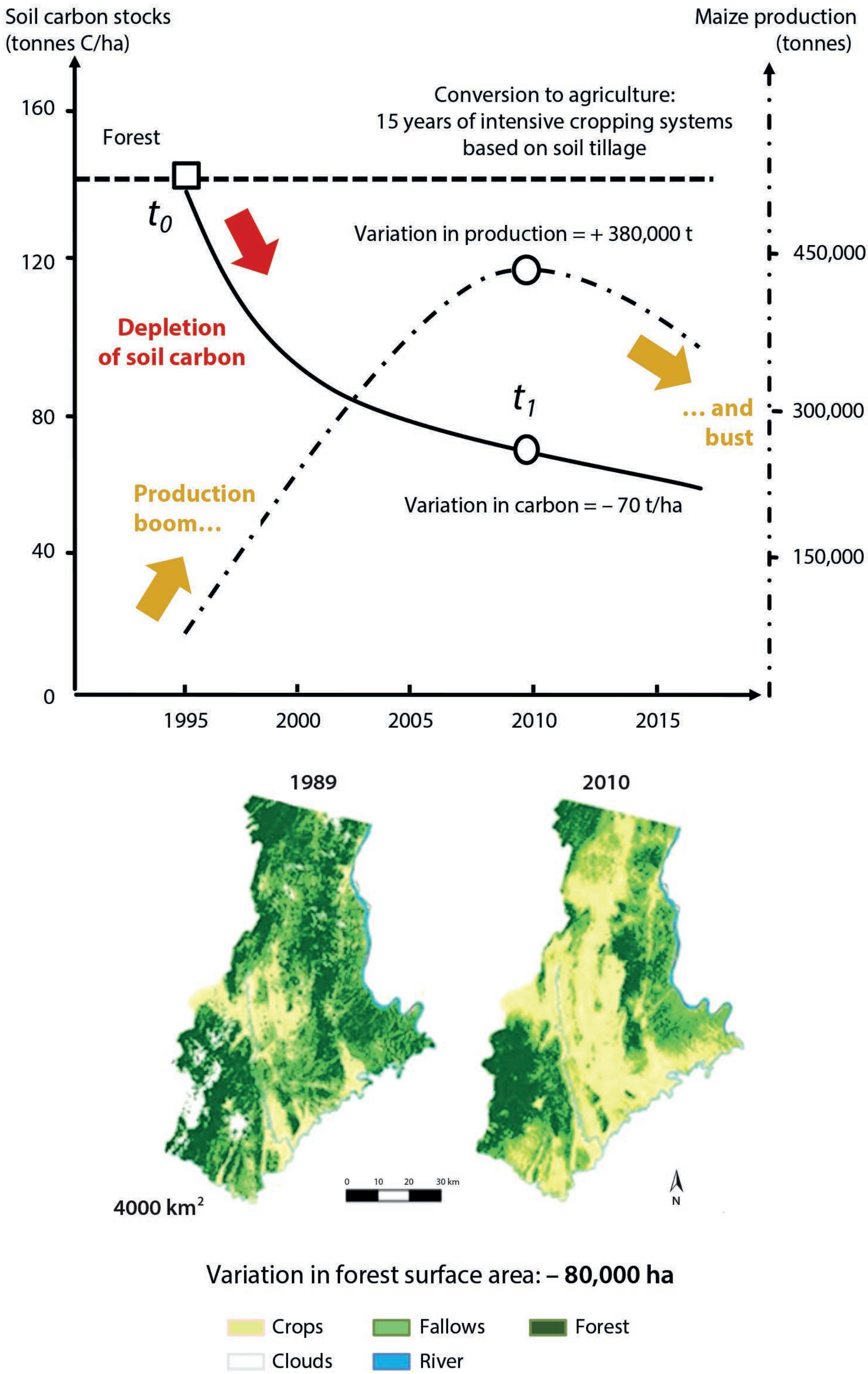

Figure 5.2. Deforestation and impact of conventional maize cropping systems on carbon stocks in the south of Sayabouri province in Laos (Tivet *et al.*, 2017).

Aware of the limitations of the current agricultural model, the Laotian authorities have been reflecting on an alternative national green growth strategy since the 2010s, but there exist competing visions on how to implement it. It is clear that agroecological practices (organic farming, conservation agriculture, agroforestry, integrated crop-livestock approaches, integrated pest management, system of rice intensification, etc.) promoted since the early 2000s by various governmental and non-governmental institutions (Table 5.1) have not been widely adopted and remain insignificant when compared to the conventional intensification model.

It is in this context that two complementary approaches are being tested since 2014 to promote an agroecological transition in Laos: action-research involving all the inhabitants of village communities located in the uplands of northern Laos (EFICAS project) and the creation of a regional network for the sharing of experiences in the field of agroecology (ACTAE project).

The approaches being tested

Eficas action-research project

EFICAS (*Eco-Friendly Intensification and Climate resilient Agricultural Systems in Lao PDR*) is a project that has been funded since 2014 by the French Development Agency (AFD) and the European Union as part of the Global Climate Change Alliance. It is being implemented by DALaM (Department of Agricultural Land Management) of the Laotian Ministry of Agriculture and Forestry (MAF) of Laos with the support of CIRAD. In each of the twelve project villages spread over the three provinces of Luang Prabang, Houaphan and Phongsaly, this project engages the entire village community in order to implement agroecological practices adapted to different landscape units: lowland rice paddies (e.g. system of rice intensification, off-season crops), home gardens (e.g. composting, integrated crop-livestock system), plots on slopes (e.g. conservation agriculture with legume crops in association with cereals, agroforestry, domestication of non-timber forest products, development of livestock-rearing areas or production of fodder).

The activities of the EFICAS project revolve around:
– the co-design of land use plans to meet the needs and demands of village communities and local agri-chains by incorporating innovative agroecological practices;
– the capacity building of extension agents, so that they can play the role of facilitators in negotiating processes (between farmers, local authorities and traders), and of producers (skill training in technical itineraries, conservation of planting material, making the best economic use of by-products from associated crops);
– the monitoring and evaluation of the resilience of agricultural communities to external shocks (economic, climatic) in order to assess the performance of technical and organizational innovations and, more generally, the territorial dynamics at village level.

The networking approach of the ACTAE project

ACTAE (Supporting the Agroecological Transition in Southeast Asia) is a project funded by AFD since 2015 and implemented by CIRAD and the French NGO GRET

Table 5.1. Overview of agroecology in Laos in 2013 (sources: Castella and Kibler, 2015a; Lestrelin, 2015; Lienhard *et al.*, 2014).

Agroecological practice	History of its promotion in Laos	Level of adoption (in 2013)
Organic farming	Since the early 2000s Initiatives of local and international NGOs. For example Helvetas (Profil project), ASDSP, Saeda, PADETC, Oxfam, AgriSud, SNV, GAA Mainly concerning rice and vegetable production CIRAD is supporting the development of the organic coffee sector on the Bolaven Plateau (AGPC)	No aggregated data at the national level but still marginal (in terms of acreages and volumes produced) Local results seem to be encouraging: Profil (700 families), Saeda (2 groups), etc.
Integrated pest management (IPM)	Initiated in 1996 by FAO and MAF (plant protection service) Farmers' Field Schools (FFS) approach Complementary initiatives since 2000 supported by NGOs. For example ABP, AgriSud, SNV, Oxfam Belgium, ASDSP Mainly concerning lowland rice and vegetable sectors IPM national government network established in 2013 with the appointment of an IPM correspondent/expert at the agricultural services level for each province and for certain districts Promotion of the IPM and FFS approaches in all Laotian provinces for rice and in eight provinces for market gardening systems	No aggregated data at the national level Level of local adoption varies by province (and the size of the market garden sector and extent of lowland areas) The use of pesticides in agriculture is, however, still growing
Agroforestry	Since the early 2000s Three areas of intervention: - protection and regeneration of endemic forests - development and protection of non-timber forest products - promotion of agroforestry systems associating commercial plantations (rubber, oil palm) with annual crops (rice, maize) or multi-year crops (ginger, galangal) Northern Laos Main institutions/actors: Sida-Narc-FSRC, PADETC, SDC, GRET (bamboo), Agroforest Cie (benzoin), CCL and GDA (cardamom)	No aggregated data at the national level
System of rice intensification (SRI)	Started in 2006 through two initiatives: ProNet 21 and NCMI project MAF decree of September 2008 for the national promotion of system of rice intensification in all irrigated basins	No aggregated data at the national level Project data (2010): adoption by more than 10,000 families and for 3600 ha
Conservation agriculture	Since the early 2000s Pilot projects in two provinces, supported by CIRAD and MAF-Nafri/Dalam MAF decree and circular for the promotion of conservation agriculture at the national level (2005 and 2011)	Little dissemination outside pilot intervention areas Substantial abandonment in pilot intervention areas on the completion of projects

ABP: Agro-Biodiversity Project; AGPC: Bolaven Plateau Coffee Producers Group Association; ASDSP: Association to Support the Development of Peasant Societies; CCL: Committee for cooperation with Laos; Dalam: Department of Agricultural Land Management (managed by the MAF); GAA: Welthungerhilfe, German Agro Action; GDA: Gender Development Association; Nafri: National Agricultural and Forestry Office; NCMI: National Community-Managed Irrigation network; PADETC: Participatory Development Training Centre; Profil: Promotion of Organic Farming and Marketing in Lao PDR; Saeda: Sustainable Agriculture and Environment Development Association; SDC: Swiss Agency for Development and Cooperation.

with national and regional partners in Cambodia, Laos, Myanmar and Vietnam. It supports and helps develop initiatives and foster networking of the different stakeholders of agroecology, from producers to consumers, including research, academia, civil society, policymakers and the private sector. The project is structured around two components: one led by CIRAD to strengthen the CANSEA network (Conservation Agriculture Network in South-East Asia), mainly focused on the promotion of conservation agriculture; the other, led by GRET, with the aims of establishing a multi-stakeholder regional platform for bringing together the different domains of agroecology in the Mekong region: the Agroecology Learning Alliance in South-East Asia (ALiSEA).

The ACTAE project's activities include the production of knowledge about agroecology through the accompaniment and co-financing of initiatives to encourage multi-actor collaborations and thematic studies, including the assessment of agroecological practices and of consumer perception, and institutional framework analyses (Castella and Kibler, 2015b). The dissemination and networking of experiences is made possible through an online knowledge sharing platform[1] and the organization of multi-actor thematic workshops at national and regional levels. A third area of intervention concerns the promotion and visibility of the agroecological movement among policymakers and consumers through the use of dedicated communication tools, with the objective of preparing future joint advocacy actions. The ALiSEA network disseminates the results of the many existing initiatives in the Mekong region through a quarterly newsletter, a web portal, a presence on social networks (Facebook, YouTube) and the organization of exchange workshops and promotional events.

The EFICAS project approach favours a territorial perspective and a change of scale from the plot to the village landscape. The ACTAE project networks like-minded national projects and local initiatives, and thus facilitates the exchange of experiences and the capitalization and dissemination of results at national and regional scales. It contributes in this way to forging an advocacy for agroecology with decision-makers in order to argue for a political impetus to the agroecological transition.

Accompanying and supporting the agroecological transition

The ACTAE and EFICAS initiatives intervene in a complementary manner on eight levers identified during feasibility studies to accompany and support the agroecological transition in Laos (Figure 5.3).

Understanding the trajectories and drivers of change

Studies have been carried out on agrarian dynamics in three regions of northern Laos that have been producing hybrid maize for export for over ten years. The analysis of changes in land use and natural resources reveals (Lestrelin and Kiewvongphachan, 2017; Phaipasith, 2017):

– a process of deforestation driven by the expansion of cultivation of cash crops and the laying of rural roads;

1. https://ali-sea.org.

Figure 5.3. Levers identified to support the agroecological transition in Laos.

– a reinvestment of income from cash crops (maize) in terracing of rice fields, off-farm activities and the education of children (strategies for exiting from agriculture);
– a diversification of agricultural activities towards perennial crops (fruits), livestock husbandry (improved pastures) and, to a lesser extent, towards other annual crops (cassava, Job's-tears [*Coix lacryma-jobi*], canna) when maize profitability declines;
– the leading role of the private sector in these dynamics, as much concerning access to markets (farming contracts), to inputs (seeds, pesticides), and to services (agricultural equipment) as the financing of investments needed for agricultural production (credit financing of secondary roads to expand production areas).

Identifying windows of intervention

The processes of agricultural transformation take place extremely rapidly and are spatially diversified. The challenge of designing innovative agroecological systems consists of intervening at the right time in the right place. The identification of windows of opportunity, i.e. key moments of intervention during the successive stages of intensification and degradation of agricultural land, has proven to be essential to promote the adoption of agroecological practices.

For example, we have shown that there exist two windows of intervention for the promotion of conservation agriculture in the context of a boom in the cultivation of hybrid maize in Laos (Lestrelin and Castella, 2011; Castella *et al.*, 2016c). The first window corresponds to the initial stage of the agrarian transition, when the producers begin to introduce cash crops into production systems still predominantly oriented towards food self-sufficiency. The second is after the cash-crop boom, in areas that were long engaged in intensive agriculture and are affected by significant problems of land degradation. Farmers are then confronted by the environmental problems caused by cash monoculture and are more open to the diversification of production practices and systems. Conversely, technical interventions during the expansion-intensification phase of the cash crop are unlikely to succeed with producers in the absence of a strong incentive – or coercive – framework.

Improving intervention mechanisms

The adoption of agroecological practices depends on the farmers' full participation in the planning and innovation processes (Castella *et al.*, 2016b; Lienhard and Lestrelin, 2016). Village communities have thus to be involved in the definition and implementation of territorial projects. The collective exercise leads to a shared vision of the desired landscapes in the medium and long term, which is then translated into an action plan with objectives, achievement indicators, and rules for the use of resources. Every year, the agroecological innovations tested as part of these action plans are evaluated collectively by the various actors (farmers, researchers, extension agents, local authorities, associated private sector). Activities for the upcoming agricultural season are modified and fine-tuned after discussions of the reasons for the successes and failures of the past year.

Researchers and extension workers play a facilitating role in negotiations between farmers and traders to forge more balanced contractual partnerships (for example organic coffee, locally processed soya beans, stick lack produced on the stalks of pigeon peas, value chains development for peas produced in managed fallows). Agricultural technical centres are also involved in the innovation process through the production of planting material and agronomic references (diversified cropping systems, varietal collections) and the provision of technical and training support services to producers.

Finally, monitoring and evaluation systems for the long-term evaluation of agroecological production systems' performance and impacts (quality of life of local populations, ecosystem services, resilience of agricultural systems in the face of climate change) are put in place to sustain the long-term commitment of all the actors of innovation, ranging from the local populations to donors.

Co-designing and co-evaluating practices

Different agroecological innovations are co-designed and tested with the producers according to the priorities defined in the village action plan. They pertain to different compartments of the village landscape:

– reconfiguration of the interactions between cropping and livestock systems, with negotiations of enclosures to better control ruminant roaming and improvement of livestock systems (fodder systems, animal health, improved access to water and stabling);

– support for the protection and intensification of lowlands (e.g. reinforcement of banks, small irrigation equipment, system of rice intensification, composting, off-season diversification);

– promotion of diversified rainfed cropping systems incorporating legumes (e.g. pigeon pea, soya bean, *Vigna* spp.) in association with partner projects, State services and the private sector, for the integration of legumes into local diets;

– conservation of genetic material;
– development of agri-chains (production and local processing of soya beans for cattle feed, production and marketing of stick lack);
– promotion of agroforestry systems (e.g. coffee, medicinal cardamom) in association with the private sector.

The performance of the innovations is analysed with the entire village community through an annual presentation of the results obtained by the farmers and technicians involved (Figure 5.4).

The project's impact on the resilience of agricultural communities to external shocks is assessed through a monitoring mechanism that combines variables and indicators in order to assess the three identified components of resilience: village community vulnerability to climatic and economic hazards, the individual and collective capacities of adaptation, and agricultural and non-agricultural land uses. Data are collected at different scales (plot, farm and village), and according to a dual approach: diachronic (evolution over time of the variables and indicators for a given village) and synchronic (comparison between villages on a given date).

Building capacity of stakeholders

In the EFICAS project, emphasis is laid on the capacity building of local stakeholders: farmers and technicians in charge of agricultural extension, who are the main

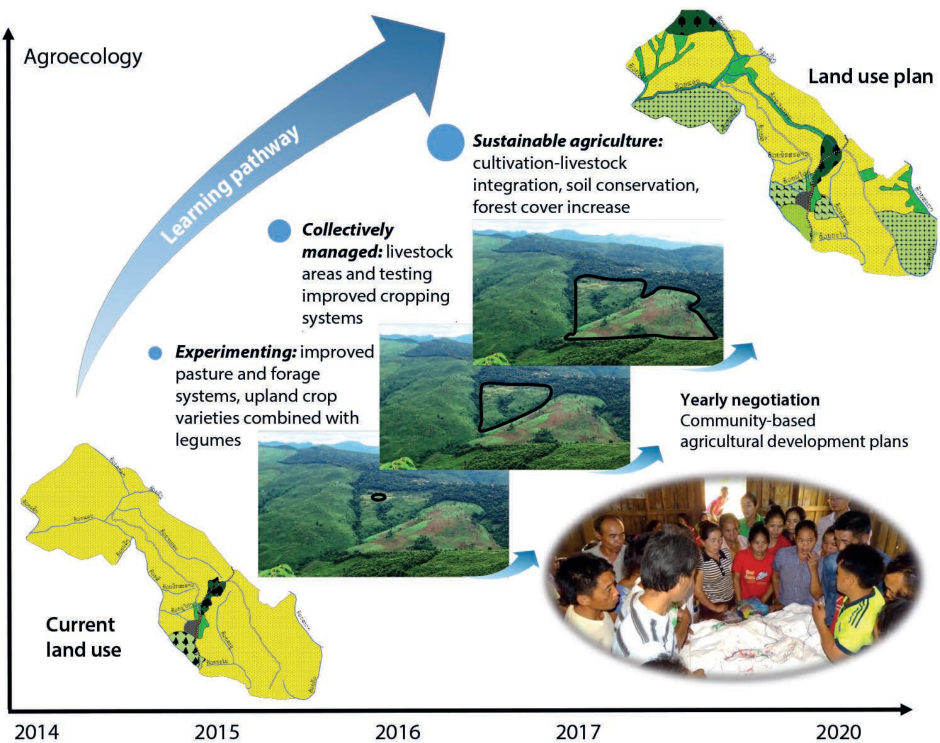

Figure 5.4. Example of a negotiated landscape trajectory (Pouthong village, Luang Prabang province).

actors engaged in the planning, implementation, and evaluation of activities. Technical training sessions conducted by local trainers (composting, forage technologies, system of rice intensification, stick lack production, etc.) make it possible to enhance existing skills. Simulation games are used to explore scenarios of evolution of local practices, discuss issues concerning the sustainability of agriculture, and identify technical and organizational alternatives (for example, the Mahasaly game [Ornetsmüller *et al.*, 2018], the EFICAS game).

In the ACTAE project, the focus is on raising awareness among the wider public (decision-makers, consumers) and on academic training, on the basis of field experiences of research and development projects with, in particular:
– support for the production of teaching material on agroecology for undergraduate and master's level students (Cambodia, Laos) and farmers (e-learning modules in Khmer in Cambodia). In Laos, collaborative work supported by the ALiSEA network between the four main universities (NUoL, Soupanouvong, Savannaket and Champasak) has resulted in the production of four training manuals (agroecology, agroforestry, organic farming and integrated farming) that are now in use by students (bachelor's and master's, between 200 to 250 students per year);
– training in simulation games (Laos, Cambodia, Myanmar and Vietnam). Even though only two training programmes have been conducted so far, the first beneficiaries expressed a great deal of interest. Some partners have incorporated this approach and these tools in their research and development activities (for example, the NGO CISDOMA in Vietnam, CASC in Cambodia, etc.);
– training in using smartphones to record videos in order to document practices, share them among peers and use them as a communication and training medium. To date, 42 people have benefited from this training (innovative farmers, development agents, extension agents) and nearly 40 videos have been produced and disseminated (YouTube, village screenings). These videos help in building up the farmers' self-respect and pride, and encourage the sharing of experiences between actors.

Promoting access to resources and markets

In the EFICAS project, access to resources and markets is promoted through the networking of local and national actors around:
– village seed collections and banks to facilitate the conservation of genetic resources and their exchange with national technical centres and seed companies that are based in Laos (for example Lao Forage Seeds and its network of forage seed producers);
– agricultural equipment tested in the project villages (brush cutters, straw choppers, electric fences, etc.), available on local markets or sold by Laos-based companies;
– exchanges between producer groups and local businesses/traders (coffee, soya bean, stick lack).

In the ACTAE project, regional exchange networks are organized around:
– agricultural practices (production, conservation) and planting material. These networks bring together national technical centres (Laos, Cambodia) and private entities (for example, Echo Asia);

– markets, regional agri-chains (Laos, Cambodia, Vietnam), species that are currently neglected and under-utilized in agriculture but which are essential for the design of diversified cropping systems;
– pilot models of farmer organizations (agricultural cooperative for the production and marketing of natural fertilizers in Cambodia).

Adding value to agroecology products

As part of ACTAE, and more specifically of ALiSEA's Small Grant Facility, several initiatives have been supported to test and document participatory guarantee systems approaches (locally anchored quality assurance systems). This method of alternative certification by peers (which does not automatically lead to a paper certificate) is especially well-suited for agroecology products that target the domestic market (Georges and Ferrand, 2017). It is a low-cost method for creating trust between producers, consumers and other agri-chain actors. These initiatives are being undertaken by different types of actors (producer organizations in Myanmar, private sector in Cambodia, NGOs in Vietnam), with the vast majority of them concerning vegetable products (Cambodia and Vietnam), as also also coffee and fruits (Myanmar). The ultimate goal is to combine takeaways from the various experiments (ALiSEA's, of course, but also FAO/IFOAMand ADB) of participatory guarantee systems in Laos and in the region, in order to produce recommendations for policymakers.

Additional studies on consumer perceptions of agroecology products are under way in Laos, Myanmar and Vietnam (Kousonsavath *et al.*, 2018). These studies characterize consumer demand for these products and make recommendations to policymakers to support the development of the requested products.

Communicating about agroecology initiatives and actors

The agroecology web portal for the Mekong region, ALiSEA's communication and knowledge-sharing platform[2], offers free access to more than 510 resources, including 53 case studies of agroecological innovations (15 of which are from Laos). The website receives an average of 15,000 views per month. The Facebook page in English[3] has 3150 followers and has links to Facebook pages in national languages (Lao, Khmer, Burmese and Vietnamese). ALiSEA's YouTube channel[4] has 11 playlists and 48 videos. A quarterly newsletter has more than 1200 subscribers (from the Mekong region and beyond) and is a means for sharing and disseminating success stories, lessons learnt, case studies and upcoming events about agroecology in the Mekong region. Since most of these resources are in English, their main users are development practitioners or are from academia and the research community. This is why, in order to reach the producers themselves, a study is under way in Cambodia to better understand their means of access to information (information channels, nature of information sought, etc.). A similar survey has already been conducted in Myanmar where several initiatives have been launched to provide technical information to producers through smartphone apps (Greenway, Golden Paddy, etc.).

2. https://ali-sea.org.
3. #AgroecologyLearningAlliance.
4. #ALiSEAMekong.

Video is the preferred medium for the ALiSEA platform to document agroecology initiatives and share the experiences of practitioners (farmers, technicians), and is also the primary means to deliver educational resources. To this end, all the coordinators of the national secretariats have been trained in the use of smartphones to produce videos. The aim is to be able to document the initiatives funded under the Small Grant Facility and the other notable agroecological activities in the region. Ultimately, innovative farmers should be able to themselves document their practices and share videos on social networks.

An online survey of users of the ALiSEA portal (112 responses) indicates that the two most popular uses are to access case studies and training content (technical manuals) and for communications.

Raising awareness amongst the wider public

Public events organized around agroecology have reached a broad audience, including policymakers. Thus, as part of the Luang Prabang Film Festival, the ALiSEA network organized a short-film competition on 'Youth and Agroecology', which received more than 20 entries from the five countries of the Mekong region. The films selected for the competition were made available on Facebook and have had more than 370,000 views, reached more than 1.3 million people and resulted in nearly 20,000 comments and shares.[5] The screening of the short films selected for the competition was accompanied by an agroecological products fair, a photo exhibition on agroecology in Laos and a public discussion on agricultural production models and their impacts on the food we consume[6]. This public event was part of efforts to raise awareness on agroecological issues among different categories of people in Laos and elsewhere in the region.

Consumer surveys conducted in Vietnam and Myanmar (Asian Development Bank study on perception of agroecology products among 1300 urban consumers) indicate an increased need for awareness-raising campaigns and public events (festivals, fairs, etc.) to promote agroecology and to encourage changes in consumer habits towards agroecological products.

The issue of the role of young people and their relative lack of interest in agriculture has reappeared in the official documents of the Laotian Ministry of Agriculture and Forestry, and discussion groups have been created at the highest level of government on this topic. During the preparatory meetings for the Lao Uplands Conference, held in Luang Prabang from 12 to 14 March 2018, this issue aroused transversal interest and led to the production of various communication material (for example videos, posters, participatory theatre, orientation notes).

5. The selected films are available on a dedicated playlist of Alisea's YouTube channel: https://bit.ly/2CzuMqV.
6. The panellists of the public discussion included a representative from the Laotian Ministry of Agriculture and Forestry, a director of the activist think-tank Focus on the Global South (https://focusweb.org), the regional network director of The Field Alliance (www.thefieldalliance.org) and a documentary maker specializing in environmental issues. The discussion can be viewed in its entirety at: https://bit.ly/2CAm6Ai (accessed 27 February 2019).

Promoting policy dialogue

Two initiatives were jointly conducted by the EFICAS and ACTAE projects to capitalize knowledge and contribute to the formulation of public policies in favour of the agroecological transition.

The Lao Uplands initiative

This effort of capitalization of knowledge initiated by the EFICAS project and its partners[7] helped:
– reflect on recent transformations and their impacts on upland populations;
– take stock of the main lessons learnt from past and on-going interventions;
– review policy options for a green growth;
– develop a road map with the Laotian Ministry of Agriculture and Forestry and other partners of rural development towards the UN's Sustainable Development Goals.

This collective process has involved most of the national projects and institutions that are interested in agroecology and has raised awareness amongst those who do not use this concept explicitly but refer to the same principles. A forthcoming book will showcase these collective efforts.

LICA: Lao Initiative on Conservation agriculture and Agroecology

The goal of the LICA initiative by Laos is to encourage agriculture ministries in ASEAN member countries to define and adopt a common position about agroecology.

It is a matter of agreeing upon:
– a common definition of the agroecological transition;
– flexible and low-cost institutional mechanisms to mobilize and build up existing expertise in agroecology in the Asean region;
– tools to foster cross-sector initiatives and policies (in the areas of communication and education, agriculture and agro-processing, financial and commercial mechanisms, marketing and labelling of products of agroecology, etc.) based on partnerships between the public and private sectors, producers and consumers.

Finally, in order to facilitate the appropriation by all concerned parties, this initiative supports extension approaches in four areas in particular: agroecology, agro-entrepreneurship, participatory approaches, and territorial approaches.

Two accompaniment approaches: what lessons learnt?

Both the approaches described in this chapter are intended to promote the agroecological transition in Laos. They are clearly complementary, but nevertheless each has its own limitations in terms of implementation and medium-term impacts.

In the EFICAS project, the landscape and participatory approach promoted is difficult to implement in the socio-economic conditions of the ethnic minorities of northern Laos and the potentially conflicting interests of the government and

7. https://laouplands.org (accessed 27 February 2019).

agricultural communities (support for foreign investment through the allocation of agricultural concessions *vs* support to family farming). This approach is also complex to implement since it relies heavily on facilitation skills, in which extension agents are not yet trained for the most part. However, it remains the best way to build up skills and to strengthen the decision-making and management capacities of extension agents and the farming communities concerned.

In the ACTAE project, the transaction costs associated with its regional management are significant and raise the question of the financial sustainability and governance of such tools after the end of project funding.

The resources mobilized to act on the different levers of the transition (Figure 5.3) and the actual duration of the interventions (three years) remain largely inadequate given the challenges.

In Laos today, the agroecological transition still corresponds to a sum of initiatives whose impact is yet difficult to measure. To engage in a real transition, it is necessary to continue the activities undertaken at the various levels of intervention by concentrating on the following objectives.

A territorial approach

Participatory land-use planning, the promotion of innovative agroecological practices, and the negotiation of rules related to the use of resources and the marketing of agricultural products must be combined in a common framework in order to overcome the difficulties faced by these approaches when they are implemented independently of each other. For example, the promotion of more diversified cropping systems, incorporating the cultivation of crops after the main crops (i.e. relay crops), is more likely to be successful if it includes village-level negotiations to better control animal roaming (Castella *et al.*, 2016a).

Learning loops in a collective engineering process

Development does not follow a linear trajectory. Village development plans should be discussed and renegotiated regularly (ideally annually) by the entire community in order to be able to adapt to:

– unpredictable events (climatic hazards, pest attacks or market opportunities);

– behaviour that deviates from initial plans (for example, opening up of cultivated plots on protected forest areas, crop damage caused by the roaming of domestic animals despite the adoption of collective rules, etc.);

– the evolution of local policies (for example promotion by local authorities of goat farming, coffee or rubber plantations).

Diversified and multifunctional agricultural landscapes

A diversified landscape is more resilient to external shocks than a uniform one. The capacity of the entire production system to resist economic or climatic shocks, or to recover from them, is strengthened by the diversity of agricultural activities, the use of agroecological practices, and the diversification of income-generating activities.

The diversification of landscapes and income will require:
– a revision of the indicators used to assess agronomic performance (currently measured on purely economic criteria: area × production × production per unit), in order to include ecosystem services (e.g. biodiversity, quality of life) in agricultural production objectives;
– policies promoting the recognition and preservation of, and access to, diverse genetic material through mechanisms involving farming communities, government services and the private sector;
– the provision of subsidies, the tax exemption of equipment and agricultural inputs required for the diversification of agricultural practices (for example, direct seeding drills, legume inoculants, tools for biological pest control).

Building up the capacity of extension agents

For an effective agroecological transition, extension agents have to play a facilitating role in the processes of innovation and negotiation between actors. The use of simulation games makes it possible to better support the actors in the participatory definition of agroecological scenarios, and subsequently in the evaluation and the implementation of these transformations. Extension agents have to be important interlocutors of the private sector in the development of agroecological value chains and the production of ecosystem services: increasing social entrepreneurship, private-sector funded vocational training programmes, with a particular focus on training of and support for young farmers. It is therefore a matter of investing in the creation of educational materials for different categories of actors (farmers, extension workers, students) based on new technologies (e-learning, smartphone apps).

Creating a favourable institutional environment

To innovate is to take risks. Actors who commit to agroecology take on significant risks, since future returns remain hypothetical expectations. It is therefore necessary to support farmers and traders confronted by uncertainties and risks through original mechanisms of financing, incentives and insurance (Figure 5.5).

Finally, it is essential to make consumers aware of the benefits (health, environmental and economic) of consuming products from agroecology because it is ultimately they who will accelerate and finance the agroecological transition once the process reaches its tipping point. Agroecology can become a key element of sustainable development only when consumers create a demand for its products. To this end, it will initially be necessary to create certification and value-addition methods for these products, adapted to the Laotian context (such as the participatory guarantee system). An important prerequisite – necessary but not sufficient – for setting up such funding mechanisms is a strong political message in favour of agroecology.

Only the implementation of a wide-ranging and coordinated package of measures for farmers, agricultural extension services, the private sector, consumers and policymakers will allow the goals we have outlined to be achieved on a scale sufficient enough to bring about the hoped-for agroecological transition in Laos.

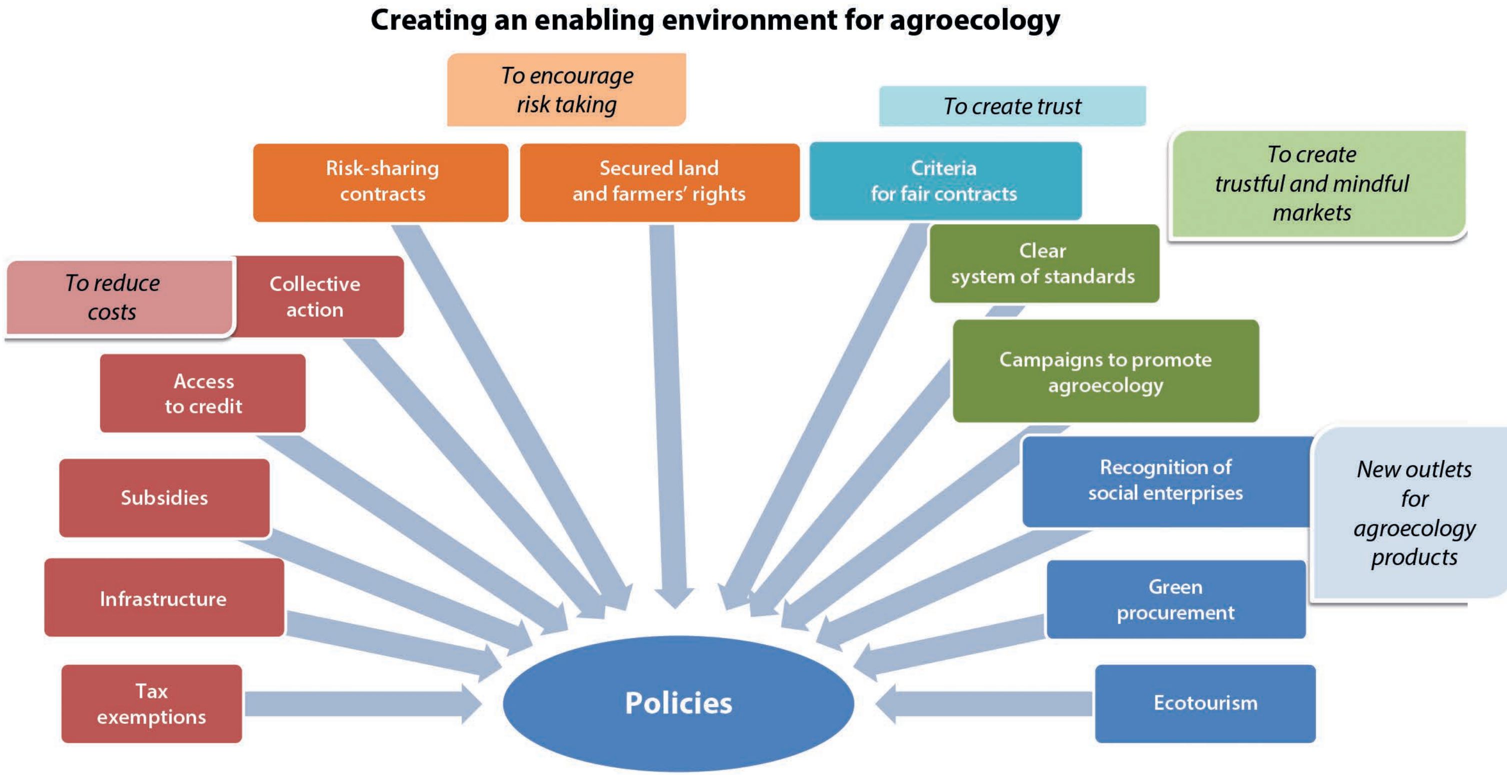

Figure 5.5. An institutional environment favourable to the agroecological transition.

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Chapter 6

The agroecological transition of Cavendish banana cropping systems in the French West Indies

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The Cavendish banana – a 'dessert banana', as opposed to 'cooking bananas' or to plantains – is cultivated in Martinique and Guadeloupe on around 7000 hectares. In the last few years, the annual marketed volume of this crop has amounted to 320,000 tonnes (Imbert and Lœillet, 2017). Production of the Cavendish banana is a major activity of the economy of the French West Indies, directly employing over 6000 people in the banana chains of these two islands and accounting for nearly 10,000 indirect and spinoff jobs (Global Footprint study). The agri-chain was reorganized nearly ten years ago, following a severe crisis of competitiveness that peaked in the early 2000s. One of the outcomes of that situation was the creation of UGPBAN (General Union of Guadeloupe and Martinique banana growers) to manage the overall strategy for developing the agri-chain and marketing its production. In the French West Indies, this production remains subject to a very strict framework of constraints, in view of the increased competition in the global market and the significant costs it entails. These high production costs are due in particular to much higher salaries than in other production areas, stringent European regulation as concerns standards, and to recurring climatic hazards (hurricanes). Societal expectations are also high in terms of protecting the environment and human health in a context of increasing urbanization. These factors force an approach of continuous innovation on the agri-chain in a permanent effort to improve its competitiveness, as well as its environmental and social sustainability.

Conventional methods of producing the Cavendish banana are being called into question due to physical, chemical and biological degradations, and the unintended pollution they can cause in cultivated and natural environments (Risède and Tezenas du Montcel, 1997). Highly productive in non-limiting soil and crop pest conditions, the Cavendish banana, which represents a single clone encompassing a set of cultivars that are closely related genetically, is in fact demanding in terms of water and mineral inputs, and susceptible to numerous aerial and soil-borne diseases and pests. These diseases and pests have, for several decades now, been managed in many parts of the world, including in the French West Indies, by a sustained use of synthetic pesticides derived from fossil fuels, to which has been added fertilization with synthetic fertilizers. These intensive cropping systems have thus resulted in adverse environmental and health impacts.

Therefore, starting at the end of the 1990s and the beginning of the 2000s, the persisting pollution from chlordecone (an organochlorine insecticide used in the region until 1993 to control the banana weevil, a rhizome boring insect) that led to an unprecedented health crisis in Martinique and Guadeloupe (Cabidoche *et al.*, 2009) was revealed and widely publicized. This pollution has resulted in the long-term fixation of chlordecone in soils and aquatic environments, the contamination of local populations and certain agricultural and livestock products. This crisis was decisive in the way issues were raised amongst all the stakeholders of the banana agri-chain (researchers, producers, public policymakers, civil society) concerning the methods of production of the Cavendish banana in the French West Indies, islands that are rich in biodiversity, and where farmland and residential areas are closely packed.

It is in this particular economic and environmental context that the 'Sustainable Banana' plan was launched in 2007 in the French West Indies to improve the economic, environmental and social sustainability of banana production. This chapter's aim is to discuss the environmental component of this plan and to assess the agroecological transition in the French West Indian cropping systems linked to it. We will, consequently, identify the determinants of this transition, the technical and organizational modalities based on which it was carried out, the related practices that were developed on the field, and the multi-stakeholder intervention frameworks in which it took shape. Finally, the lessons that can be learned from this agroecological transition are presented in a perspective outlook.

The determinants of the agroecological transition

Four major groups of factors were simultaneously involved at the start of the agroecological transition of Cavendish banana cropping systems in the French West Indies.

The consequences of a highly intensified, pesticide-dependent monoculture

In the period between the late 1980s and the early 2000s, there were sharp declines in the productivity of intensive monoculture banana systems (Delvaux *et al.*, 1990; Dorel and Perrier, 1990). The performance of these systems gradually dropped due to recurrent problems of soil fertility loss and soil 'fatigue', caused by an uncontrolled increase in soil-borne parasitism. These systems were affected, in particular, by a range of pests including multispecies communities of endoparasitic nematodes, and a soil-borne fungus that induced root necrosis whose significance was strengthened by the damage caused by these plant parasitic nematodes (Risède and Simoneau, 2004).

The repeated use of synthetic nematicides of the carbamate or organophosphorus families proved inadequate to halt the effects of water and mineral imbalances caused by these soil-borne pests, or to stem the toppling of plants affected by the alteration and necrosis of their root systems. In a similar way, the damage caused by the rhizome weevil *Cosmopolites sordidus* and the size of its population became increasingly difficult to control. In parallel, resistance to benzimidazole fungicides used to control Yellow Sigatoka disease on banana trees, caused by the fungus *Mycosphaerella musicola*, was growing, reducing the range of fungicidal molecules that could be used to control this leaf spot disease. Simply put, it was the production model taken as a whole that began failing in the context of increased biological constraints resulting in yield losses and technical bottlenecks. There was a growing realization that any solution would have to involve a paradigm shift.

Growing societal demand for more sustainable production methods

The risk of a health and environmental crisis due to chlordecone, noted as early as in the late 1970s and early 1980s (Snegaroff, 1977; Kermarrec, 1980), was identified definitively and widely publicized between the late 1990s and early 2000s. This persistent organic pollutant was first detected in several drinking water catchments in 1999, and then in edible tubers (yams, taros, etc.), as well as in other agricultural products and aquatic organisms in 2002. The resulting contaminations drew the attention of local populations, producers, public authorities and policymakers. As a consequence, environmental and health concerns acquired greater importance, which helped in efforts to find alternative solutions to control the banana weevil. They also helped in the implementation of measures to reduce the exposure of local populations to this pollutant. The French government launched a series of plans (national chlordecone action plans) to better understand how the environment was affected and to look for ways to better manage risk (ARS and Ireps, 2016).

Agronomic research already focused on the development of reasoned banana cropping systems

At the end of the 1980s, the French research institution CIRAD had already been undertaking agronomic research on banana cultivation for a long time, and was already very active in the French West Indies. It intensified its research activity in the 1990s and in the early 2000s, with this activity taking the form of a proactive and anticipatory approach intended to develop reference frameworks and sustainable technical packages for producers. These technical packages were based on reasoned practices to limit the systematic use of pesticides and synthetic fertilizers, thus mitigating their environmental impacts. In this way, CIRAD's researchers developed a soil-plant standard to control mineral fertilization on the basis of soil analyses and a foliar diagnostic method that was used from the end of the 1980s. A biological forecasting system to control Yellow Sigatoka disease, developed by CIRAD, was already widely in use at this time and helped to reduce the impacts of the fungicides used against the disease by limiting the number and amount of active fungicide ingredients used per hectare

(1 kg/ha/year in the French West Indies against 30 to 70 kg/ha/year in other parts of the world). The principle of linking soil sanitation against plant parasitic nematodes with the use of healthy banana vitroplants to avoid using nematicides had also been developed, although in practice the bulk of the producers were not yet using this technical itinerary. Similarly, methods were developed for diagnosing banana cropping systems, as also for quantifying populations of soil-borne pests (plant parasitic nematodes, weevils) and for estimating the extent of their damage (in the case of the weevil). Finally, researchers also explored ways to do away with post-harvest fungicides used to control post-harvest diseases (anthracnose and crown rot). In the marketing domain, there are two strategies – push and pull – that determine how innovations are built. In push strategies, it is the invention or innovation that is triggered by the offer. Conversely, in pull strategies, they are driven by demand. Until the 2000s, CIRAD and the research community primarily used a push strategy to come up with innovations. This resulted in the development of a set of diagnostic, prophylactic and reasoned approaches, which however did not at that time engender a coordinated and integrated application, nor lead to widespread adoption by producers.

An institutional environment conducive to a reduction in pesticide use and an ambitious innovation plan

In the early 2000s, environmental issues and sustainable development acquired particular importance at the institutional level in France. Thus 2007 was the year of the *Grenelle de l'environnement* agreements, which aimed at a long-term national mobilization for sustainable planning and development. In 2008, the Ecophyto 1 plan, formulated to reduce the use of pesticides by 50% over a 10-year period, was launched. This occurred in the backdrop of several years of increasingly strict French regulations on active ingredients, which resulted in the gradual withdrawal of and ban on the use of many compounds, including several synthetic insecticides and nematicides used in banana plantations.

This trend was subsequently strengthened at the European level by Regulation (EC) no. 1107/2009 of October 21, 2009, which concerns the introduction of plant protection products in the market, re-specifies their methods of assessment and authorization, and lists the exclusion criteria for substances classified as particularly dangerous for human health and the environment.

It is in this context that an ambitious innovation plan, the 'Sustainable Banana' plan, was launched via the concerted initiative of CIRAD researchers, the Guadeloupe and Martinique Banana agri-chain (BGM) and its different constituents (General Union of Guadeloupe and Martinique banana growers, the grower companies of Guadeloupe and Martinique: LPG and BanaMart), Martinique and Guadeloupe Regions, decentralized government services (Directorate of Agriculture and Forestry), ministries (including the Ministry of Agriculture) and ODEADOM (Office for the development of the agricultural economy in the French overseas territories). This plan was based on a twin objective. On the economic front, it aimed to determine and implement conditions necessary to maintain a high level of production and of employment. To this end, it focused on actions to improve and modernize banana farms and their related infrastructure, and on actions to add value to the banana agri-chain and to diversify it by orienting actors and imparting training to them. On the environmental front, it aimed at developing an alternative production method in the French West Indies based on agroecological concepts. The 'Sustainable Banana' plan was thus the main driver to create a trajectory of innovations for the agroecological transition in the banana production systems of the French West Indies.

Agroecological practices implemented in the field

The change to diversified systems using service plants

Several practices have helped initiate the agroecological transition of banana production methods in the French West Indies. These are mainly practices of prophylaxis, biological or mechanical pest and disease control, monitoring of these pests and diseases in line with reasoned management, as well as those concerning the reinsertion of functional biodiversity in cropping systems in order to strengthen the provision of ecosystem services. These practices combine crop and soil management methods with the deployment of functional biodiversity in cropping systems. Table 6.1, without being exhaustive, lists these practices in terms of the initial objectives assigned to them.

Developed in a partnership innovation framework in which researchers, technical actors and producers interacted, these practices were initially based on relatively specific technical 'building blocks', which were then combined with the help of feedback from different actors involved. Indeed, the agroecological transition developed through a process of a participatory co-design of cropping systems. This process did not unfold linearly over several successive stages, but rather through the coexistence of different strategies with a common thread: protection against plant-parasitic nematodes. Cover crops were initially monospecific, i.e., with only one service plant species used at a time. This species (which could, for example, be *Brachiaria decumbens*, *Neonotonia wightii* or *Crotalaria* spp.) was initially used in rotation with the banana crop. These cover crops then ensured the soil cleansing up of banana parasitic nematodes thus avoiding a resort to spontaneous fallows which include weed species that are hosts to these nematodes. In addition, they also helped restore the overall soil fertility. Gradually, these sanitizing and improved fallows replaced the spontaneous fallows. In parallel, more traditional rotations (banana-pineapple, and especially banana-sugarcane) were practised. Subsequently, cover crops based on service plants began to be associated with bananas, and soon developed into multi-species cover crops, based on a set of service plants specifically developed over time and space (Photo 6.1). In this way, a set of complementary services could be simultaneously targeted, such as biological regulation of pests and diseases, biomass production, erosion control, nutrient recycling, soil structure improvement, carbon sequestration, and atmospheric nitrogen fixation.

A design approach for banana systems based on service plants

To implement these banana cropping systems based on multi-species and multi-functional cover crops of service plants, several generations of prototypes of innovative cropping systems were necessary. They were developed, for the most part,

Photo 6.1. Multi-species cover crop (*Arachis repens* and *Desmodium ovalifolium*) associated with Cavendish banana. © Hoa Tran Quoc/CIRAD.

in the participatory and multi-partnership framework of the 'Sustainable Banana' plan. The general approach was based on a *de novo* co-design with the production of systems that departed from conventional systems, and the creation of prototypes by experts. An important step was to undertake a specific engineering effort in order to learn how to set up cover crops based on service plants, prior to designing any cropping system prototype. Improvement loops based on feedback from the different categories of actors involved (researchers, producers, technicians) on the agronomic and environmental performances of these prototypes were carried out using a step-by-step design. They were informed by the design and the assessment of pre-prototypes of innovative banana cropping systems in real world conditions (exploratory tests of parts of technical itineraries). Figure 6.1 illustrates how generations of prototypes of banana cropping systems based on service plants form part of a gradient of plant complexity and diversity, with the aim of providing multiple agroecological services. These innovative cropping systems were assessed at the beginning mainly on the basis of their agronomic and economic performances. Today, their assessment relies upon a network of Dephy farms (demonstration, experimentation and production of references on plant protection sparing cropping systems) set up in Martinique and Guadeloupe, on the basis of a multi-criteria approach, not only taking into account the economic and environmental dimensions, but also social ones pertaining to the sustainability of these innovative systems (Feschet *et al.*, 2018).

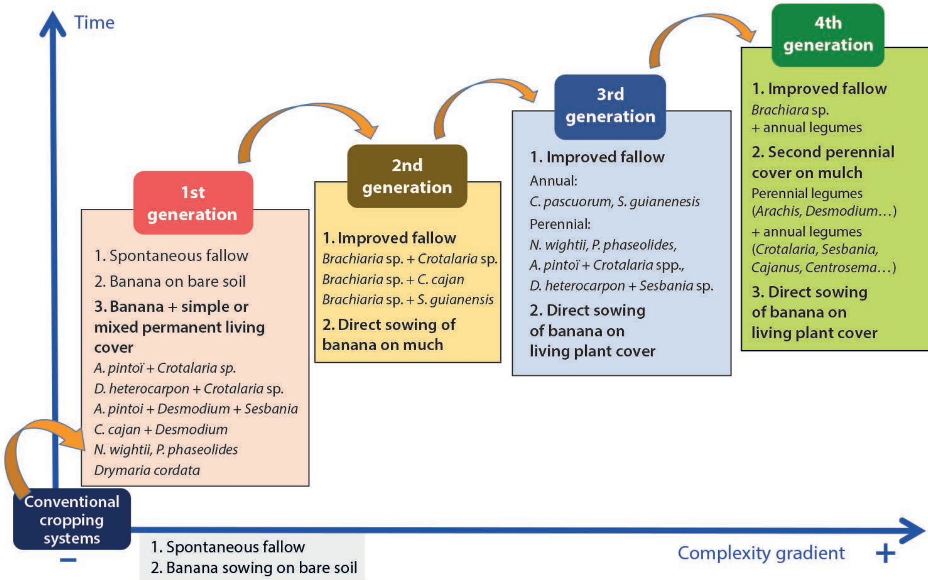

Figure 6.1. Successive generations of prototypes of innovative banana cropping systems including multi-species and multifunctional cover crops of service plants.

Results in the banana cropping systems of the French West Indies

In addition to maintaining the level of production in Martinique and increasing it by 50% in Guadeloupe, one of the key results of this agroecological transition is the substantial reduction in the use of plant protection products in banana cropping systems in the French West Indies. Thus, in accordance with the initial objective of the Ecophyto 1 plan, the quantity of active ingredients (QAI) used between 2006 and 2015 in these cropping systems was reduced by almost 60% on both islands, the reduction being more than 30% between 2008 and 2011 alone (Figure 6.2). If we calculate the quantity of active ingredients (determined by sales of plant protection products to banana producers) per hectare per year, the decrease is also more than 50% between 2006 and 2015. Over the same period, there was a substantial reduction in the use of nematicides and insecticides, amounting to nearly 90% (and a decrease of less than 50% for herbicides alone, while the amount of fungicides showed little variation over the same period).

Finally, farmers have largely adopted crop prophylaxis practices based on the coupling of soil sanitation strategies against soil-borne parasites with the use of healthy planting material (banana vitroplants). At present, more than 80% of farmers use them. The use of nematicides has become sporadic and marginal, as new cropping methods have proven to be particularly effective in limiting the development of major endoparasitic nematodes such as *Radopholus similis*. Synthetic insecticides are no longer used to control the weevil, with the practice having been substituted by biological control methods with Sordidin pitfall traps as a complement to crop prophylaxis.

Regarding Sigatoka diseases, the integrated protection strategy already implemented and then supported by appropriate management of the harvest stage, fruit removal

Table 6.1. Types of practices implemented during the agroecological transition of banana cropping systems in the French West Indies.

	Objectives	
Practice	**Management of plant parasitic nematodes**	**Management of weevils**
Prophylaxis	Destruction of old banana plantations, first by chemical means (herbicides), then using mechanical means or, for small farmers, through cattle grazing. Systematic mechanical elimination of re-growing banana suckers, potential sources of contamination by plant parasitic nematodes and weevils. Coupling of fallows and sanitizing crop rotations with service plants that are not host to the endoparasitic nematodes of the Pratylenchidae family (especially Radopholus similis), using healthy banana vitroplants. Water seclusion ditches to isolate sanitized plots.	
	In nurseries supplying weaned banana vitroplants, use of 30 µm mesh filters to limit the contamination of irrigation water for greenhouses by plant parasitic nematodes of the Pratylenchidae family.	
Biological control	Deployment in the field of a cover crop based on *Crotalaria* species (mainly *Crotalaria retusa, C. spectabilis, C. zanzibarica, C. juncea*) with nematotoxic properties	During the destruction of the plots, mass trapping using pitfall traps in association with an aggregation pheromone (Sordidin). After this step, arrangement of traps on borders of newly planted plots to prevent recontamination from the outside. During banana cultivation, mass trapping using pheromone traps.
Re-injection of functional biodiversity into banana cropping systems	Development of multi-species and multifunctional cover crops of service plants, mostly those that are non-host to the main parasitic nematodes of banana. Their procedures of introduction and management have been specified. Some (such as *Paspalum notatum*) promote biological control and improve the structure of soil food webs.	Cultivation of certain service plants (such as the *Brachiaria decumbens* + *Cynodon dactylon* association) to increase the abundance of certain generalist predators of the weevil (ants, earwigs, etc.) and the biological regulation of the weevil.
Mechanical control		
Monitoring of pest populations	Biological tests to monitor the nematological quality of soil sanitation during the fallow stage. Dynamics of plant parasitic nematode populations in roots. Regular monitoring of the sanitary status of banana seedlings in nurseries using nematological analyses of weaned vitroplants.	Monitoring of populations using Sordidin pitfall traps (private partnerships, INRA, CIRAD). Assessment of damage by rhizome dehulling.

Objectives		
Management of Sigatoka	**Management of weeds**	**Alternatives to mechanical soil tillage**
Rapid elimination of abandoned banana plantations, which are sources of contaminating inoculum. Leaf pruning for sanitary purposes by mechanical ablation of leaves or portions of leaves bearing necrotic lesions. This practice limits the dispersion of the causal fungal agent and the early maturation of banana fruits. It forms part of a broad integrated protection strategy against Sigatoka diseases, which includes: cultivation practices favouring a high rate of foliar emission to compensate for the loss of leaf area due to the disease; a biological forecasting system to limit fungicide treatments.	Installation and maintenance in banana cropping systems of a cover crop of service plants to limit the contamination of plots by weeds, some of which are hosts to plant parasitic nematodes of banana. These service plants compete with weeds through their ability to quickly cover the soil and their allelopathic effects. Setting up of banana cropping systems on litter made from cover crop residues of service plants or various dead mulch (green waste, bagasse, etc.).	
		Biological tillage in the fallow phase using service plants with a deep and fasciculate root system (such as Brachiaria spp.). These plants improve the soil structure (porosity, structural stability).
	Weed control by brush cutter or rotary chopper using a light tractor equipped with low pressure tires.	
Establishment of a regional observatory for monitoring susceptibility to systemic fungicides used to control yellow Sigatoka and black leaf streak disease.		

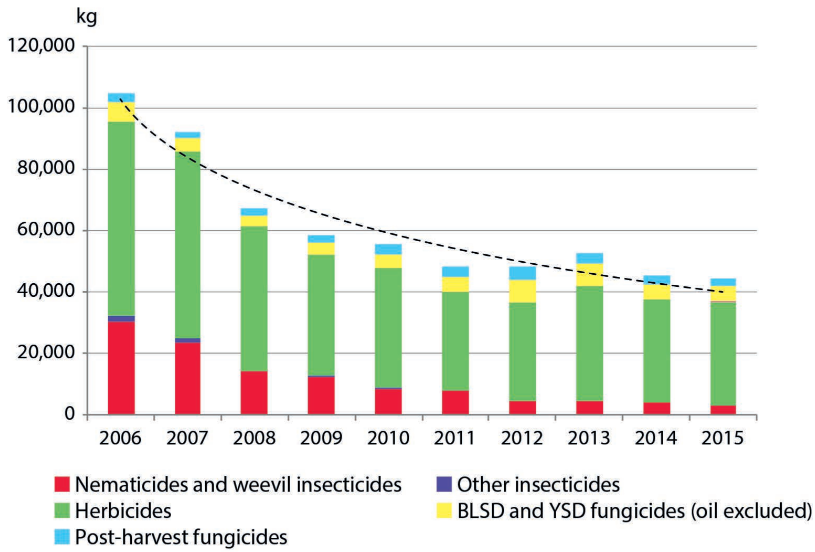

Figure 6.2. Changes in pesticide use as estimated by the quantity of active ingredients (QaI) in banana cropping systems in the French West Indies between 2006 and 2015.

practices, and increasing use of leaf pruning has so far helped to control them, despite the noticeable advent of the black leaf streak disease in the French West Indies (in 2010 in Martinique and in 2012 in Guadeloupe).

The adoption in banana cropping systems of cover crops based on service plants is gaining currency, but is not yet widespread. A joint investigation by CIRAD, the Tropical Technical Institute and the French West Indian banana producer groups is currently being carried out. The first results indicate that around 15% of the area under banana incorporate service plants, but that there is an ongoing process of real adoption, especially in larger farms.

Support by technical actors and public policies for innovation transfer processes

The agroecological transition, supported and strengthened by the 'Sustainable Banana' plan, has defined a trajectory of change and innovation that goes beyond merely technical aspects. Changes have also taken place at the organizational and partnership levels, by strengthening the skills of all the actors and creating spaces of coordination to build and disseminate innovations.

The building up of new capabilities

The creation of the Tropical Technical Institute

The Technical Institute for Banana (ITB) – today renamed as the Tropical Technical Institute (IT2) – was created in 2008 under the umbrella of CIRAD and professionals of the banana agri-chain in the West Indies as part of the 'Sustainable Banana' plan. This institute was created to strengthen the innovation capacities of the research community and producers, and ensure two functions: that of transfer, expected but still partly effected by researchers, and support for producer groups to help them scale up.

The Tropical Technical Institute is a privileged partner and link for researchers and producers in the agri-chain within the framework of the agroecological transition initiated in the banana cropping systems of the French West Indies. It has developed its own capacity to analyse the impacts of production, and has gradually expanded its activities towards the horticultural production sector as part of diversification. In this capacity, it is a member of the innovation and agricultural transfer (RITA) networks of the French Overseas Departments (DOM). With an administrative council and a scientific council, it works with an operational team of a dozen engineers in close proximity with the professionals of the banana agri-chain in the French West Indies, and has recently become a member of agricultural technical institutes and member of the network of technical institutes of the Association for Agricultural Technical Coordination (ACTA).

The launch of two collaborative innovation platforms

The agroecological transition in the banana systems of the French West Indies has also been backed by the launch and activities of two collaborative innovation platforms developed in the framework of the 'Sustainable Banana' plan: a platform for designing innovative banana cropping systems and a platform for breeding and selecting new banana varieties.

The platform dedicated to the design of innovative banana cropping systems is a space of sharing where different categories of actors involved in banana production in the French West Indies (researchers, producers, technical actors, groups, etc.) interact to develop cropping systems that are able to ensure the agroecological transition. Its mode of operation is shown in Figure 6.3. On behalf of an agronomic committee, the platform's actors define the framework of constraints of a model of sustainable banana production, the related specifications and a contract of objectives, based on which a co-design and assessment of innovative banana systems are carried out on the farms of pioneering producers. This platform has helped design banana systems based on multi-species and multifunctional cover crops of service plants. It relies on a toolbox developed by CIRAD researchers, which mainly consists of a collection of service plants, databases on the functional traits of these service plants and the associated ecosystem services, and models standardizing some of this knowledge (models of crop functioning, models of assessment of service plants, simulation and optimization models of cropping practices, etc.) (Dorel *et al.*, 2008; Tixier *et al.*, 2008; Tixier *et al.*, 2011; Ripoche *et al.*, 2012). This platform is also working on multicriteria assessment of innovative systems within the framework of a partnership between CIRAD and the Tropical Technical Institute. It thus benefits from the integration of knowledge and know-how originating from research on the functioning of innovating systems, and from expert knowledge from different disciplinary fields or originating from ecological engineering. In recent years, the actions of the platform for designing innovative banana cropping systems was strengthened by the creation of a dedicated unit to support the setting up of service plant cover crops, in which the Tropical Technical

Institute and CIRAD collaborate with the support of private entities for work on soil preparation, in order to provide assistance and technical solutions to producers willing to set up and manage their service plant cover crops.

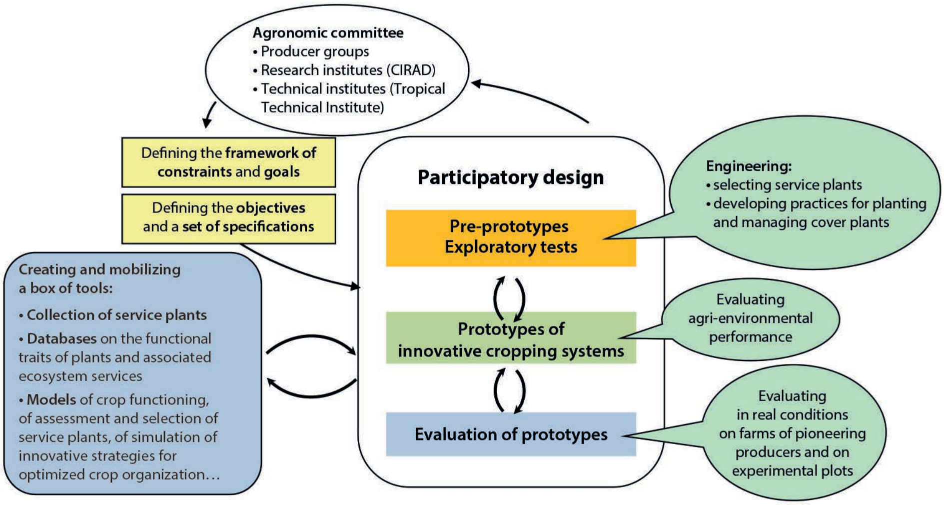

Figure 6.3. Organization of the collaborative platform of innovative banana cropping systems.

From the beginning, the platform for the breeding and the selection of new banana varieties has also functioned in a participatory manner in order to address the needs of producers and consumers. Its objective was to obtain varieties that are tolerant to pests and diseases, especially the black leaf streak disease, that are productive and adapted to the specificities of the French West Indian export agri-chain, and that meet post-harvest quality criteria. Although varietal improvement of banana is a long-term undertaking, it has been included, from the beginning, into the objectives of the 'Sustainable Banana' plan and of the implementation of the agroecological transition. Even though the time taken to develop new varieties is considerably longer than the fine-tuning of new technical itineraries, it was immediately admitted that new varieties would be necessary for the development of technical itineraries that use little or no pesticides. Therefore, acquiring proactive capacities (to be able to breed varieties that will be used in the future) and reflecting on the development of these varieties together in parallel with the development of new cropping systems appeared relevant in terms of tactical choices, improvement targets and speed of implementation. Mobilizing researchers from CIRAD who were specialized in banana breeding and selection, and engineers from the Tropical Technical Institute in charge of varietal development, the platform for the breeding and selection of new banana varieties helped, within the framework of the 'Sustainable Banana' plan, implement an original tool for fine-tuning new varieties (Figure 6.4). It was organized around CIRAD's collection of banana genetic resources (one of the largest in the world, hosted at the Tropical Plant Biological Resource Center of the French West Indies), a plot to crossbreed hybrids that is specially dedicated to the platform, selection plots in the open field in CIRAD's Neufchâteau (Guadeloupe) experimental station, as well as a network of assessment plots set up in the fields of pioneering producers. Structured around a breeding committee involving different actors, this platform has benefited from the inputs of different CIRAD laboratories in the French West Indies and in Montpellier (genetics, physiology, phytopathology, etc.), as well as of the post-production stages and UGPBAN's ripening facilities for pre-industrial testing in agri-chains of products originating from the platform. It has made it possible to optimize breeding strategies and considerably increase the number of hybrids produced annually (800 to 1000 in recent years as compared to just 400 in 2007). Several series of hybrids have been created, but without achieving all the qualities expected and defined in the specifications of the platform. Among these, one hybrid evinced special interest: the 'Cirad 925' hybrid. It exhibits a partial resistance to yellow Sigatoka disease and black leaf streak disease, has low susceptibility to the endoparasitic nematodes *Radopholus similis* and *Pratylenchus coffeae*, and produces good quality bunch structure with a rapid completion of the cycle. The taste of its fruits is comparable to that of the Cavendish banana. CIRAD, the Tropical Technical Institute and some pioneering producers made an attempt in 2015 to produce this variety on a significant scale (6 ha). The attempt failed as it was carried out based on a conventional technical itinerary suitable for the Cavendish. In addition, this variety proved to be much taller than the Cavendish, making it particularly difficult to undertake bunch management and harvest operations. Furthermore, several types of post-harvest limitations not conducive to marketing emerged: a susceptibility of the fruits to chilling injuries and peel splitting, a mismatch between the fruit's peel and pulp during the fruit's maturation, and a browning of the fruit epidermis after export. However, as we will note below, a new situation has emerged in recent years for this variety, with the lifting of the main remaining technical roadblocks.

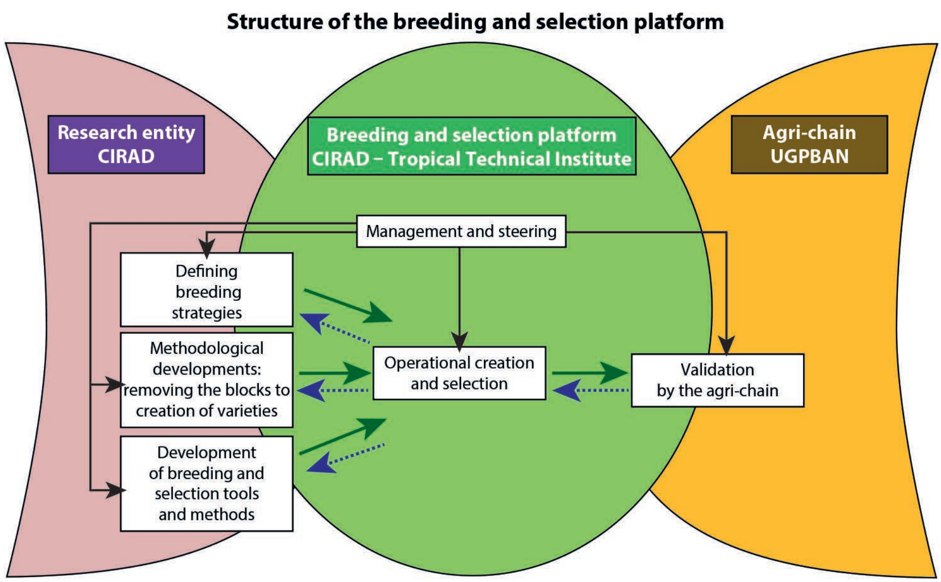

Figure 6.4. Functioning of the platform for the breeding and the selection of new banana varieties at the interface of research and the banana production agri-chain (UGPBAN).

The place of research in the agroecological transition

In addition to its role in the creation of the 'Sustainable Banana' plan and in the development of the two collaborative innovation platforms and the Tropical Technical Institute, CIRAD has been involved in its own advanced research activities, which could help drive the innovations of the 'Sustainable Banana' plan and also anticipate the fine-tuning of solutions allowing the agroecological transition currently under way to continue.

In order to promote ecological intensification through cropping practices, research was undertaken to understand the functioning of the banana agrosystem by focusing on the study of the biological mechanisms and processes involved. The roles of spatial organization of innovative cropping systems on banana pests and diseases were studied. The effects of plant diversity on the structuring, diversity and stability of food webs in banana cropping systems have also been the subject of research to better understand how biological control works (Carval *et al.*, 2016; Chauvin *et al.*, 2015; Mollot *et al.*, 2014; Poeydebat *et al.*, 2017a; Poeydebat *et al.*, 2017b; Poeydebat *et al.*, 2018). Various modelling approaches have been used to try to unravel the processes involved in biological control, and to test the effect of cover cropping practices.

New issues at the juncture of ecology and agronomy have been, and continue to be, addressed. Researchers have, for example, explored an approach based on the observation of the functional traits of plants (individual characteristics representative of the way the plants function) which helps explain the interactions between plants, the agroecological functions they ensure and the ecosystem services provided in banana agrosystems (Damour *et al.*, 2015; Tardy, 2015). This has enabled the determination of the functional profiles of plants that are part of the collection of service plants in the platform dedicated to the design of innovative banana cropping systems in the 'Sustainable Banana' plan (Damour *et al.*, 2016; Tardy *et al.*, 2017). These functional profiles have been matched with identified usage profiles as part of a participatory approach for designing cropping systems that involves producers and the Tropical Technical Institute. These profiles were used to define the spatio-temporal arrangement of service plants in prototypes of innovative cropping systems. This type of work has facilitated the design of innovative functional systems and helped draft practical recommendations concerning service plants (IT2, 2015).

However, researchers at CIRAD also solved new technical constraints encountered by the producers, as and when they deployed the proposed solutions. For example, the agronomists were able to adapt the technical itinerary for cultivating the Cirad 925 variety, thanks to a late selection method of successor suckers and an adaptation of desuckering (suppression of suckers) (Dorel *et al.*, 2016). In addition, a team of fruit physiologists and technologists joined the platform dedicated to the breeding and the selection of new banana varieties and addressed the post-harvest disorders affecting the Cirad 925 variety. The problem of chilling injuries was solved by setting the transport temperature at 15 °C (Bugaud *et al.*, 2016; Luyckx *et al.*, 2016a), that of peel splitting by a better control over the relative humidity in transportation cartons (perforation of polybags) and through the use of flow-packs (Brat *et al.*, 2016). As for the fruits' peel-pulp ripening mismatch, it was solved by reducing, as far as possible, the time interval between arrival in the storage warehouse and the ethylene treatment of the fruits (Luyckx *et al.*, 2016b). There remained the problem of fruit peel browning after export. New results based on non-chemical solutions have recently been obtained but have not yet been validated by tests in the supply chains. Research has also been conducted to determine the best deployment strategies for new varieties in order to limit the risk of future adaptation of pests and diseases to them. A simulation model to support the design of new methods for the control of black leaf streak disease has been developed (Landry *et al.*, 2017). At the same time, work on the phylogenetic organization of diversity, the understanding of the genome structure of banana plants, and the genetic determinism of traits of agronomic interest have also been conducted in support of varietal breeding (Baurens *et al.*, 2017; D'Hont *et al.*, 2012; Perrier *et al.*, 2011).

Support of public policies

Entities at the regional and national political levels were important actors in implementing the 'Sustainable Banana' plan. The decision of the French government and Europe to reduce pesticide use took several forms. The transition that began in the late 1990s and early 2000s was supported by the definition and implementation of various institutional tools such as the Agricultural Orientation Law (LOA) of 1999, the Departmental Agricultural Advisory Commissions (CDOA), and incentives such as territorial farm contracts, sustainable agriculture contracts, and agri-environmental measures, meant for producers to adopt more environmentally friendly practices and reduce dependence on synthetic pesticides. Subsequently, there was a steady increase in the eco-conditionality of public aid. Multi-stakeholder arenas, such as that of the regional group to study pollution caused by plant protection products, have emerged. At the same time, research and research-and-development efforts have allowed funding to be obtained from European structural Docup funds (Single Programming Document). In 2008, the launch of the 'Sustainable Banana' plan, with the consolidation of public aid allocated to the banana agri-chain in the French West Indies as part of Posei (Programme of options specifically relating to remoteness and insularity) and Odeadom, once again consolidated these orientations and was carried out mainly thanks to European (EAFRD), national and regional funds, with the support of the Martinique and Guadeloupe Regions.

Generic lessons learned from the experience and future steps

How to measure the success of the agroecological transition in banana production in the French West Indies? If we use as metric the reduction in the use of pesticides in recent years and the comparison of this level of use in the French West Indies with that in other production areas, the agroecological transition can said to be well underway. Similarly, if the metric is the level of involvement of producers and the governance structures of the Guadeloupe-Martinique Banana agri-chain, we observe a strong encouraging discourse and actions promoting a new way of production that reflect the profession's commitment to this agroecological path.

Some, however, believe that the 'Sustainable Banana' plan, and the agroecological transition associated with it, served as an opportunity for the agri-chain to bounce back following the chlordecone crisis by the maintenance of a high level of subsidies and the cornering of diverse types of aid available to remote French territories from various sources, which could possibly have deleterious results for some food products which can be produced locally, but which are imported into Guadeloupe and Martinique. The researchers' position leads us to avoid rejecting *a priori* these remarks and questions out of hand. This is why we conducted the analysis of the successes and failures of the 'Sustainable Banana' plan based on factual data and with a 'temporal' perspective on the trajectory of the agroecological transition, since this transition cannot be limited to the duration of a single development plan such as the 'Sustainable Banana' plan. We highlight here the steps we think need strengthening in order to consolidate this agroecological transition of banana production in Martinique and Guadeloupe.

The need for multi-criteria assessment of innovative banana cropping systems associated with the agroecological transition

The 'Sustainable Banana' plan has been the subject of regular assessments by various ministerial bodies and by funding entities in general, resulting in a systematic monitoring of the plan's activity. It appears, however, that the assessment of the agri-environmental and socio-economic performances of the new cropping systems created for the agroecological transition, and of their impacts, is also an essential process that needs strengthening. An assessment of this type must take into account the different scales of intervention (plot, farm, watershed, region, territory) and the perception of the actors. It requires the definition of appropriate tools (conceptual frameworks for studying relationships between cropping practices and their impacts, methods, indicators, models, etc.) (Feschet *et al.*, 2018; Lairez *et al.*, 2015). It must also be based on monitoring units for acquiring agri-environmental data (statements on use of external chemical inputs in soil and water, biodiversity, etc.) and socio-economic data (production costs, employment, arduousness of work, new occupations, etc.). In the French West Indies, there already exist such type of monitoring units, which have started compilation of environmental data in the context of projects financed by European funds (Rivage projects, ERDF funds, second phase of the 'Sustainable Banana' plan). They should be able to become clearly labelled reference locations of the agroecological transition that allow the environmental, economic and social value addition of this transition to be objectivized.

Regular reassessments of the framework of constraints to ensure a continued dynamic of agroecological innovations

The agroecological transition of banana production systems in the French West Indies is a phenomenon that spans a long period of time, and which consequently implies a regular reassessment of the framework of production constraints.

At the launch of the 'Sustainable Banana' plan in 2008, the black leaf streak disease had not yet arrived in the French West Indies. It is an air-borne fungal disease whose effects are more marked than those of yellow Sigatoka disease. It was first detected in Martinique in 2010, and in Guadeloupe in 2012. At about the same time, aerial sprayings of systemic fungicides, used in conjunction with the forecasting system, were banned in 2012 and 2013. These elements show to what extent the context can change rapidly (in its various legislative, technical, social dimensions, etc.) and why it is necessary to periodically reassess the framework of constraints of the agroecological transition. Indeed, it is a matter of ensuring the continued relevance of this transition's specifications. In the case of the Sigatoka leaf spot diseases (Yellow Sigatoka disease, YSD, and mainly Black Leaf Streak Disease, BLSD) in the French West Indies, the situation has acquired a marked urgency as new legislative restrictions on the only curative fungicides for a reasoned plant protection were announced to be implemented with very short notice (late 2018 to early 2019). This is forcing technical actors, producers and researchers to completely rethink reasoned control measures for Sigatoka leaf spot diseases by optimizing the techniques and organization of prophylactic deleafing methods, and by linking pre- and post-harvest operations in an integrated manner so as to reduce these diseases' effects and impacts. A new emphasis is thus being laid on the importance of mobilizing, in the short term, all the actors in the value chain (from producers to distributors), and on the relevance of promoting a banana variety that is resistant to black leaf streak disease (BLSD), which is compatible with export requirements and, even if it is unable to completely replace the Cavendish banana, one that could help to control the disease sustainably, especially in areas where the disease pressure is high.

The need for a broader framework for sharing objectives and deploying the agroecological transition

We have seen that there is still only a partial adoption of banana cropping systems based on service plants. The determinants for adopting these systems must be better understood in order to press for a more widespread agroecological conversion. This growth in its acceptance must include both a wider deployment of innovations to all producers, as well as to other actors not involved in production.

At a quantitative level, the modalities of a wider transfer of innovations and alternative solutions co-developed by the actors still need to be organized. This transfer must continue in a participatory and interactive manner between producers, researchers and technicians, supported by training in the use of the co-constructed innovations and by the disseminatory capacities of institutions. The two collaborative platforms, the Tropical Technical Institute, and the technical unit for providing support to growers for setting up service plant cover crops are all essential tools for achieving this goal. While an action plan that relied on the agri-chain and production actors appeared logical and the most likely to succeed, the broadening of the concept of sustainability to the entire agri-chain and the territories in which this plan is implemented becomes the new stage to be executed. From a qualitative point of view, in order to increase acceptance and adoption, it is necessary to move into new arenas of consultation between different actors (producers, groups, technical institutes, researchers, institutions, etc.), with a more prominent role accorded to civil society. It is in this way that the objectives of the agroecological transition will be jointly consolidated and therefore will be better shared. Downstream actors (post-production stakeholders) in the value chain, such as distributors and large and medium-sized retailers, must also be able to appropriate these objectives and participate in definition of the associated specifications, in order to help structure a multi-actor dynamic in space and in time, in line with the expectations of consumers, and to additionally ensure that these production approaches find their true value in new markets.

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Chapter 7

Development of agroecological horticultural systems in Réunion

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In Réunion, agriculture plays an important economic and social role, with a diversity of animal and plant production. The major crops are horticultural and sugarcane. The main pillars of Réunion's agriculture are defined in the Réunion Plan for Sustainable Development of Agriculture and Agri-Food (French acronym: PRAAD), with two main objectives: to ensure food self-sufficiency, specifically by increasing local fruit and vegetable production, and by developing agroecological cropping systems in this sector.

Pests and disease have continually blighted fruit and vegetable crops in Réunion and, from the 1980s, led to large-scale use of agrochemical protection. However, the limitations of this solution are now evident: reduced effectiveness, adverse effects on the environment, health risks, ecological imbalances. Over the past ten years, agroecological crop protection (ACP) techniques have been used on vegetable crops (Cucurbitaceae: chayote, courgette, pumpkin) and fruit crops (mango) (Deguine *et al.*, 2015, 2018). Agroecological crop protection is an ecological concept focusing on the sustainability of agroecosystems (Deguine *et al.*, 2017).

ACP brought together partners in the agricultural sector, placed producers at the centre of the project and took place before, during and after research and development projects (Gamour for Cucurbitaceae[1], Biophyto for mango[2]). This made it possible to compare the performance of conventional horticultural cropping systems (using agrochemicals) to those based on agroecological practices. The aim of this chapter is to present the results, examine the numerous encouraging trials and to draw generically applicable lessons from them.

1. Gamour: Agroecological management of vegetable flies in Réunion, http://gamour.cirad.fr/site.
2. www.agriculture-biodiversite-oi.org/Biophyto.

The drivers of the agroecological transition

The search for alternatives to conventional agriculture

In Réunion, the search for sustainable alternatives to conventional agriculture gained importance in the 2000s when the advantages of this approach became clear (ecological sustainability of agroecosystems, environmental and human health), though some reservations about the adoption of agroecological principles due to socio-economic factors remained. A sustainable agroecological approach was vital for Réunion's fruit and vegetable sectors, especially so for chayote and mango, which have high cultural and heritage value and are consumed locally in large quantities.

In the 2000s, significant drops in chayote production and alarming declines in cultivated acreages were observed, to the point that the disappearance of this emblematic crop seemed likely. Similarly, there were significant losses in courgette production, sometimes even total losses, leading to the decline in acreages devoted to this crop. For these crops, production was unable to meet local demand. The agronomic, phytosanitary and socio-economic deadlocks confronting these Cucurbitaceae crops thus accelerated the design and implementation of new agroecology-based farming systems. Faced with a succession of pests and diseases, mango producers have expressed their interest in agroecological production with a stated goal of improving brand image, and quality and economic performance of the agri-chain, in particular in order to access new markets (healthier products from organic farming, access to export markets).

Agroecosystems that are compatible with exceptional natural ecosystems

Another driver behind the development of agroecological production of horticultural crops is the desire to co-exist with the various outstanding natural ecosystems found on the island, such as the Marine Nature Reserve or the Réunion National Park, which is a UNESCO World Heritage site and is considered a global biodiversity hotspot.

Regulatory developments

The driving force behind the agroecological transition is a combination of actions, commitments and efforts by local agricultural stakeholders, ranging from the research community to public authorities. Regulatory developments have also accelerated the agroecological transition. Certain EU directives (e.g. 2009/128/EC) have played a significant role, both in reducing the number of speciality plant protection products that can be used and, in general, by providing crop protection guidelines. Similarly, in 2007, the French *Grenelle de l'environnement* led to the creation of the national Ecophyto plan (2008-2018), which aimed to halve the use of chemical pesticides; the 2012 agroecological project for France advocated the transition to new agroecological production systems and encouraged 'different ways of teaching' in the agricultural world; and the Law on the Future of Agriculture, Food and Forestry, adopted in 2014, strongly encouraged farmers to work together in economic and environmental interest groups.

Agroecological practices implemented

Agroecological crop protection (ACP) and its implementation on the field

The aim of this approach is to promote ecological processes by optimizing interactions between animal and plant communities and by promoting soil health. This reduces the risks of pest infestation, infection and disease outbreaks. Biodiversity and soil health are the two mainstays of agroecological crop protection. The implementation of ACP is based on three pillars: preventive measures, which are always preferred, biological pest control through conservation biological control, and habitat (and inhabitant) management via cropping and agronomic practices.

Agroecological crop protection relies on a systemic approach, incorporating larger scales of space and time, given the aboveground dispersal capabilities and survivability in the soil of certain pests and diseases. Management strategies have to look beyond the local scale and specific crop management sequences and have to be implemented at the farm or landscape level, which requires coordination between stakeholders (collective management). In addition, all stakeholders must be included in a participatory approach: farmers, of course, but also land managers, policymakers, researchers and others (experimentation, extension, training, transfer).

Application on the field involves a methodical strategy of phytosanitary and agronomic practices to manage populations of pests and their natural enemies (Deguine *et al.*, 2017). The three main priorities of this approach are to:
– promote plant biodiversity;
– promote soil health;
– prioritize biological pest control through conservation biological control.

Agroecological practices implemented in Réunion

Practices implemented in Réunion are chronologically summarized in Table 7.1 (Deguine *et al.*, 2017).

The results of these trials, after several years of decline, are very encouraging. They are rich in lessons and have clear generic interest. The main results obtained from the Gamour and Biophyto research and development projects are presented in detail in Deguine *et al.* (2015, 2018) and are summarized below.

The reduction or elimination of insecticide and herbicide treatments has led to socio-economic changes[3]:
– for courgette: conventional cultivation using a pyrethroid-organophosphorus combination (several hundred grams per hectare of crop) replaced by agroecological protection consisting of a few grams of a biological insecticide on border plants;
– for chayote: the use of insecticides and herbicides completely eliminated in agroecological cultivation;

3. The farmer no longer has to spend as much time on pest control, allowing him to undertake other more enjoyable and/or useful activities.

Table 7.1. A methodical phytosanitary strategy for agroecological crop protection, adopted in the experiments on Cucurbitaceae and mango in Réunion.

Recommended agroecological practice(1)	Vegetable crops (Cucurbitaceae)		Fruit crops
	Chayote	Courgette	Mango
Discontinuation of conventional insecticide treatments	Yes	Yes	Yes
Discontinuation of herbicide treatments	Yes	Yes	Yes
Sanitation (augmentorium)	Yes	Yes	Yes
Permanent vegetal cover	Yes	No	Yes
Trap plants	No	Yes	Yes
Flower strips	No	No	Yes
Refuge plants	No	No	Yes
Reduction of mineral fertilization	Yes	No	No
Organic amendments	Yes	Yes	Yes
Traps	Yes	Yes	Yes
Use of adulticide baits	No	Yes	Yes
Curative measures(2)	No	No	No

Chayote and courgette are considered separately (with other field crops such as pumpkin and cucumber being clubbed with courgette) since chayote is grown on arbours and can be managed as a perennial crop. Courgette, on the other hand, is a field vegetable with a short cycle. In the table, 'Yes' means that the practice is recommended and 'No' that the practice is not recommended.
(1) Observation has to be a key aspect in the implementation of any of these practices. It must remain an ongoing and continuous activity.
(2) In these curative measures, the use of chemical pesticides is considered to be a last resort and they must be used in an optimized and targeted way, with as little impact as possible so as not to jeopardize biological controls.

– for mango: a decrease in the treatment frequency index (TFI) from 22.4 before the Biophyto project to 0.3 by the end of the project (Figure 7.1).

Furthermore, costs have dropped significantly: 75% savings in protection costs for courgette (Table 7.2) and chayote, and a 35% reduction in mango production costs.

Finally, according to the measurements carried out in the research and development projects, production did not decrease on the whole. Indeed, agroecological cultivation of Cucurbitaceae led to increases in production. As part of the Gamour project, over 26 courgette cropping cycles, production increased from 13.1 t/ha on agrochemical plots to 19.3 t/ha on agroecological plots (+47%). On 7.6 ha of chayote cultivated on arbours in Salazie between 2007 and 2011, annual production increased by 48% (Figure 7.2).

For mango, observations showed equivalent yields between conventional plots and Biophyto plots using agroecological protection (Gloanec *et al.*, 2016). Lower yields, while not significant, were observed in a few cases, mainly in areas susceptible to gall midge, especially in plots with high production potential ('Cogshall' variety which permits significant intensification). Certain organic-compatible fungicides for powdery mildew were not always applied because the prevalence of this disease was often underestimated. This may have contributed to production losses.

Table 7.2. Comparison of costs and labour time of protection between agrochemical protection and agroecological protection for courgette cultivation. Source: farmers' statements in the Gamour project area (adapted from Deguine *et al.*, 2015).

Protection	Criterion	Agrochemical protection	Agroecological protection
Characteristics	Number of insecticide applications	1.5	1
	Commercial products	Cyperfor-Danadim	Synéis-appât®
	Active substances	Cypermethrin-dimethoate	Spinosad
	Quantity of active substance applied (g/ha/treatment)	45 + 450	0.008
	Application location	Entire crop	Spot application on border plants
Labour time	Collection of damaged fruit (h/ha/week)	0	2 at the beginning and 0.25 after some weeks
	Treatment (h/ha/week)	4.5	1
	Setting traps (h/ha/3 months)	0	1
	Planting trap plants (h/cycle)	0	10
	Total time spent on protection (h/week)	4.5	4.1
Cost (€)	Per week	66	18
	Per cycle	1320	370

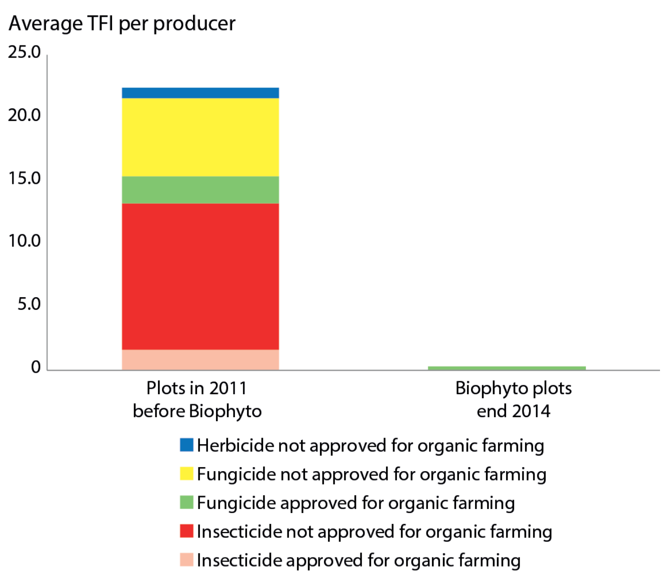

Figure 7.1. Treatment frequency index (TFI) before and after the Biophyto project.
Averages of five Biophyto farms in the Dephy mango Ecophyto network (Réunion Chamber of Agriculture, 2015), taking into account approved and unapproved organic treatments (adapted from Deguine *et al.*, 2017).

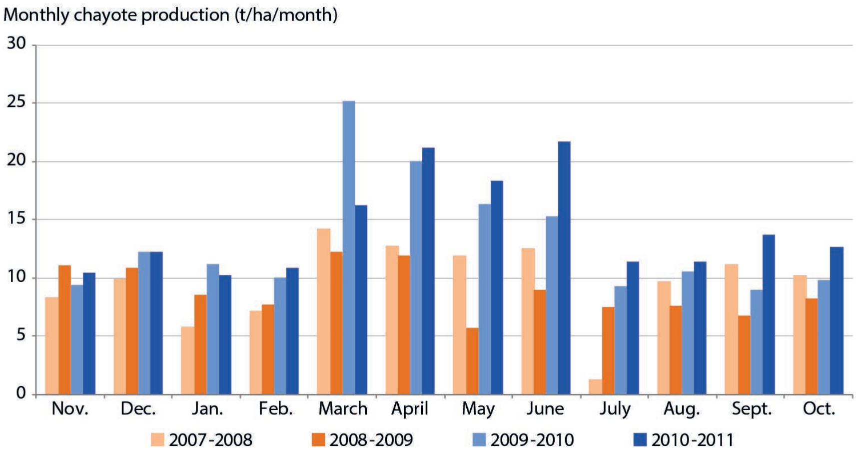

Figure 7.2. Monthly chayote production on a Salazie farm of 7.6 ha, in 2007 and 2008 (in orange, before the Gamour project, with agrochemical protection), and in 2009 and 2010 (in blue, during the Gamour project, with agroecological protection) (adapted from Deguine *et al.*, 2015).

Large reductions in insecticides and herbicides have had beneficial effects on both flora and fauna. In addition, it can be assumed that the treatments had a favourable impact on water quality and human health although these were not explicitly measured.

In addition, the ecology of these agroecosystems has improved, as observed in an increase in functional biodiversity. Vegetable and fruit crop experiments have made the general public (and farmers in particular), more aware of the role of biodiversity in farming. In-depth studies on mango orchards have generated new data. For instance, more than 120,000 arthropods were collected from orchards and nearly 800 morpho-species[4] were identified. Of these, only a few species can be considered as harmful to mango, while there were nearly 200 morpho-species of parasitoids. Furthermore, according to farmers, the discontinuation of the use of agrochemicals in chayote cultivation has brought about an increase in the number of natural pest enemies, such as arthropods (spiders) and reptiles (chameleons). In the Gamour project's pilot area in Petite-Île, farmers mentioned that bees had returned to their courgette fields.

Technical accompaniment and support through public policies

Adoption of practices, productions in transition

On the whole, the pilot farmers involved in the Gamour and Biophyto research and development projects adopted agroecological practices and expressed great satisfaction, in particular because these practices proved to be more effective and less expensive than conventional ones.

The impact on the market of the growth of agroecological production is already clear for certain crops (60% of the chayote production was organic in 2017 and prices paid

4. Morpho-species are species distinguished from others only by their morphology.

to producers have increased) and will soon be for others (there has been an increase in the number of mango farmers who have joined economic or environmental interest groups and who have embraced organic farming). For the mango, the possibility of obtaining a higher market price was analysed in the Biophyto project through a market survey of 400 consumers and a survey of the production chain (from the farmer to the distributor). These surveys have not only highlighted the commercial potential of mangos produced using Biophyto techniques, but also made it possible to determine the best ways of marketing them and of deriving value from them (Técher *et al.*, 2015). It was found that affixing a small sticker to each fruit (saying, for example, 'I protect biodiversity' or 'I protect my island') makes more sense and is more locally relevant than a certification label (e.g. 'Agroecological Mango'). Moreover, the increase in organic mango production expected in the future should make it possible to target the export market in addition to the local market. Importers in the Rungis market, the wholesale market supplying Paris, have already expressed interest.

After the Gamour and Biophyto projects ended, the challenge was taken up by the agricultural organizations including producer associations and the island's Chamber of Agriculture. They have found support from public authorities in the promotion and dissemination of agroecological practices and the expansion of organic farming.

Adoption of agroecological practices by other farmers after the end of the projects varied depending on the crop. The adoption rate was very high for chayote and is currently increasing satisfactorily for mango. However, it is less satisfactory for open-field Cucurbitaceae (courgette, pumpkin, cucumber). Good and low levels of adoption have provided lessons for future production trials.

Complementary partners and an exemplary organization

Faced with an agrochemical deadlock, the entire agricultural profession, including producers and policymakers, were amenable to the idea of joining forces in order to pursue agroecological solutions. The profession expressed a wish to test the principles of agroecological protection in a farm environment, reflecting their common desire for a change in practices.

The design, implementation and evaluation of these agroecology trials, as well as the transfer phase, proceeded very smoothly:
– the research community (CIRAD) launched this initiative and coordinated the implementation on the ground of research and development projects;
– Réunion's Chamber of Agriculture provided the technical coordination between the various partners;
– the organizations involved in experiments on crop protection and in providing support (Armeflhor technical institute, FDGDON federation[5]) offered their expertise to the project;
– development agencies and public authorities were instrumental in the transfer of innovations.

5. Armeflhor: Réunion Association for the modernization of the fruit, vegetable and horticultural economy; FDGDON: Departmental Federation of Pest Control Groups in Réunion.

The territory of Réunion is fortunate in being host to an exemplary partnership that has facilitated the agroecological transition. Promoting agroecology is one of PRAAD's six strategic axes. Applied to fruit and vegetable systems, this initiative is being steered within the horticultural Network for Agricultural Innovation and Transfer (French acronym: RITA) created in Réunion to facilitate the transfer of research results to users. Alongside the RITA horticultural network is the SPAT joint technology unit (Plant Health and Agroecological Production in Tropical Areas), which, in Réunion, brings together CIRAD, ANSES (French Agency for Food, Environmental and Occupational Health and Safety), Armeflhor and FDGDON. It aims to impart coherence and synergy to the research and experimentation activities of the organizations involved in or concerned by the agroecological production of horticultural crops. Finally, at the economic level, the relationships between partners working towards agroecology were facilitated by the creation of a fruit and vegetable hub, bringing together Arifel and AROPFL[6].

An orderly and collective approach

The collective and participatory approach involved in the agroecology experiments in Réunion was based on an orderly methodology. The approach was applied at large spatial scales, for example the 'cirque de Salazie', historical production area of the chayote in Réunion, the area of Hauts de Petite-Île known for the open-field cultivation of Cucurbitaceae, or the Saint-Gilles region, the island's main mango production basin. In addition, the trials took place in several coherent temporal phases (Table 7.3):

– a first phase for the collective sharing of the findings and for taking stock of the situation, as well as for co-designing, research and for obtaining funding for a partnership research and development project;

– a second phase, in the form of a partnership research and development project for on-field implementation by the producers of the proposed agroecological practices, with close monitoring by the other agricultural actors;

– a third phase, consisting of the transfer of practices to other producers on the island and the rollout of incentivizing public policies to support the agroecological production of crops.

In parallel with these phases, research was carried out on a continuous basis in order to provide the necessary knowledge for actions in the field: bioecology of pests and diseases, functional biodiversity, ecological and agronomic processes in cropping systems, development and efficiency of agroecological practices, etc. These research activities, consisting of description and understanding of processes and of providing management assistance, were undertaken simultaneously and interactively, so that each activity could benefit as quickly as possible from the results of other activities. In a similar manner, iterative exchanges between research activities and field practices of partners and practitioners helped improve the efficiency of research and accelerated its application.

6. Arifel: Réunion Interprofessional Association of Fruits and Vegetables; AROPFL: Réunionese Association of Fruit and Vegetable Producer Organizations.

Table 7.3. Different phases of experiments of agroecological crop protection in Réunion.

Phases	Stage, content, activities	Vegetable crops (Cucurbitaceae)	Fruit crops (mango)
1. Before the research and development project	Collective sharing of the diagnosis and taking stock of the situation	2007-2008	2010-2011
	Co-design of a research and development project		
	Search for funding for a research and development project (Special Accounts Allocated to Agricultural and Rural Development or Casdar, Ministry of Agriculture, Food and Forestry)		
	Research activities (cognitive and integrative)		
2. During the research and development project	Implementation of practices on the field by farmers	2009-2011 (Gamour)	2012-2015 (Biophyto)
	Monitoring and assessment in partnership		
	Final report and perspectives (seminar)		
	Research activities (cognitive and integrative)		
3. After the research and development project	Training, advice, and support for the transfer	Since 2011	Since 2015
	Support for extension by public policies and instruments		
	Research activities (cognitive and integrative)		

Tools to help transfer and disseminate practices

Several tools to support the transfer of practices and facilitate actions on the ground of development organizations (Chamber of Agriculture, professional organizations) were developed: technical guides and DVDs, audio-visual media, identification sheets (plant bugs, fruit and vegetable flies, crop beneficials), websites, newsletter, PQUC/ACP professional qualification university certificate, proceedings of the Gamour and Biophyto project seminars, posters, etc.

When the Gamour and Biophyto projects ended, a diploma course was made available starting in 2013 for the benefit of farmers and farm support workers. Thus, a professional qualification university certificate (PQUC), entitled 'Agroecological crop protection', issued by the University of Réunion, co-organized by the University Institute of Technology and by the Chamber of Agriculture, is now offered by different partners (CIRAD, Armeflhor, FDGDON, Chamber of Agriculture), requiring 42 hours of learning spread over six days. The training has been organized every year since 2013 and already more than 80 farmers have benefited from it. Graduates then play the role of leaders on the ground and help transfer agroecological practices to their colleagues.

Instruments of the Ecophyto Plan

Several levers of transfer were created as part of the national Ecophyto Plan. Agroecological crop protection practices are all the more effective if they are planned and implemented at the scale of a production basin. In this perspective, two collective projects have been recognized by the public authorities. They have taken the form of two economic and environmental interest groups: the first was created in 2016 in the mango production basin in Saint-Gilles; the second in 2017 in the Salazie chayote production basin. These groups provide technical and financial aid to farmers in these areas, so that they act with a collective agroecological purpose.

Dephy Farm Networks[7], another instrument of the Ecophyto Plan, facilitate the transfer of innovations. In 2015, a Dephy network of mango farms was created. The treatment frequency indices for all the farms in the network decreased considerably (-43% from 2012 to 2015). In 2016, the network consisted of 14 farms.

Also concerning the mango, the Biophyto project led to the creation in 2015 of two agri-environmental and climate measures (AECM) to encourage producers to engage in the agroecological protection of fruit crops: Lbio 1, aiming at the insertion of biodiversity in orchards, and Couver 2, encouraging vegetal cover of perennial crops. Producers can now benefit from an annual compensatory aid of 880 €/ha or 700 €/ha depending on the AEMC they have signed up for, with a commitment period of five years. To qualify, orchards must have a total vegetal cover and a permanent layout of flowering strips with a minimum area of 500 m^2 for every hectare of the orchard (5%). These agri-environmental and climatic measures contribute to the popularization of agroecological practices, not only in the island's mango orchards, but also in other fruit production systems (citrus fruits, papayas, bananas, etc.).

Promotion of and support for organic farming

The Gamour and Biophyto projects have shown that agroecological crop protection practices are compatible with organic farming. Thus, not only has the cultivation of the chayote been revived in its historical stronghold of the 'cirque de Salazie', but the organic production of this vegetable has increased considerably, too. Similarly, for the mango, agroecological practices are compatible with orchard management in organic farming: the fungicides used (to control powdery mildew) comply with the corresponding specifications. No mineral fertilization is used.

While the context and public policies encourage the development of organic farming, unexpected socio-economic reasons have also contributed to its growth. Agroecological practices, which are less expensive, have thus brought about a simplification when compared to conventional practices: discontinuation of insecticide and herbicide treatments; sanitation through the use of augmentoria; planting and maintenance of ground vegetal cover; and the recourse to organic amendments. They improve soil health and increase biodiversity at the same time.

In addition, the transfer to farmers of these agroecological systems has been supported by the government and facilitated by development partners. For example, the Chamber of Agriculture provided significant logistical and human support: an individual was responsible for implementing agroecological systems in vegetable systems, a second in charge of the promotion of organic farming, and a third responsible for ensuring the 'research-development-transfer' continuum and feedback within the framework of the Ecophyto Plan.

7. Networks of trial farms for the demonstration, experimentation and production of references on the systems that are economical in the use of plant protection products.

In addition to investment aid, financial incentives have been offered to producers. For the chayote, compensatory aid (complementary to agri-environmental and climatic measures) makes it possible to cover the certification costs and any possible loss of production resulting from the transition to organic farming:
– aid for conversion to organic farming (from 1800 to 2700 €/ha/year during three years of conversion);
– maintenance aid (from 900 to 1800 €/ha/year).

In addition, assistance from the Programme of Options Specifically Relating to Remoteness and Insularity (POSEI) are incentives for some agri-chains, such as that of the chayote, to structure themselves. This aid is provided on the basis of marketed volume (0.50 €/kg).

The results of the agroecology trial on the chayote in Réunion had a strong impact on the development of organic farming on the island. The increase in the production of organic mango has benefited from this dynamic and the results of the Biophyto project. In 2015, the chayote represented 97% of the volume of all organically grown vegetables marketed in Réunion. In 2017, more than 60% of chayote cultivation (by area) was certified as organic. Half of the remaining areas are in the process of converting to organic farming. Today, Réunion is the overseas department of France with the biggest organic sector.

Lessons learnt from agroecology trials in Réunion

The trials on agroecological crop protection in Réunion were pioneering at the national level and they were conducted on a large scale in a production environment. We recall that even though Réunion is one of the overseas departments of France, it has specific local characteristics: physical (insularity), climatic (tropical climate), agricultural (sugarcane, horticultural crops), institutional, and organizational. Agricultural actors on the island are directly supported by the Regional Council, the Departmental Council, the French State, European agencies and institutions, and they enjoy close support from partners and technical services (the research community; technical institute; FDGDON; ANSES; Chamber of Agriculture; Department of Agriculture, Food and Forests; etc.).

In spite of Réunion's specific context, the results obtained there and lessons learnt from them are of great generic interest for the design and implementation of future agroecological experiments in other contexts.

How to conduct agroecology trials in production environments?

The trials in Réunion allow us make a non-exhaustive list of the conditions that are necessary – but not sufficient – for conducting large-scale agroecology experiments:
– raising awareness of and motivating agricultural actors, starting with the farmers. In Réunion, this was achieved through the action of many technical partners, each with its own means and tools;
– a phytosanitary problem of concern or interest to many actors, either because it leads to a socio-economic or environmental impasse, or because it makes it possible to take a significant step towards the adoption of agroecological practices and to access new and key markets;

– research capabilities, which will make it possible to change the scope and topics of research, with the aim of acquiring and better integrating new scientific knowledge. The studies undertaken in Réunion revealed, for example, the need to acquire knowledge in the fields of landscape ecology, organic farming, functional biodiversity (aboveground and soil), etc.;
– a synergy between research and development, in order to bring together the various partners' complementary activities in a coherent way (research, experimentation, training, teaching, advice, transfer/dissemination);
– a unifying research and development project in partnership, whose preparation and smooth running require several conditions and activities (a collective taking stock of the situation, the co-design of the programmes to be implemented, the coordination of actions by an agency in charge of transfer/dissemination);
– the adoption of a systemic and participatory approach, at appropriate spatial and temporal scales and according to updated criteria, taking into account, for example, the ecological sustainability of agroecosystems;
– support by public authorities, before and during the agroecological transition period.

The determinants of the adoption of agroecological practices

The detailed analysis of the determinants of the adoption of agroecological protection innovations in Réunion is the subject of an ongoing study. We list here the main lessons learnt. It should be remembered that the adoption of agroecological protection practices for crops in the production environment can be described as good for the chayote and the mango, but only mediocre for Cucurbitaceae cultivated in open fields.

It is easier to adopt a strategy of 'investing' in agroecological practices in the case of perennial crop systems. Mango producers are motivated to adopt agroecological practices such as sanitation or permanent vegetal cover. So are chayote producers – when the chayote is cultivated in arbours and thus can be considered a perennial crop. We know that these practices are more effective, but over a time scale that is longer than the simple annual crop cycle. Producers of courgettes lack this motivation since they choose to plant a plot of this crop on the basis of very short-term reasoning (market price). Indeed, the location of the plot planted with this crop may change from one cycle to the next, and the state of health of the planted plot depends on the health status of the other neighbouring courgette plots.

When agroecological practices simplify the technical itinerary (discontinuation of insecticide and herbicide treatments), they are more readily adopted. This is the case for the chayote and the mango. Conversely, courgette cultivation is more demanding (anticipation, regular monitoring, planting of trap plants [maize borders] one month before the courgette planting) and it is thus difficult to plan or carry out additional treatments with adulticidal baits (consisting of 99.9% protein and 0.01% biological insecticide).

In addition, the typology of farmers appears to be a factor in the adoption of innovations. The producers of chayotes and mangos are clustered in production basins. They know each other and have regular exchanges and discussions. Agriculture is their core activity and they receive regular training. They are open to the idea of collective management in the production basins (as is the case in economic and environmental interest groups) and have an ultimate aim of ecological and healthy production. Courgette producers, for their part, have a completely different profile. There are nearly 2000 of them in Réunion and, for many, agriculture is just one of their activities. These producers are quick to take advantage of changes in context (weather, market prices, timetable, etc.), with the aim of making quick profits from a crop cycle, using predictable and conventional means. These producers are often isolated and communicate little with each other and are less trained in agroecology and less open to it.

Finally, three other factors help to explain the differences in the levels of adoption between the chayote and the mango, on the one hand, and the courgette, on the other:
– the market. The chayote and the mango are consumed in large quantities domestically. Their cultivation is profitable and adopting agroecological practices, often compatible with organic farming, provides access to new, more profitable markets (short circuits, organic farming, exports). This is not the case for the courgette, whose cultivation depends above all on the market price. From one year to the next, or from one quarter to the next, depending on respective market prices, the growers may plant carrots or lettuce instead;
– the heritage value. The chayote and the mango are traditional crops, whose production is consumed daily (all year for the chayote, during the production season for mango). This is not the case with the courgette;
– the incentive to shift to organic farming. Policies that support organic farming have proven their effectiveness for the chayote. The production of this crop is expected to become 100% organic, whereas just ten years ago, the vines received insecticide treatments once or twice a week.

Publicising and communicating about agroecological practices in Réunion

The development of agroecological cropping systems is being publicised as part of a film- and multimedia-based action-research programme, led by CIRAD (PVBMT joint research unit) and the University of Aix-Marseille (Laboratory of Arts Sciences Studies). This programme aims to describe, share, understand and contribute to the implementation of interdisciplinary research activities on agroecological crop protection practices in Réunion. It is situated at the interface of the ecological and agronomic sciences, social sciences and film sciences. Various audio-visual aids are being used in this innovative approach: short films, training or awareness-raising modules, television documentaries, web documentaries, etc. These media are intended for different audiences (general public, agricultural actors), thus helping to promote agroecology and to encourage societal reflections on agricultural practices in the 21st century.

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Chapter 8

Accompanying the agroecological transition of agroforestry systems in Central America

Bruno Rapidel, Jean-François Le Coq, Elias de Melo, Jacques Avelino, Sandrine Freguin-Gresh

Since its introduction and development in the 20th century, coffee production has not only become an essential source of stability of the balance of trade of some Central American countries (Nicaragua, Honduras), but has also grown into a cultural identity (Tulet, 2008) and a means to project power (Demyk, 2007).

While production methods vary from one country to another, much of the production originates from small producers. In general, coffee is grown on steep slopes and the labour required for manual harvesting results in significant seasonal migratory flows between countries, especially from Nicaragua (Baumeister *et al.*, 2008).

The coffee sector's institutional structures also exhibit diversity, ranging from coffee institutes, either representing the entire national chain (e.g. Icafe in Costa Rica) or only the producers (e.g. Anacafé in Guatemala), to weaker governance structures, as in Nicaragua.

The levels of State intervention and support also differ across countries. Nevertheless, some general trends can be observed: a general simplification of cropping systems, transitioning away from complex agroforestry systems that are not very intensive (in capital, in labour), which is still largely the case in Nicaragua, to systems combining fewer plant species and managed in an intensive way, as in Costa Rica or Guatemala (Jha *et al.*, 2014); and high sensitivity to world coffee prices which, in these perennial systems, is manifested primarily through modifications in cropping practices and, in the medium term, by a gradual decrease in cultivated acreages in favour of other agricultural products selected on the basis of location, farmers' strategies and opportunity costs of farmland and labour.

This chapter aims to analyse how the agronomic research carried out in Central America within the framework of a Research and Training Platform in Parnership (PCP AFS-CP) created in 2007 by CIRAD, CATIE (*Centro Agronómico Tropical de Investigación y Enseñanza*, a research, education and development organization) and their regional and international partners, supports Central American coffee cultivation in the context of current challenges facing the sector and, in particular, those of the agroecological transition.

The constraints and opportunities of coffee cultivation systems

Arabica coffee (*Coffea arabica*) is an indigenous plant from the dry forests of the highlands of the Horn of Africa, which is therefore adapted to certain conditions of altitude and forest shading. However, this species can be cultivated under the full sun, and since its expansion in Central America in the mid-19th century, coffee cultivation systems have evolved in a wide range of conditions, from cultivation under forest trees or planted trees to monoculture systems under full sun (Samper, 1999). These changes in farming practices have been encouraged by public policies, especially between the 1940s and 1960s, that supported the development of large plantations owned by political and economic elites and foreign investors (Italians, Germans, North Americans, Britons, etc.), who set up small planters at the same time to assure themselves of the crucial labour force required for their own plantations. Today, coffee production in Central America has essentially passed into the hands of these small and medium producers.

Coffee cultivation is subjected to various kinds of pressures (Figure 8.1). Two of them, arising from external conditions are important determinants of technical choices: international prices and climate change. These conditions affect the decisions on the major aspects of coffee plantation management. While these plantations are recognized as biodiversity havens, they also represent points of tension given the desire to decrease the use of pest control products. More generally, their sustainability – environmental, social and economic – is subject to controversy. The research activities we undertook on these issues, their interconnections and their relationships to the design of agroforestry systems are shown in Figure 8.1.

Since 1998, the international price of coffee has fallen steadily, well below production costs in Central America (Figure 8.2). However, options for reducing production costs remain limited: in particular, mechanization is difficult because of the topography, with plantations generally located in steep, mountainous areas, and manual labour used for harvesting continues to be the main expenditure head. Strategies were adopted between the mid-1990s (first price crisis) and the early 2000s (second crisis), based on the recognition of the extrinsic production quality (related to production conditions, social as well as environmental, giving a significant impetus to agroecology) and the intrinsic quality (cup quality).

The long coffee price crisis only came to an end in the late 2000s, with prices peaking in 2011. However, the increase in prices paid to producers led to contradictory effects on the adoption of practices encouraged by certification labels: the economic focus was then put on the quantity of production rather than on its intrinsic or extrinsic quality. Thus, the average premium obtained by coffee originating from Costa Rica (linked to the general reputation of this area of production in the global market), as well as the minimum price guaranteed in the context of Fairtrade, can be compared to the evolution of price (Figure 8.2). It is understandable that, at the turn of the decade, producers intending to recapitalize after nearly a decade of very low prices sought to maximize their production without any restriction on their cropping systems. However, prices have been less favourable since 2012, and strategies for promoting coffee quality are once again gaining importance.

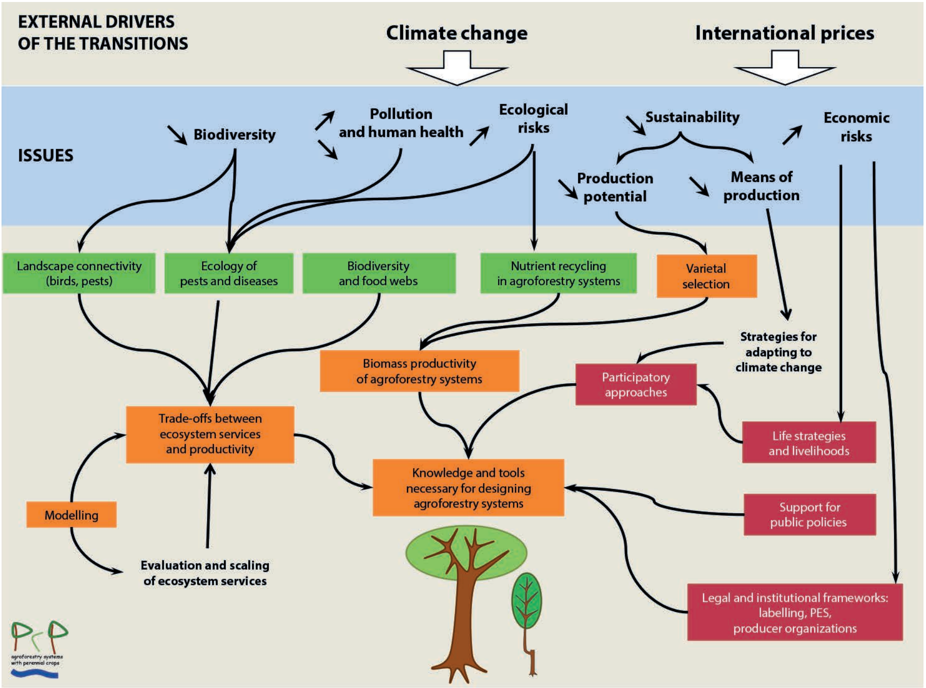

Figure 8.1. The multidisciplinary scientific approaches of PCP AFS-CP for supporting the transition of coffee-based agroforestry systems.

The research activities described are indicated according to the possible dominant disciplinary fields: ecology (green frames), agronomy (brown frames) and sociology and economy (red frames).

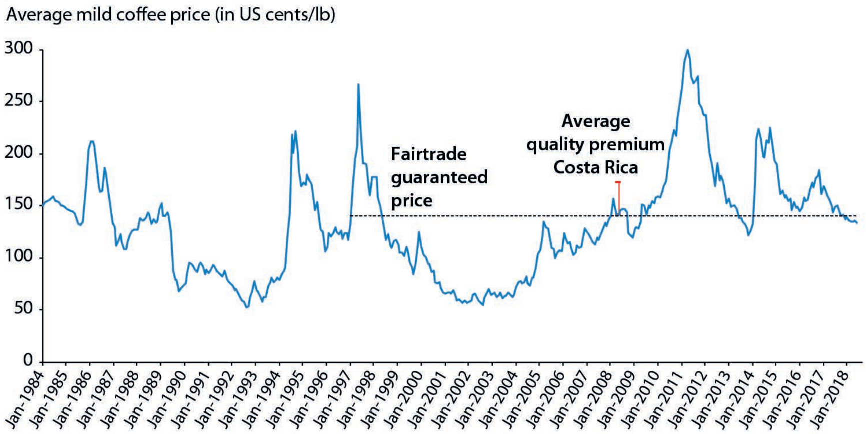

Figure 8.2. Evolution of the coffee price on the New York Stock Exchange (ICO) (Sources: www.ico.org, www.fairtrade.net, icafe.cr).

Climate change is another source of tension: Central America mainly produces Arabica coffee, and these coffee plants are sensitive to temperature. The expected rise in temperatures could render production areas at low altitudes unsuitable for production, decreasing the overall land available to cultivate this crop, thus increasing pressure on protected areas (Jha *et al.*, 2014). These changes translate into increased pest and disease pressures, for example the recent epidemic of coffee leaf rust, which is partly linked to climate change (Avelino *et al.*, 2015). Agroecology, and in particular the introduction of shade trees in plantations, is seen as a way of mitigating these changes by moderating diurnal temperature variations of coffee leaves.

To these external tensions are added internal changes. Natural resources are degrading, especially water (chemical and organic pollution attributed to the use of agrochemical products, dumping of crop residues and release of water used in coffee processing) and soil (erosion, landslides, loss of topsoil that is used by crops, soil compaction, etc.). Trees disappear from the landscape, either because of deforestation or due to felling in agricultural plots during a change of land use and/or a change of coffee variety, or even because of a change in shade management. These developments are not new, but their negative effects are increasingly being felt by urban and rural populations, while local environmental protection organizations are progressively gaining in influence. In addition, there are socio-economic difficulties, in particular, poverty amongst many producers, sometimes associated with food insecurity, aggravated by coffee price fluctuations and pest control problems, which restrict productive investment.

The research strategies in response to these pressures and developments are also schematically depicted in Figure 8.1, and have mobilized various disciplines.

The contribution of research to promote the agroecological transition of coffee cultivation systems

Technical solutions for the provision of ecosystem services

Coffee plantations in Central American cover over a million hectares, with a high diversity of production systems, ranging from plantations under full sun that have applied all the recommendations of conventional intensification advocated by the Green Revolution to agroforests with low levels of management and low productivity. With a goal of promoting the ecosystem services that these systems can provide to society, recommendations have been made to improve them that are in line with the two principal paths of agroecology (Griffon, 2013): a path of diversifying simple systems (coffee plantations under full sun in the shade of service plants), and a path of intensification of complex systems (agroforests in which coffee plants are managed more or less extensively under the shade of very diverse trees, often vestiges of the original forests).

These agroforestry systems, which mainly associate perennial plants, are complex, not only because of the association itself, but also due to the time steps that have to be considered. For example, the interactions between the roots of species we could observe in a ten-year-old plantation depend partly on the conditions of establishment of the association ten years earlier, e.g. if a species was established before another, it could spread into a volume of soil without interference. This complexity makes it more difficult to derive generic rules.

In order to be able to provide useful elements for the design of agroforestry systems, we have studied the ecosystem services provided, the relationships between these services, and the conditions necessary for the provision of services, of course in the context of the presence of trees in coffee plantations. Various types of services, defined by the Millennium Ecosystem Assessment (2005), were thus studied:
– provisioning services, and most importantly coffee productivity (Bhattarai *et al.*, 2017), as also the comparative productivity of different types of products obtained from plantations, whether sold or not;
– provisioning of groundwater recharge, with an assessment to compare the contradictory effects of agroforestry systems, in which the presence of trees generally increases water consumption, but also improves rainwater infiltration (Padovan *et al.*, 2018);
– climate regulating services, with work on carbon sequestration in agroforestry systems, as also emissions of other greenhouse gases (Hergoualc'h *et al.*, 2012);
– regulating services for controlling pest and diseases in agroforestry systems, with detailed studies of the effects of associations on the epidemiology of certain diseases, such as coffee leaf rust in coffee (Lopez *et al.*, 2013; Boudrot *et al.*, 2016), as also on pest complexes that attack the coffee plant and interact with each other (Allinne *et al.*, 2016);
– support services, mainly nutrient recycling (highly modified by the presence of shade trees and the rooting of trees and coffee in the soil profile, Padovan *et al.*, 2015), the production and recycling of biomass, fundamental elements in the lifecycle of agroecological systems (Defrenet *et al.*, 2016).

The first takeaway from these assessments of the services provided by agroforestry systems is that these systems are truly complex and it is difficult to draw generic principles of action from this complexity. In particular, it is difficult to find synergies between productivity and ecosystem services pertaining to environmental protection. Even though it is well understood that biodiversity forms the basis of the services provided, determining how to use it at the local level remains a complex undertaking and good practices are especially difficult to extrapolate due to the large number of interactions. Furthermore, the broad ecological hypotheses are of little help in developing generic rules that can be applied to these highly anthropized systems.

Several paths of innovation have been studied with producers, and have been tested in long-term trials (Figure 8.3). To attain the objective of increasing the presence and diversity of trees in plantations, the most common current practices are to cultivate coffee plantations in association with service trees of the genus *Erythrina* (*Erythrina* spp., Photo 8.1), or some species of Inga. These trees, almost exclusively grown for shade, can be 'managed' in a relatively comprehensive manner based on the needs of coffee plants and nitrogen fixation. However, they generally do not generate any additional income, except for certain Inga species whose logging residues can be used as firewood, essential in some countries of the region.

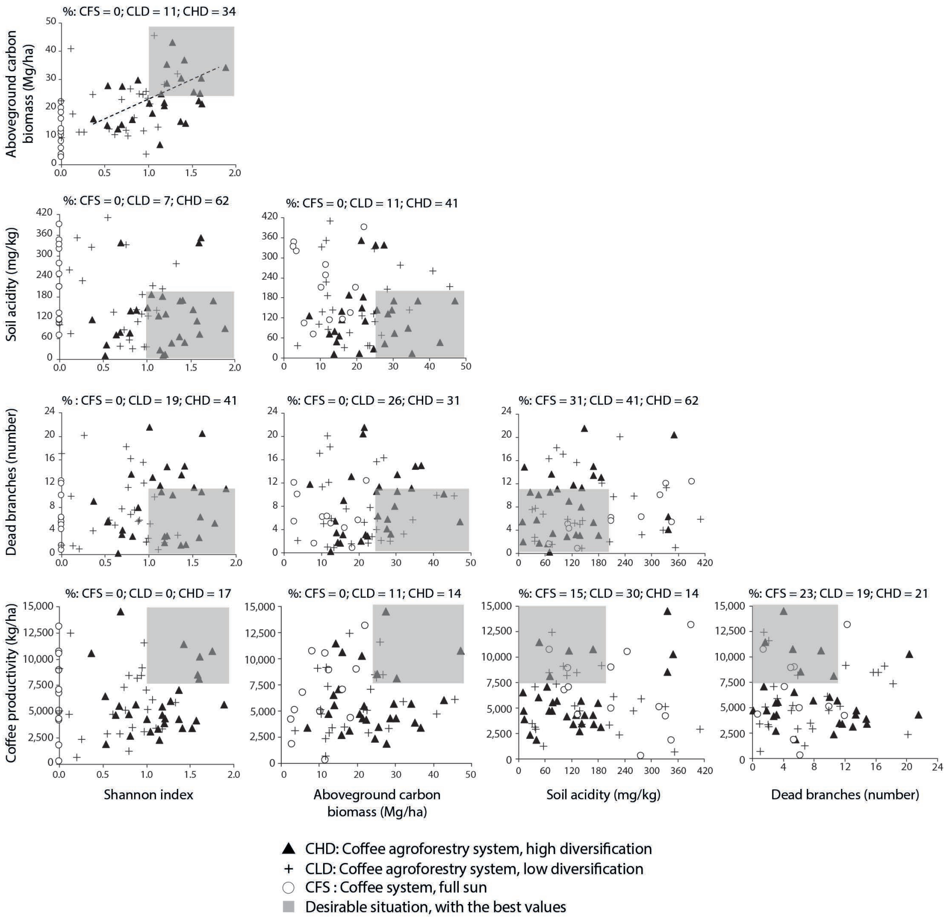

Figure 8.3. Relationships between ecosystem services provided by coffee plantations based on their level of diversity (Costa Rica, Cerda *et al.*, 2017).

Trials were conducted to replace these species with timber tree species (Photo 8.2; Haggar *et al.*, 2011). The revenue generated can be significant, especially in times when planters are particularly vulnerable, such as in the event of a sharp decline in coffee prices or a total renovation of the plantation (Beer *et al.*, 1998). This strategy was tested in Honduras, which has taken up a nationwide programme to establish coffee agroforestry plantations. Timber productivity was assessed on these plots (Jiménez *et al.*, 2012) and, as per our expectations, the productivity per tree was higher than the productivity measured in forest plantations (less competition for light due to low densities, and effects of fertilization of coffee). To our knowledge, trade-offs with coffee productivity have not been assessed. While, however, the biological performance of this innovation appears correct, its economic performance is controversial. It is more difficult than expected to derive value from the timber produced, partly because the quality of the timber decreases with fewer straight boles, and also because the timber sector is very different from the coffee sector, and it is not easy for a coffee producer to negotiate the sale of his timber. However, policies to combat

Photo 8.1. Typical coffee plantation in the Tarrazú region, Costa Rica: high coffee-plant densities on sloping land, associated with heavily pruned *Erythrina* (*E. poeppigiana*) and some banana trees. © Bruno Rapidel/CIRAD.

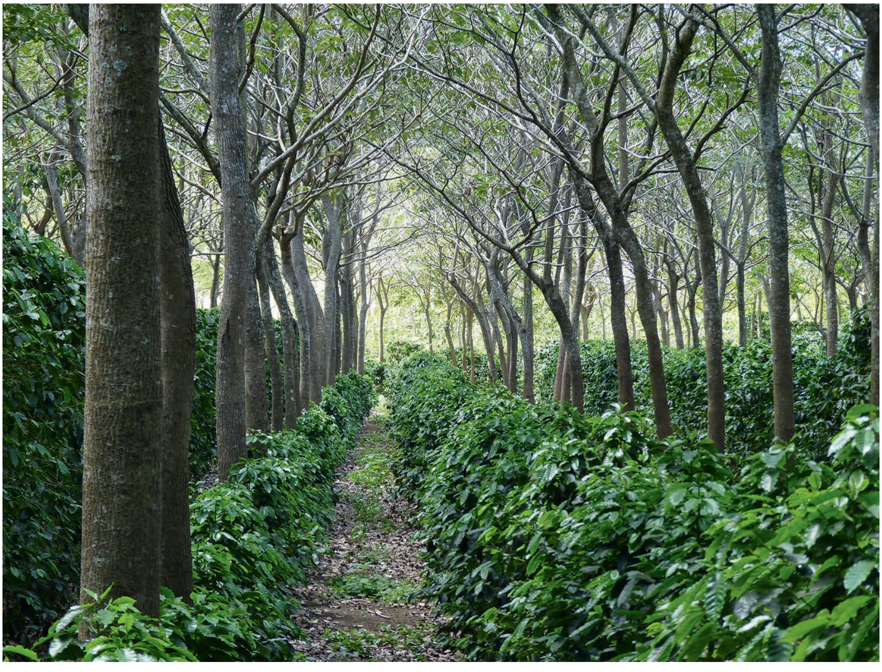

Photo 8.2. Commercial coffee plantation in Masatepe, Nicaragua, under shading by a timber tree (*Tabebuia rosea*). © Bruno Rapidel/CIRAD.

deforestation and strengthen controls on origins of timber (and in some cases certification) could stimulate demand for cultivated timber. Finally, the production of coffee under mature trees requires a periodic pruning of trees, in addition to thinning. This pruning poses considerable technological problems and requires significant amounts of labour (Photo 8.3). Mechanized cutting systems are, however, being tested.

Photo 8.3. Pruning of shade trees in Nicaragua: the producer, perched on the forks of branches, must not only ensure his own safety, but also take care that falling branches do not damage the coffee plants. © Bruno Rapidel/CIRAD.

Another strategy consists of promoting the diversification of tree species planted for shade. This strategy, widely promoted by several labels (Rainforest Alliance, Bird Friendly), produces very diverse systems in selected tree species and densities. However, studies generally show that further room for manoeuvre is still available to produce sets of ecosystem services without the limiting factors (mutual co-limitations) being reached (Cerda *et al.*, 2017). This strategy is also observed in the field with the association of fruit species, when the agri-chains are organized: in particular, dessert bananas are frequently associated with coffee plants in very variable densities, from an almost continuous cover over coffee plants in certain regions of Nicaragua

(Photo 8.4) to a few dozen pseudo trees per hectare in other cases. The income from banana production, spread out over the year, supplements coffee revenues, which are concentrated over two harvest months. This diversification is also observed with other fruit species, which are planted less densely and are more varied. The fruits produced are usually for self-consumption by the family, contributing to the diversification of its diet (Cerda *et al.*, 2014; Notaro, 2014).

Photo 8.4. Coffee plantation in La Dalia, Nicaragua, under simple shade: agroforestry system associating coffee and banana, a good economic complementarity. © Bruno Rapidel/CIRAD.

Strategies of adaptive management of plantations have also been implemented, so that their management can be based on the current or expected future state of the biophysical or socio-economic environment. In the short term, especially in order to take advantage of periods of high coffee prices, these strategies consist of adapting the pruning of the coffee plants and shade trees[1]. In the medium term, fertilization of the plantation can also be adjusted according to shade management: when prices are high, shading is reduced and fertilization is increased at the same time; when prices go down, denser shading increases nutrient recycling, but also reduces production and production costs. While the results of these strategies are yet to be analysed, they are already being practised by some producers.

1. It is necessary to prune coffee plants at certain intervals, every 4 to 7 years depending on the situation. However, since coffee flowers bloom only on branches one year old, the plant will not be productive in the first year following renovation, even if it catches up to its potential in the subsequent year. Producers therefore tend to hold off on renovation in years of high prices, expecting them to be transitory. We also observed producers slowing down on the pollarding of shade trees during periods of ENSO (El Niño - Southern Oscillation) in anticipation of long, dry seasons.

Finally, other complementary strategies focus on the coffee plant rather than on shade trees. Until now, coffee varieties were selected for very low shading conditions or for cultivation under full sun. By chance, some of these new varieties performed well in very shaded conditions (Bertrand *et al.*, 2010). It is only recently that breeding programmes have been taken up with the aim of offering varieties that are specifically adapted to the conditions of agroforestry systems (see Bertrand *et al.*, Chapter 9 in this book). However, the additional investment needed to buy seedlings from these new, sometimes hybrid, seeds often discourages small farmers.

Better understanding of and support for innovation

The technical innovations presented above have different origins: some were directly proposed by the research community, especially the use of shade species that generate marketable products or remunerative services, but many originate from production environments or from economic operators (e.g. the diversification of shade species initiated by Rainforest Alliance). The modalities of supporting the adoption of these innovations have to be adapted to the context.

Several approaches were implemented locally to encourage coffee producers to reflect on their practices and on ways of improving them. In Costa Rica and Nicaragua, following a characterization phase, and a subsequent study of the diversity of coffee plantation management practices (Meylan *et al.*, 2013), we decided to model the choice and effects of various practices. The aim was to integrate the full range of technical issues of homogenous farmer groups into the farm structure and choice of practices. This conceptual approach helped producers not only come up with solutions to the problems they faced, but also to envisage the evolution of their practices in response to various public policy instruments. While the model that was used, and subsequently modified, was not designed for this, and did not take into account all the necessary processes, it facilitated, following a progressive process of learning, an interaction between producers regarding technical processes they could not observe on their own (mineralization of organic matter, symbiotic fixation of nitrogen from the air). This model finally played the role expected of it: that of representing interactions in the cropping system, and conducting virtual experiments on the initiative of the producers. It also served as a platform for exchanges between researchers and producers, as a training tool, and has helped propose experiments for the future, as shown in Table 8.1 (Meylan, 2012).

The labels we mentioned as promoting agroecology also play a role in providing support. Very often, for the small producers, the contracting and management of these labels is carried out by cooperatives, which maintain registers and communicate with the certifiers. In some cases, multiple certifications are obtained (e.g. Fairtrade and Starbucks Café Practice) with only part of the production sold under any one label. The cooperatives, which maintain certification registers, are also in charge of verifying that agricultural and social practices correspond to the labels' requirements, and, above all, of training producers in these practices. This role of cooperatives as intermediaries between certification companies and small producers (role of a broker) is essential and allows these labels to have a positive effect on the agroecological transition. Specialists from the cooperatives fulfil a role that producers do not have time to assume, and do it probably more effectively, thus reducing the transaction costs of certification. However, we also note that many labels certify already existing activities and often do not contribute to an evolution of the practices: Fairtrade certification is often sought because the producer knows that he already fulfils the criteria (Quispe, 2007). However, certain labels certify agroecological orientations with criteria that are sometimes considered not sufficiently rigorous, but they do so with the intention of promoting a gradual modification of the practices towards standards that match the requirements of certification that the producer has already held for a long time. This is the case, for example, with the Rainforest Alliance, which awards its label without certain certification criteria being fulfilled, but on the condition that the producer demonstrates that he is taking action to meet these criteria in the future, with subsequent verifications to confirm this evolution. In such cases, it is virtuous trajectories that are being certified rather than existing situations.

Table 8.1. Some examples of the results of participatory simulation workshops on the effects of coffee cultivation practices on productivity (in tonnes of cherries), the nitrogen cycle and erosion (Llano Bonito, Tarrazú, Costa Rica, according to Meylan, 2012).

Group of producers	Initial practices	Modifications tested	Simulation results	Critical evaluation of the results by the group of producers
Not intensive	2 × 60 kg N/ha/year 60% pruning of shade trees (average) in May and October	40, 46 and 60 kg N/ha/year pruning of shade trees in March (increased to 80%) and September	Productivity increased from 4.15 to 5.26 t/ha/year (average over 7 years) Leaf area index (LAI) of shade trees lower, but LAI of coffee higher Higher runoff at first, then lower Higher N mineral (≈ × 2)	Attracted by the higher productivity, but apprehensive of additional fertilization Lack of conviction on the benefit of reduced shading (less shading would tire the plants in the long term)
Labour intensive	82/82/58 kg N/ha/year 300 trees/ha pruned in June, September and November	58/58/58/58 kg N/ha/year Pruning of trees twice a year (3 weeks before flowering, then in August) during an El Niño year	Productivity increased from 7.25 to 7.57 t/ha/year on average over 7 years LAI of shade trees higher, but pruned just before flowering Late application of fertilizer, promoting the growth of coffee cherries	Logically devised trials to lower fertilizer applications and the frequency of pruning of shade trees
Dense shading	3 × 83 kg N/ha/year 800 trees/ha pruned 3 times/year, to 40%	66, 50 and 83 kg N/ha/year First pruning of shade trees 3 weeks before flowering of the coffee plant 600 shade trees/ha pruned to 50%	Productivity increased from 7.22 to 7.41 t/ha/year Erosion not significantly higher Higher N mineral	Trials proposed to decrease fertilization on the basis of simulation results
Intensive in inputs	3 × 75 kg N/ha/year Shade trees pruned to 70%, 3 times/year	4 × 50 kg N/ha/year Shade trees pruned to 60%, 2 times/year	Productivity increased from 6.96 to 7.20 t/ha/year on average Decreased soil erosion Higher N mineral (significant)	Proposed trials to split fertilization while maintaining total quantities Lack of effect of weather conditions on N mineralization rate

Innovation platforms and support for adoption processes

Innovation platforms have been set up in Nicaragua, in coordination with a cooperative in the La Dalia region, north of Matagalpa. The coffee plantations are managed under shading that is often dense and diversified, but with a reduced productivity, generating insufficient income.

Innovation platforms initiated by researchers

The modifications proposed are aimed at two things. On the one hand, it is a matter of selecting the associations of species that are most beneficial for the producers, so as to protect these associations within the context of an intensification approach that conserves the essential functions of the complex agroforestry systems. On the other hand, we attempt to adjust the rules governing variations in fertilization based on the degree of regulation of tree shading. These modalities were planned following diagnostic work in the region (e.g. Notaro, 2014). Under the joint initiative of the research community and the cooperative's management team, producers interested in collaborating with the researchers were identified and contacted, and their production systems were documented. A day-long meeting was organized to enable the different actors to select research themes. Research modalities were discussed and each producer optionally registered in one of the groups. Initial protocols were drafted and fine-tuned after the meeting. Periodic meetings were organized for each group as the research activities progressed. The experiment is still ongoing as part of the Stradiv project (System approach for the Transition to bio-diversified Agroecosystems), co-financed by the Agropolis Foundation.

Innovation clusters initiated by the private sector

The private sector implements very different systems for promoting innovation, often in the form of clusters, i.e. groups of farmers selected based on company-specific criteria, which may themselves be based on the terroir and farming practices. These farmers receive special support, often seasonal loans repayable in the form of coffee delivered at harvest time. These initiatives are obviously very market-related, since they aim to ensure, for the buyer, a supply of coffee of predictable quality. This, for example, is the case of the Nespresso company. Its technical recommendations not only include elements aimed primarily at ensuring the coffee's organoleptic quality, but also, in an ancillary way, respect for the environment, thus coming closer to agroecological practices. Very similar to this scheme, and at the initiative of the Moringa Foundation (an investment fund founded by the Edmond de Rothschild Group and ONF International), an agroforestry farm in Nicaragua called La Cumplida was partially purchased and an agroforestry area was earmarked around the farmland. Under a temporary lease, coffee plots were completely renovated with recent varieties (F_1 hybrids [Bertrand *et al.*, 2010] or varieties of the Catimor family) and planted with forest species with high added value. Investors have a network that ensures access to profitable export markets. Specific monitoring is undertaken by a subsidiary of Moringa, with which CIRAD is associated within the Matrice project (Matagalpa Agroforest Resilient Landscape program) to guarantee the sustainability of farming practices. In the first phase, this cluster only brought together large and medium-sized farms (between 20 and 100 ha, covering about twenty producers). The contract specified that the profits of the first five years would be entirely allocated to the repayment of investments, thus requiring the owners to have additional means of subsistence independent of the plots allocated to this renovation scheme. The project recently started including small producers (about 50) under a more flexible contract.

The actors promoting agroecology and organic farming

Institutions and public policies

As in many other parts of the world, the trajectories of agricultural and rural public policies and the actors involved in these processes are context-specific and strongly tied to national histories. Nevertheless, it is possible to analyse a number of convergences in the Central American countries.

To begin with, and much like other nations of the Global South, Central American countries have been engaged in processes of economic liberalization and privatization of the agricultural sector driven by the structural adjustment policies of the 1990s. These processes have resulted in a more or less marked weakening of the State[2], in particular of the public establishments for agricultural research and extension[3]. At the same time, local actors, social movements and technical cooperation actors have, through development projects, favoured the emergence of production methods alternative to those of the Green Revolution (Sabourin *et al.*, 2017). In some countries, economic, political and environmental crises have facilitated this search for solutions in a context of a shortage of foreign exchange, as in the case of Nicaragua (Fréguin-Gresh, 2017). It is in this context that the concepts of organic farming and agroecology emerged in the region in the 1990s (see Chapter 17).

However, even if in some cases these production models are encouraged in national political agendas, they currently remain relatively marginal in practice. One explanation for this limitation could lie in the desire to maximize productivity in a context in which the import of agrochemical inputs is subsidized, and in which the orientation of coffee cultivation is partly provided by the sellers of agricultural inputs, either through field technicians or simply as a service at the time of selling inputs across the sales counter. This situation is obviously not conducive to the large scale dissemination of an agricultural model that is less dependent on inputs. Another part of the supervision and guidance is provided by cooperatives and coffee processing plants, which are primarily interested in fulfilling their export contracts and thus have specific interest in the quantities produced and supplied to them. In principle, they are less interested in the direct sale of inputs, especially when they are also responsible for certification. However, their sensitivity to the volumes of coffee produced may also encourage them to promote the consumption of inputs, especially fertilizers.

2. In the region concerned, however, two countries have been less affected than others, probably because the State has historically been less present in the domain: Guatemala and Honduras.

3. Quasi-public structures supporting coffee cultivation developed early, funded by a tax levied on coffee exports, and have retained a significant presence in the field, e.g. Anacafé in Guatemala and Ihcafe in Honduras.

A success

However, some policy instruments have made considerable progress in the development of agroforestry systems, including, among others, the programmes for the payment for environmental services.

Even though the first national system of payments for environmental services was set up in 1992 in Costa Rica to protect a forest for the purpose of tourism, it was only in 1997 that a more successful form was devised, with the sale of the precursors of carbon credits to Norway. In that same year, the national programme for payments for environmental services was created, spearheaded by forestry companies and under the aegis of Fonafifo (National Forest Financing Fund). It targeted the provision of different ecosystem services (climate regulation, water quality, biodiversity conservation, natural beauty) and assumed different forms (support for plantations, for conservation, and, from the beginning, the planting of trees in coffee and cocoa plantations). The programme was initially funded by international entities, and later by a tax on petrofuels, a move that was socially well accepted in Costa Rica. Apart from the relatively marginal modality of encouraging tree planting in agroforestry plots, this payment for environmental services is, for the most part, oriented towards forestry activities (reforestation, conservation). Nevertheless, a new modality for agroforestry coffee cultivation consisting of providing a payment based on the acreage of the agroforestry coffee system (and not merely for planting trees in plots of agroforestry systems) was introduced in 2011 and is now accessible by coffee growers[4].

These experiences of payments for environmental services, which are particularly advanced in Costa Rica, have been adopted, in various forms, in almost all the Central American countries. They were usually set up at the initiative of forestry companies, except in Nicaragua, where the first programmes were clearly oriented towards agroecology and were created at the municipal level.

Programmes for the payment for environmental services, when made part of national standards, are useful tools for promoting agroecology. A participatory simulation (a kind of role-play, initiated by the research community) was implemented to explore the potential effects of a change in the institutional environment of producers (several types of instruments and rules were tested) on the adoption of practices, including shade management, reduction of fertilizer doses and protection of watercourses (Bonifazi, 2015). The simulations carried out during sessions which brought different producers together helped identify this potential for influencing the management of agroforestry systems (fertilization, management of weeds and shade), the planning of plot lay-outs and the provision of services (coffee production, biodiversity) and 'disservices' (soil erosion, nitrogen pollution). While increased control of river protection areas has positive influences on biodiversity and reduces problems of erosion and nitrogen pollution, it also negatively affects coffee production by the simple effect of reducing coffee acreages.

The introduction of positive and targeted incentives ('green credits' or payments for environmental services) seems, however, to have stronger effects than measures of normative controls in terms of improving ecosystem services. These incentives greatly reduce disservices (soil erosion and nitrogen pollution) by increasing the provision of

4. https://www.fonafifo.go.cr/es/servicios/actividades-y-sub-actividades/ (retrieved on 3 May 2019).

support services (biodiversity) and supply services (coffee production). The balance between different services depends, however, on the type of positive incentives and the targeting of these incentives in terms of practices: green credits (lower borrowing rates for loans that meet environmental criteria) lead to an increase in coffee production that is higher than that observed in the payment for environmental services scenario, while payments for environmental services result in a larger increase in support services (biodiversity) and reduction of disservices (soil erosion and nitrogen pollution).

Certification and label incentives

Following the crisis of coffee prices that began in the late 1990s, strategies were put in place by the private sector to promote and enhance the environmental and social quality of this product by setting standards for its production and by creating labels to certify compliance with them (Soto and Le Coq, 2011).

Consequently, the production of 'organic' coffee saw a huge increase starting in the 2000s, partly due to better prices, with the organic price premium helping to offset, in case of low prices, the shortfall resulting from lower productivity (but without offering sufficient compensation in case of high prices). Organic plantation systems use denser and more diverse shading to help control pests, diseases and weeds. A large number of other practices are also adopted, such as foliar applications of elicitors of natural plant defence mechanisms and microorganism cultures sourced from forests, whose effectiveness, however, has yet to be tested.

In addition, other labels have been created for the coffee sector, which often combine environmental and social standards: Fairtrade (Max Havelaar established in 1988 for coffee from Oaxaca, southern Mexico), Rainforest Alliance (the first agricultural certifications in Central America, first for banana, then for coffee in 1995), Smithsonian's Bird Friendly coffee in 1996 and finally UTZ Certified (originally Utz Kapeh, created for coffee in Guatemala in 2002). All these standards impose, to varying degrees, environmentally friendly coffee practices within the production chains. The main practices modified are the use and diversification of shading, as also the discontinuation of the use of certain pesticides or the regulation of chains of contamination resulting from their use.

Another major strategy has been based on the promotion of coffee quality and, in some cases, on its improvement. It is mainly linked to companies downstream of the chain. For example, Starbucks, a chain of cup-based coffee retailers, based primarily in the United States but which has global ambitions, created the Coffee And Farmer Equity (C.A.F.E.) standard. Only growers adhering to these practices can offer to sell their coffee to Starbucks. In a similar strategy, Nespresso created the AAA programme, promoted largely in the context of coffee clusters, i.e. groups of producers who already produce a quality coffee and who receive special technical assistance related to the sale of their production to Nespresso.

For the past ten years, designations of origin have also appeared, based on a reputation for quality and a specific history of coffee cultivation in the regions concerned. While these designations pertain primarily to the area of origin of the coffee, they also tend to mandate certain practices, specifically the cultivation of certain varieties.

These different strategies, which all claim to promote the sustainability of coffee production, do not have the same effects on the adoption of agroecological practices. They try to reduce (totally in the case of organic practices) the use of chemical products, but their contribution to the increase of biodiversity varies: restricted in the case of exacting certifications like Bird Friendly, negotiated more on a case-by-case basis for market-related certifications, such as Rainforest Alliance, Starbucks Café Practice, or strategies based on the designation of origin.

On the other hand, the cooperative sector has gained in importance over the decades. In Nicaragua, following the relative fiasco of the Sandinista agricultural cooperatives promoted by the State in the 1980s, NGOs took over in the liberal years (1990s and 2000s) and encouraged the emergence of cooperatives to support coffee production and exports. Some cooperatives have flourished, become highly professionalized, especially as concerns the promotion of quality coffee and negotiations for exports, and become effective production support structures. In Costa Rica, cooperatives have largely developed with State support, and control much of the coffee export. CooCafé, a federation of cooperatives, has set up its own certification, Café Forestal, based on agroecological criteria. These cooperatives, where they exist, are key actors in accompanying innovation and for access to certifications (Faure *et al.*, 2012) and thus in the promotion of agroecological practices.

Lessons learned

This brief summary of the principles of the association of species and of the ways of promoting it provides us with some conclusive inferences.

There is a reservoir of knowledge and of practices of agroforestry producers that is yet poorly exploited. The systems are very diverse and some producers have practices that deviate from the standard. All marginal practices are not beneficial, of course, but we must equip ourselves with the means and methods to explore and evaluate these practices and this knowledge.

It is not easy to find predictable ways of deriving value from additional products obtained from agroforestry. Vertical integration plays an important role: the more actors succeed in transforming products, the more they manage to reduce these uncertainties. This is especially true for timber produced by shade trees.

Practices concerning shade trees have to be easy to implement in order to ensure their adoption and use: not only reproduction and planting, but also, and above all, ease of management and flexibility in the choice of species in order to be able to adapt to constraints that vary over time. Thus, species that can withstand two occasions of near total pruning per year have met with approval by the producers, e.g. *Erythrina* and some species of Inga.

The perennial aspect of the systems forms the basis for the provision of numerous ecosystem services: protection against erosion, protection of biodiversity, nutrient recycling, etc. Nevertheless, there is a lack of clarity regarding a certain number of elements, arising from the differential effects of certain species or combinations of species on pests and diseases and on soil biology. Few studies have so far focused on the functional traits of shade trees that could increase the provision of these services.

The complementarity of the species depends on the complementarity of the niches explored (Sanchez, 1995), but it is necessary to extend this notion, used originally in ecology. While this notion can, no doubt, concern the niches explored by the roots and by the aboveground elements for capturing sunlight, it can also pertain to niches in the economic sense: in terms of annual distribution, the income from banana, for example, harmoniously complements that of the coffee plant.

Price is, without doubt, the main element to be considered in understanding the evolution of practices. This is as true for coffee cultivation in Central America as it is for other productions in other parts of the world. Even if some room for manoeuvre still exists, agricultural systems cannot comprehensively move towards a better consideration of environmental objectives in the current framework of price fixing and fluctuations. Given this context, we need to focus more on the economic assessment of agroecological options, especially agroforestry, for managing coffee plantations in order to better document these debates and inform public decisions.

Communication about the labels within organizations that administer them – cooperatives in particular – is essential. Much of their effect on changing practices depends on it: producers need to know the requirements of certifications. Furthermore, being certified endows producers with some pride, and this pride has beneficial effects on practices. Finally, the cooperatives that manage the application of these labels can become responsible for a good part of the training, a fundamental element of the agroecological transition.

The research community is still searching for generic principles of action for agroecology that can serve as a framework for the introduction of remunerative practices for producers. We must strive to understand the complexity in order to optimize it.

The general societal push for agroecology is an important element of the transition, even though its impact on practices remains difficult to assess. It facilitates the development of normative frameworks, the appearance of labels for domestic markets, as also the taking of concerns and practices of agroecology into account by producers. This is a development we have observed in Costa Rica and, to a lesser extent, in other Central American countries, where coffee cultivation is less intensive.

Conclusion

Coffee-based agroforestry systems represent agroecological options of great interest, combining the cultivation of quality coffee with other productions, diversifying in this way not only the producers' income sources but also the diets of their families. These systems are, however, complex and there is insufficient knowledge of their functioning and the conditions under which they could be improved.

Following a phase of acquisition and capitalization of knowledge on agroecology, the partnership platform (PCP AFS-CP) is moving on to another stage of the transition. This step consists of the implementation of options for changing production conditions, in a closer working relationship with public authorities, private operators and NGOs, which can give it the means for this scaling up. It is these new challenges that this platform has decided to address in its second phase, starting in 2017.

We have shown at the beginning of this chapter that prices, their changes over time, as also the ways of modifying them, are essential elements of an agroecological transition in this sector which is closely tied to international markets. Other drivers are becoming apparent, and they must be integrated into our work.

Thus, the first appearance of coffee leaf rust on coffee plants in Central America, in 1976 in Nicaragua, has resulted in the creation of a regional network of coffee research institutes to promote the development of innovations and the modernization of coffee production: Promecafé (*Programa Cooperativo Regional para el Desarrollo Tecnológico y la Modernización de la Caficultura de Centroamérica, República Dominicana y Jamaica*). While this disease kept a relatively low profile in Central America for decades (Avelino *et al.*, 1999), it resulted in significant losses in 2012-2013, and become a driver of changes in the region's coffee plantation systems. One of the reasons behind this increased damage from the disease may be climate change, since coffee and the coffee leaf rust agent, *Hemileae vastatrix*, are both very sensitive to temperature (Avelino *et al.*, 2015). An immediate outcome of the crisis was the development of the coffee genetic bank, with the rapid replacement of susceptible traditional varieties by resistant varieties. However, the disease seems to have already started overcoming resistance, indicating that integrated management of coffee leaf rust, based on shading and nutrition, and especially on soil conservation, is needed (Avelino *et al.*, 2006; Toniutti *et al.*, 2017). A systemic approach to the control of this disease has to be adopted (Lewis *et al.*, 1997). The transformation of the production system in its entirety has to considered in order to maximize the preventive forces of the control of diseases and pests, by mobilizing several ecological control/regulation mechanisms (Avelino *et al.*, 2011) that form the basis of the agroecological system, and using conventional control measures (chemistry, genetics) only as a backup or support. Their effectiveness could then be increased because of the reduced pressure of pests and diseases in these new systems. This strategy seems the only solution for pests and diseases for which no genetic control is possible (case of non-specific pathogens like *Mycena citricolor*) or because it has shown its limitations (case of coffee leaf rust). While shading is a key aspect in this approach, studies need to be conducted to identify shading ideotypes that achieve this goal of effective regulation of the pests-and-diseases complex.

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Chapter 9

New varieties for innovative agroforestry coffee systems

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In the plant breeding industry (also known as the seed industry), the breeder applies specifications that are based on a productivist rationale which considers the environment as a production medium and cares little about the quantities of inputs to be used. Furthermore, this industry is not interested in tropical perennial crops (rubber, cocoa, coffee, coconut, etc.) that are mainly cultivated by small producers with little means, and which is thus economically unattractive. Varietal creation and seed production for these crops are sometimes carried out by professional or national organizations. As a result, the overall supply of new varieties in these agri-chains is extremely small and genetic progress is very limited. In a context of global warming and biodiversity loss, it is therefore necessary to create varieties that are more adapted and to reorient the selection criteria for tropical perennial crops.

In order to illustrate this need of revisiting breeding targets in a context of the agro-ecological transition, we present the example of new coffee varieties adapted to agroforestry systems.

Arabica coffee is mainly grown in Central America at elevations of 600 and 1200 m above sea level and in Peru (close to the Equator) at altitudes between 1000 and 1500 m. In these regions, this crop is cultivated mainly in agroforestry systems providing numerous ecosystem services, including biodiversity conservation, water cycling in watersheds, and carbon sequestration. At a socio-economic level, coffee cultivation is very labour-intensive and helps to arrest the rural exodus and illegal migration to the United States. The majority of the producers in these areas find it difficult to gain access to the so-called ‘special’ coffee market which is more remunerative.

The goal of this chapter is to show why productive and ‘healthy’ varieties are the cornerstone of the push to re-establish the profitability of coffee cultivation in the Central American countries, the Andean States and Mexico, in the low-lying areas that account for more than 90% of the Arabica coffee produced in El Salvador, Honduras and Nicaragua, 50-60% in Costa Rica, around 40% in Guatemala, over 50% in Chiapas in southern Mexico, and more than 80% in the latter country's northernmost cultivation areas, mainly located in the states of Veracruz and Oaxaca.

We will briefly recall the constraints and challenges of this form of coffee cultivation practised for the most part in agroforestry systems. We will describe breeding targets in the context of agroforestry and varieties that are most adapted and then discuss how to produce and disseminate these varieties.

The challenges to be met

An unsustainable form of coffee cultivation

The use of pesticides in agriculture, even in a reasoned manner, has environmental consequences. There are many such effects as the products resulting from the degradation of agrochemicals spread out widely and are likely to end up not only in various compartments of the environment (air, water, soil, etc.) but also in food. Coffee cultivated under full-sun conditions relies on chemical inputs: synthetic fertilizers, herbicides, fungicides and insecticides. Farmers are directly exposed to chemicals and the surrounding communities are also affected by residues that travel easily from one compartment to another where they accumulate.

The risk of biodiversity loss

The loss of biodiversity today, which is occurring at a rate that is 1000 times greater than the geological average, corresponds to the sixth mass planetary extinction since the appearance of life on Earth. Even though the disappearance of plant and animal species is part of the natural course of Earth's history, human activity is responsible for this accelerated rate of extinction. According to the theory of island biogeography (MacArthur and Wilson, 1967), which has formed the basis of research in conservation biology for the past 40 years, the reduction in available habitat results in a proportional loss in the number of species, and vice versa. As a result, an agricultural landscape with a large tree cover contains more forest species than a natural landscape without trees. The link between coffee cultivation and deforestation was highlighted by WWF (World Wide Fund for Nature, also known as World Wildlife Fund), which showed that of the 50 countries with the highest rates of deforestation, 37 are coffee producing countries.

Increased pressure from parasites

Different shading levels in coffee plantations influence the overall functionality of the food web, mainly through light intensity and relative humidity. Pest and disease pressures, as well as the impact of control agents (microflora and fauna), differ according to climate, altitude and soil type (Staver *et al.*, 2001). For example, outbreaks of rust (the main disease affecting coffee leaves and caused by *Hemileia vastatrix*) increase and intensify with climate change. Indeed, warmer temperatures affect both, the development of this fungus and the physiological state of the plant under environmental stress.

Coffee cultivation that is not very profitable

Coffee is often the only crop that provides income for farmers in the mountainous areas of Central America, Colombia and Peru. Collection networks for green coffee have been created even in the remotest locations to transport it to drying and sorting centres, and thence to ports for export to roasters who process and market the product.

The producer is, however, dependent on a price that is set elsewhere. He is aware of the volatility of world prices, and knows that the coffee he produces must stand out from cheaper coffees. He also realizes that if major producing countries such as Brazil or Vietnam – which practice intensive coffee cultivation systems that are highly dependent on pesticides and fertilizers – produce too much, the world price will collapse and the market price will no longer even cover his expenses. Producers can rarely resort to bank loans under such adverse conditions. In fact, national banks are of the opinion that factors such as price volatility, recurring epidemics like the series of rust crises since 2008 (McCook and Vandermeer, 2015; Avelino *et al.*, 2015), risks arising from climate change, and weak producer guarantees render the coffee cultivation sector a risky bet. Consequently, all they offer producers are loans at usurious interest rates (between 12% and 20% per annum).

Furthermore, in many coffee producing countries (with the notable exception of Colombia where the National Federation of Coffee Growers have given the production chain a robust structure), and to a lesser extent in Honduras and Costa Rica, the State does not play its regulatory role concerning credit and agricultural extension, seed supply, and research and innovation. Taxes collected from exports are only partially reinvested in the production chain. As for coffee varieties, the absence of a structured seed sector results in the production of poor quality seeds and plants, both in terms of genetics and horticulture. Non-standard varieties are often disseminated, and have a negative impact on productivity. At least 40 countries rely on innovation in other countries (Brazil, Colombia) for the creation of new varieties. The import of seeds from these countries is rarely facilitated by national governments. Varieties are therefore sometimes introduced illegally, with very poor traceability.

The creation of varieties adapted to agroforestry

Properly managed agroforestry systems make optimal use of biological and economic synergies, leading to sustainable land management and stable and localized income sources for stakeholders (essentially small farmers). It is understood that cultivation in shaded systems, such as agroforestry systems, reduces reliance on external inputs. Unfortunately, as observed for other crops, the productivity of coffee-based agroforestry systems is lower by 30% than that of full-sun systems (Vaast *et al.*, 2005). One reason for this situation is that varieties cultivated in such systems were bred for full-sun intensive systems, and are thus not adapted to agroforestry systems (Bertrand *et al.*, 2011; Van der Vossen *et al.*, 2015). Varietal improvement for intensive systems has provided growers with varieties that are unsuitable for growing under shade, while wild Arabica coffee is naturally tolerant to shade, and thus to agroforestry systems.

The BREEDCAFS project

The solutions which will be described here are currently being studied within the framework of a H2020 European project (2017-2021) called BREEDCAFS (BREEDding Coffee for Agroforestry Systems)[1]. Its goal is to establish a new breeding strategy to create coffee varieties with increased resistance and greater resilience to climate change in agroforestry systems. Coffee is seen here as a model perennial crop; most of the expected results and experience gained on coffee will serve as a basis to improve other tropical perennial crops such as cacao.

Using the new F_1 hybrids of *Coffea arabica* as a case study, the BREEDCAFS project designs and tests coffee varieties that are better adapted to low levels of inputs, to agroforestry systems and to climate change, while maintaining a robust defence system against biotic and abiotic stresses.

The project combines several mechanisms to compare hybrids to cultivated varieties and/or hybrids to their two parents in different scenarios that mimic global warming (increase in CO_2, increase in thermal regime, with or without shading, etc.), either in phytotrons under controlled conditions (in order to test the effects of temperature, light, drought, CO_2 and N_2, for example), as also in field trials, or in networks of plots at producers' locations. It is being implemented in eight countries: Nicaragua, Costa Rica, France (in French Guiana and in greenhouses in Montpellier), Cameroon, El Salvador, Vietnam, Portugal and Denmark. Roasters are involved in the improvement process as assessors of the beverage quality while the producers are involved in field measurements and profitability assessments. In Vietnam, Nicaragua and Cameroon the opinions of producers and roasters are taken into account via dialogue platforms.

Kinds of varieties for agroforestry: hybrids *vs* pure lines

Since *C. arabica* was introduced in Latin America from a very small number of plants, a genetic bottleneck has resulted (Anthony *et al.*, 2002). However, this low initial genetic diversity has given rise to varieties adapted to full-sun conditions, which has allowed their adoption in intensive cropping systems, mainly in Brazil, Colombia and Costa Rica. Nevertheless, the combination of these varieties with high-density crops (often mechanized) and systematic disease control methods has never been adopted in the rest of Latin America and Africa. Coffee plants in these areas continue to be grown under shade without any major technological improvements, with the result that yields are either stagnating, or even declining.

In 1990, CIRAD and its public and private research partners (CATIE[2], Icafé[3], ECOM Trading[4]) created F_1 hybrid varieties that were adapted to agroforestry systems by using a selection process based on cross-breeding of American pure line varieties and wild individuals from Ethiopia and Sudan (Photo 9.1) which were phylogenetically distant

1. www.breedcafs.eu.
2. The Tropical Agricultural Research and Higher Education Center, Turrialba, Costa Rica.
3. Central American Coffee Research Institutes.
4. Ecom Trading is a world leader in the commodities trading business.

(Van der Vossen *et al.*, 2015). It was thus possible to obtain hybrids that helped boost production by 30-60% in agroforestry systems without increasing fertilizer quantities (Bertrand *et al.*, 2011), and also improved aromatic quality (Bertrand *et al.*, 2006). The selection period for F_1 hybrids being significantly shorter than those of conventional pure line varieties (8 years as against 25 years) was also an argument in their favour.

Photo 9.1. F_1 hybrids of *C. arabica* planted in agroforestry systems (Matagalpa, Nicaragua). © Benoît Bertrand/CIRAD.

The study of the responses of F_1 hybrids to multiple stresses (Photo 9.2) helped better understand of how heterosis (i.e. hybrid vigour) manifests itself in response to environmental constraints. Under shading, the photosynthetic efficiency of hybrids is not only higher than that of pure line varieties but is, in fact, much more stable and stronger (which is what is called homeostasis) under conditions of multiple abiotic stresses (Toniutti *et al.*, 2017, 2019). Homeostasis is actually one of the major components of heterosis in improved plants and in Arabica in particular (Bertrand *et al.*, 2011, 2015).

Since plants exhibit resistance levels to stress in proportion to the amount of energy they possess to cope with it (Kangasjärvi *et al.*, 2012; Ballaré, 2014), it is only logical that hybrids have better resistance to stress. Measurement of the chlorophyll fluorescence (a), by providing access to the functioning of Photosystem II and the electron transport chain, has proved to be an excellent marker of the health status of coffee plants, and is capable of predicting their health and their ability to resist rust. Conversely, the more the photosynthetic efficiency is affected, greater is the oxidative stress. This can be observed in pure line varieties that are less adapted to environmental constraints (Toniutti *et al.*, 2017, 2019).

Photo 9.2. Measurements of photosynthesis on hybrid varieties of *C. arabica* cultivated under shade simulating agroforestry conditions (Teocelo, Veracruz, Mexico). © Luc Villain/CIRAD.

Before the BREEDCAFS project, adaptation to future climatic constraints and low light intensities characteristic of agroforestry systems had never really been a breeding objective and homeostasis of hybrids was used to cultivate them in agroforestry (Figure 9.1). Significant progress in the adaptation of Arabica hybrids to agroforestry systems, and to biotic and abiotic stresses, seems all the more attainable as we can now rely on new tools (genomic, transcriptomic, metabolomic) and on genome sequencing (Denœud *et al.*, 2014).

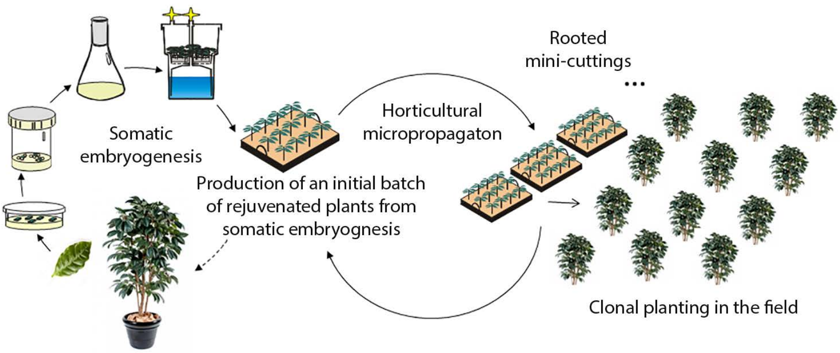

Figure 9.1. How hybrids are vegetatively propagated.

Period	Programme	Selection of F_1 hybrids	Material, selection stages	Selection targets	Expected results
1990-2017	IICA-CIRAD-CATIE-Promecafe, CIRAD-Ecom programmes	Phenotypic selection on F_1 hybrids	American varieties × Ethiopian varieties (wild or traditional cultivars)	Resistance to rust, cup quality, high productivity	
2017-2021	BREEDCAFS, European Union H2020 project	Assisted selection of F_1 hybrids with biomarkers	Identification of robust markers (allelic, epigenetic, metabolic, molecular) for prediction of breeding lines and early evaluation of F_1 hybrids	Adaptation to agroforestry systems and climate change, resistance to diseases, cup quality and high productivity	Early predictors of performance of F_1 hybrids
			Validation of markers with a large population of hybrids and parents grown in agroforestry systems		Prediction of the best parents in a large panel of genotypes
2019 -	New model of international governance to be found (private and public partners)	Selection based on new 'omic' tools for predicting heterosis and adaptation to agroforestry	Evaluation and selection of BREEDCAFS F_1 hybrids	Adapted to agroforestry systems and climate change	Worldwide distribution and accessible by all coffee growers. Varieties adapted to agroforestry and climate change

Figure 9.2. Towards a new selection strategy for F_1 hybrids of *C. arabica*.

Figure 9.2 schematically shows the changes proposed by the H2020 BREEDCAFS project during the hybrid breeding process. The goal is to evolve from a phenotypic selection to a genome-based selection. *Coffea arabica* is a polyploid species with reduced genetic diversity. BREEDCAFS offers software for the analysis of polymorphisms of polyploid species. This software will be used for detecting markers, and can also be easily adapted for the analysis of epigenetic data. Variations in (epi)genetic markers between reciprocal F_1 hybrids and their parents cultivated under various environmental conditions are sought and linked to the ideotypes identified in experimental and field trials. These data are used to predict genotype-phenotype-environment interactions for expected complex traits.

Improving selection tools and methods

The goal of BREEDCAFS is to move from an exclusively phenotypic breeding of hybrids to a breeding assisted by genomic and transcriptomic tools (Figure 9.3).

Figure 9.3. Implementation of a horticultural vegetative propagation process using rooted mini-cuttings from rejuvenated plantlets of *C. arabica* derived from somatic embryogenesis.

a: 15-week rejuvenated plants obtained by somatic embryogenesis and planted in plastic boxes
b: Plantlet cuttings from somatic embryogenesis
c: Planting of mini-cuttings in honeycomb plates
d: Rooted mini-cuttings obtained after 6 weeks of acclimation in the greenhouse
e: 8-week rooted mini-cuttings with horticultural substrate lumps
f: 8-week rooted mini-cuttings with bare roots
g: Rooted mini-cuttings after 3 months of hardening in the nursery
h: Rooted mini-cuttings after 6 months in the nursery and ready for transfer to the field plot.

Using transcriptomic and transgenic approaches, candidate genes involved in drought tolerance in *Coffea canephora* and *C. arabica* have been identified (Marraccini *et al.*, 2012; Mofatto *et al.*, 2016; Alves *et al.*, 2017, 2018; Torres *et al.*, 2019). By coupling the phenotypic, ecophysiological, transcriptomic and biochemical approaches, the detection of biosynthetic pathways that are over- or under-expressed during adaptation phenomena (primary or secondary metabolic genes, photosynthesis, photoprotection, volatile green coffee compounds) will help reveal marker genes that can be used in the selection. In addition, a more traditional approach to finding genomic selection tools is also being implemented.

Box 9.1. The transcriptomic approach to coffee breeding

The environment is used as a source of variation to identify correlations between gene expression and growth characteristics (QTT or Quantitative Traits Transcripts) linked to shading adaptation. The use of environmental variations to identify QTTs has been proposed by Passador-Gurgel *et al.* (2007), in the case of the resistance of drosophila to nicotine, and applied by Joët *et al.* (2009) to determine the accumulation of chlorogenic acids in coffee seeds. This method is based on the principle that the environment is a powerful factor that modulates gene expression levels and thus allows the detection of QTT correlated to the measured character. This approach is suitable for an allopolyploid plant with little polymorphism.

The adoption of varieties by producers

In an agri-chain characterized by strong conservatism, what are the reasons that can convince producers to adopt new varieties?

An increase in productivity can be a motivation because it is necessary in agroforestry systems. This requires more productive varieties that are different from those currently used. We have been witness to a massive varietal change over a period spanning less than a decade. This change has taken place in the context of the great rust crisis (McCook and Vandermeer, 2015), by making use of the 'Catimors', 'Sarchimors' and 'Castillo' introgressed pure line varieties, which are reputed to be strongly resistant to leaf rust. Unfortunately, the disease is overcoming the resistance of these varieties. The search for new resistance genes has not been successful for many years, except in Colombia. Consequently, producers will be left with only two choices in the near future: either resort to a solution of a systematic and expensive phytosanitary umbrella based on fungicides that pose a danger to the environment; or use an intermediate solution by planting hybrid varieties, which are also sensitive, but are more tolerant and resilient (Toniutti *et al.*, 2018, 2019). Rust outbreaks can be controlled with copper treatments (approved in organic farming) on these susceptible hybrid varieties.

Certain conditions must be satisfied for a successful renewal of coffee plantations with hybrid varieties. We review them here.

Organization and guarantees of a seed chain

Once a coffee variety has been created by breeders, we must be able to reproduce it on a large scale in a consistent manner, and be able to provide it to producers at an affordable price (Bertrand *et al.*, 2012; Figure 9.4).

In Costa Rica, Honduras, Colombia and Brazil, for example, State agencies or cooperatives distribute seeds (beans) of pure line varieties of very good germinal quality, and a varietal purity of 90-95%, at a subsidized rate of US$ 8/kg, or about US$ 15/ha.

In other countries, coffee growers rely on non-certified seed producers, which puts them at risk in terms of varietal purity (very heterogeneous seeds due to mixtures and cross-pollination), of highly variable germination depending on the batch, of poor productivity, and of uncertain coffee quality, which can sometimes be well below the standard.

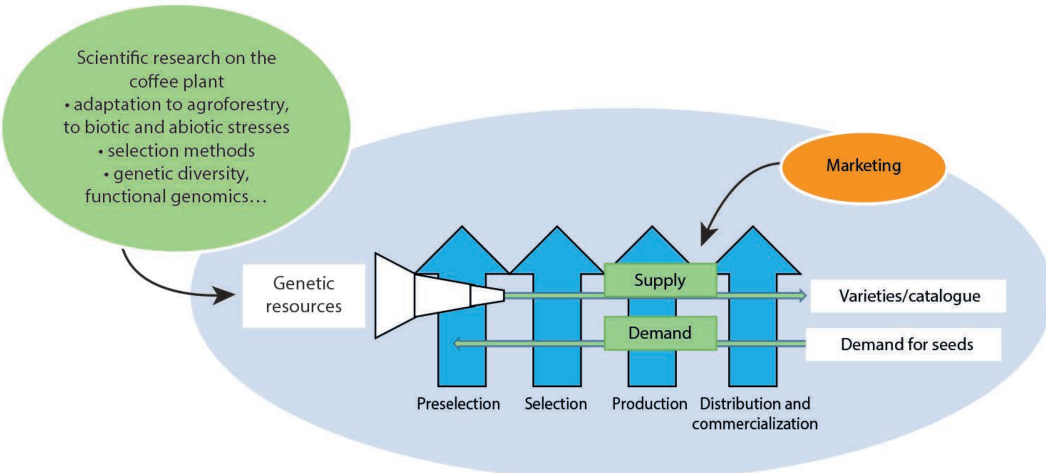

Figure 9.4. Varietal creation process of *C. arabica* for adaptation to agroforestry and climate change. It can basically be broken down into research in plant science, conservation and utilization of genetic resources, followed by stages of pre-selection, selection (with a necessary step of multi-local field validation), seed production and marketing.

The BREEDCAFS project assumes that, in a context of climate change, the best varieties for agroforestry systems are F_1 hybrids of *C. arabica*. The dissemination of these F_1 clones, however, poses new commercial and logistical problems. These varieties, which are propagated by vegetative propagation (and not by seeds), must be delivered in the form of developed plants, at the lowest possible price, to small producers, who often live in remote and mountainous areas.

The lack of a seed chain for F_1 hybrid clones (described above) is even more serious since no State or private organization (apart from the CIRAD/ECOM alliance on Arabica) is currently disseminating these new varieties. It should also be noted that, until recently, the production cost of a ready-to-be-planted F_1 hybrid plant (US$ 0.70-0.80) was much higher than that of seed-grown seedlings (US$ 0.15-0.20), which has greatly limited their dissemination.

To sum up, there are four major stumbling blocks to the dissemination of F_1 hybrids:
- the high plant cost;
- the logistical problems in reaching small producers;
- the need for certification of the plant production chain;
- the lack of financial means of small producers.

Horticultural solutions to lower the cost of F_1 seeds

The general idea is to professionalize the coffee seed sector so that clones of F_1 hybrids can be produced in large quantities (several tens of millions each year), with 100% traceability, an excellent horticultural quality and following a well-defined technical itinerary (high-tech greenhouses and certified nurseries using inert substrates).

The CIRAD/ECOM alliance produces a few hundreds of thousands of F_1 hybrids each year using somatic embryogenesis (Etienne *et al.*, 2012, 2016, 2018; Bobadilla-Landey *et al.*, 2013). The recent development of the propagation of horticultural rooted mini cuttings (Georget *et al.*, 2017) has increased the number of plants produced from a somatic embryo (by a factor greater than 10), and thus cut the cost of producing a hybrid plant by half, as compared to a plant directly derived from a somatic embryo. With the CIRAD/ECOM alliance having shown the way with this production model, we believe that this technology to produce hybrid F_1 plants of *C. arabica* can be replicated by the horticulture industry, as is the case with other plants (ornamental plants, fruit trees, forest trees, etc.). This would lead to plants being offered at competitive rates (US$ 0.40-0.50/plant), given the high productivity of these clones.

Seed cooperatives for remote areas

Given that remoteness and distance can make industrialization unviable, we have developed the technique of mini cuttings in rural areas (Etienne *et al.*, 2018). We have set up seed cooperative networks on the pattern of farmers' seed systems, which are especially adapted to reproduction from seeds. The horticultural technique of rooted mini cuttings is thus transferred to women's cooperatives in order to:
- reduce the production cost of mini cuttings;
- reduce inequalities between men and women;
- promote access to F_1 hybrids and popularize their use.

This experiment was set up as part of the BREEDCAFS project in three very different contexts: those of Vietnam, Cameroon and Nicaragua[5].

Starting from a small number of initial explants from a certified seed producer and renewed every year, the women's cooperatives take up the reproduction of mini cuttings, and their marketing to producers in the area. The cooperatives also undertake to pay a royalty every year in order to acknowledge the rights of the breeder.

Seed certification: a guarantee for the industry

This process has been initiated since 2003 by the CIRAD/ECOM alliance in Nicaragua, Mexico and Costa Rica. The industry is fully cognisant of the value of this

5. http://www.snv.org/update/press-release-project-breedcafs-nicaragua-advances (retrieved 4 May 2019).

approach and has created and financed, since 2015, the World Coffee Research (WCR) not-for-profit organization. Programmes were set up to verify varieties and production nurseries, e.g. the 'WCR Verified programme'[6]. This is the first global standard for coffee plants to ensure that producers of coffee seeds or clones of *C. arabica* F_1 hybrids, and associated nurseries, produce healthy and genetically pure plants.

A fair price for a supply guaranteed in terms of quantity and quality

In times of a price crisis, or when production costs are too high, or when the terms of trade are too unfair, small producers adopt non-investment strategies that have a significant and long-lasting impacts on yields and quality. At the same time, medium-sized producers who have taken usurious bank loans are ruined and sometimes even abandon their farms. Thus, uncertain terms of trade, price volatility and low productivity undermine the modernization of the coffee agri-chain and contribute to its loss of competitiveness. This eventually results in the undermining of the entire value chain. The best example is Mexico, a leading economy but whose coffee sector, mostly comprising of agroforestry systems, is arguably one of the least productive and least profitable in the world.

The fair-trade solution was successfully applied to small coffee growers in Mexico (Van der Hoff, 2010). This solution was then adopted for many commodities around the world. However, it is now clear – despite significant impacts on producers' living standards – that fair trade is not enough for an in-depth modernization of coffee cultivation. In addition, this solution is available only for small producers (less than 5 ha). We believe that the real challenge is to increase farm profitability. This not only requires a per-hectare increase in productivity, but also an increase in the value derived from the product.

Varietal innovation to ensure the profitability of agroforestry coffee systems

The variety as a tool for traceability and differentiation

The basis of this concept is that the variety and the coffee it produces become a tool for traceability, and an instrument of differentiation because of its relative novelty. Indeed, since there are very few varieties[7], any new one not only introduces new characteristics of resistance, productivity, and cup quality, but also a unique genetic heritage that modern genetic marking techniques are able to identify, not only in green coffee but also in roasted coffee (Morel *et al.*, 2012). The ability to trace the product through the entire agri-chain, including up to the stage of roasted coffee, is a unique tool to guarantee the origin, practices and, possibly, maintain the rarity of the product, which will ensure a demand for it from buyers who wish to offer something new to consumers.

6. https://worldcoffeeresearch.org/work/seed-and-nursery-verification-program (retrieved 4 May 2019).
7. https://varieties.worldcoffeeresearch.org.

The 'Business driven' agroforestry cluster: a new integrative approach

The general idea behind this approach is to promote the creation of clusters. A cluster is a group of producers in a given territory who come together to produce coffee that is compliant with environmental and agronomic standards and is 100% traceable. Quality levels and quantity to be produced are set according to the coffee company' requirements, which, in return, commits to a minimum price. Agroforestry clusters comply with strict specifications concerning the planting of shade trees (number, diversity per hectare), with associated environmental services, on a given terroir. They promote as much direct trading as possible to offer a consistent product that corresponds to the standards required at the end of the agri-chain by the industrial roaster which markets the product according to its high quality standards. The set of environmentally responsible practices, the terroir, the practices of a more equitable trade, and the sensory qualities specific to the variety, possibly improved by post-harvest processing, result in the creation of a coffee that is not only high in quality, but is also distinctive.

The 'Business driven' agroforestry cluster is thus: a terroir + agroforestry practices (UTZ and/or Rainforest certified) + fully mastered post-harvest processing + a certification + 100% traceability.

A prototype cluster of 1350 ha[8] was set up in Nicaragua around the 'Marsellesa' variety (a CIRAD-ECOM variety) to produce an exceptional coffee for industry (Nespresso's Master Origin Nicaragua capsules). The concept is applicable across countries. This model is intended to be replicated on new terroirs, for projects of 1000 to 2000 ha and a minimum annual production of 2500 tonnes of coffee, the minimum amount necessary to justify the investments necessary.

Perspectives

The development of sustainable and profitable agroforestry systems for coffee cultivation involves the selection and adoption by planters of new hybrid Arabica varieties adapted to low light conditions characteristic of agroforestry. This requires a better understanding of molecular processes that underpin a better adaptation to shading, in order to redefine selection targets, and create specific tools and methods. The example of *C. arabica* can be used by other agri-chains to offer varieties that are better adapted to agroecology. This is the case for the majority of tropical perennial crops. However, because of future climatic and epidemic challenges, and also to differentiate itself, and preserve biodiversity, it is necessary to not only create new varieties continuously, but also to produce them, market them and encourage their adoption by producers and industry alike.

For coffee, the research community, coffee companies and producers have collectively started to find solutions. While these solutions are still not perfect, they represent

8. https://www.moringapartnership.com/cafetalera-nica-france and https://www.oikocredit.coop/what-we-do/partners/partner-detail/46387/nicafrance-nicaragua-outgrower-holdings (retrieved on 15 April 2019).

significant progress. Finally, governance rules proposed for the coffee agri-chain must respect the rights of the countries that own the genetic resources (notably Ethiopia, Côte d'Ivoire, Central African Republic, Gabon, Cameroon, Angola, Democratic Republic of the Congo).

The BREEDCAFS project also aims to study the conditions required for the emergence of a seed industry for coffee-based agroforestry systems, while proposing rules governing the ethics and common governance for the conservation and access to genetic resources, and the creation and dissemination of varieties. This example of research into comprehensive governance of an agri-chain should inspire similar initiatives for other tropical perennial species.

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Part 2

Thematic focus

Chapter 10

The drivers of agroecology in sub-Saharan Africa: an illustration from the Malagasy Highlands

Jean-Michel Sourisseau, Jean-François Bélières, Jacques Marzin, Paulo Salgado, Florent Maraux

The controversies that surround the various definitions of agroecology reflect the current debates on the future of agriculture, its place in societies and the evolution of agricultural models. Some definitions of agroecology are more strict in their injunctions against the use of synthetic inputs, others less so. Some concern themselves only with the productive dimension while others take agroecological practices across the entire food system into account. Some incorporate the social and societal dimension of agro-industrial systems and alternative food systems while others do not (Altieri *et al.*, 2017; Reboud and Hainzelin, 2017; FAO, 2015). Some advocate family and peasant farming, as defined by FAO[1], or small-scale agriculture (these different forms of organization are described in Bélières *et al.*, 2014). The different definitions of agroecology also refer to various forms of collective or public action: the production of public goods; the building up of local capacities to manage the commons (Perret and Stevens, 2006; Knox and Meinzen-Dick, 1999); the different forms of learning, from the most academic to peasant-to-peasant training (Altieri *et al.*, 2012). Furthermore, with the reorientation of public funding and/or the expansion of the control of market forces to new domains, the issue of the globalization of trade is now at the heart of the differences between the definitions of agroecology: some embrace the globalization of trade in a liberalized world whereas others stand firm in radical opposition to this globalization.

We do not intend to rule on these controversies in this chapter since very many authors have already done so (Wezel *et al.*, 2009; Altieri *et al.*, 2017; FAO, 2015) as do some other chapters in this book. This chapter aims at examining the dynamics of change driven by agroecological transitions in sub-Saharan Africa by incorporating, in line with the definitions proposed by FAO[2], all the economic, social and environmental

1. http://www.fao.org/resources/infographics/infographics-details/en/c/270462/ (retrieved 23 December 2018).
2. http://www.fao.org/agroecology/knowledge/10-elements/en/ (retrieved 23 December 2018).

dimensions of change. To this end, this chapter revisits the notions of agroecological transition and agricultural intensification, the latter's various forms being at the heart of reflections on the definitions of agroecology and challenges of development, especially in sub-Saharan Africa. We then explore the issues and possible drivers of the agroecological transition as well as the demographic and macro-economic context in this region of the world. Finally, on the basis of the example of family farming in the Malagasy Highlands, we show the weighty influence of structural and social constraints in agricultural dynamics and – despite the extent of these constraints and the temptations provided mainly by buoyant markets to modernize and implement Green Revolution models – the resilience of a form of agriculture with very little intensification, many of whose practices are agroecological, and which persists in the absence of structural transformation. We conclude on the inadequacy of solely technical solutions (even when their performance is accepted), at least in sub-Saharan Africa, to meet the challenges of increasing incomes while controlling disparities, improving livelihoods, increasing production when necessary, and managing territories in a context of sustained population growth. There is therefore a real need for renewal of agricultural, food and territorial policies to accompany and support changes in family farmer practices, and to stimulate development of territories that promotes and leverages agroecological practices.

A controversial global movement with many local forms

In order to avoid ambiguity and to clearly describe the frameworks we use as reference in this chapter, it is necessary to list the main agricultural models found in sub-Saharan Africa.

Most of these models pertain to agriculture that uses few inputs (fertilizers or pesticides), has low levels of mechanization, and incorporates practices with agroecological aspects (use of peasant seeds, crop associations and rotations, short fallows, crop-livestock associations). For the sake of simplicity, we will call these models 'traditional' even though we admit that they originate from a historical process of adaptation. These combine on- and off-farm activities, with agriculture often being just one component within complex activity systems. Indeed, agricultural households strive above all to optimize the performance of these activity systems, and thus to optimize the contribution of agriculture within these systems.

Alongside these traditional models, there exists another set of agricultural models – whose implementation in this region of the world is not easy and thus its instances are encountered in very small numbers – that specialize in agricultural exports or in supplying to cities, with a higher level of intensification through the use of improved seeds and synthetic inputs, animal traction, often with greater control over water use. We will call this form of agriculture 'conventional', in reference to the Green Revolution model of intensification, now found across the planet.

Finally, a third set of agricultural models exists in specific situations. It includes agricultural production with foreign investments, especially on irrigated perimeters; alternative forms of agribusiness funded by national investors, generally novices themselves in agriculture; and highly capitalized farming in South Africa and in a few dedicated zones elsewhere. We will call this set of models 'mechanized conventional' since increased mechanization accompanies the intensification through inputs, significantly increasing labour productivity by reducing the amount of labour required for agricultural production.

At the global level, conventional agricultural models, whether mechanized or not, are being condemned for their negative environmental and social impacts and their lack of sustainability. Indeed, the research community has arrived at a consensus regarding their undesirability and shortcomings (IAASTD, 2009), as have international bodies governing agriculture and food (FAO, 2015, 2016). But the development of these conventional agricultural models is still being pursued implicitly in national and regional agricultural policies in sub-Saharan Africa. In this region, the necessity of intensifying production to increase food, energy and fibre biomass and to satisfy a growing demand takes precedence (this necessity, although less shared today on a global scale than in the past, remains generally accepted). In the end, the proposed solutions to the requirement of an agriculture that is more productive and, at the same time, less harmful to the environment and society, differ so much so that they become polemical. They range from the advocacy of the principles of the Green Revolution (Agra, 2016), to its softening through more natural resource-friendly ways (Griffon, 2013), to a call for radical paradigm shifts based on the ecologisation of production and the complete overhaul of food systems (Altiéri, 2012; Giraldo, 2018), or, on the contrary, to the exploration of agricultural models turned firmly towards new technologies and extreme artificialisation (Thérond *et al.*, 2017). But irrespective of the options selected, the solutions to the challenges facing agriculture all call for changes to the entire agrifood system; we cannot focus solely on the sector of production.

The debates around agroecology thus refer to divergent conceptions, largely pertaining to the circumstances of their emergence:

– an agroecology of practices, based on technical and organizational changes that do not affect the overall governance of agrifood systems and which is driven by the knowledge and understanding of the negative environmental externalities of the Green Revolution's technical model;

– an integral agroecology, more political, advocating a change of technical paradigm as well as a recomposition of food systems, breaking with the industrialization of production and consumption models (Giraldo and Rosset, 2018).

It seems necessary to add a third conception, corresponding to 'traditional' agriculture, especially prevalent in sub-Saharan Africa. It is not a matter of ecologising intensive agricultural practices but instead of intensifying practices that are already predominantly agroecological. Indeed, in this region, production systems have either incorporated the practices of the Green Revolution very minimally or have ignored them altogether. But they have to intensify production to respond to the demographic pressure that is fragmenting family farms and to growing consumer demand from both urban and rural areas. The pressure on resources increases the vulnerability of these production systems, whose sustainability depends on farmer knowledge and know-how that is little needed in the other two conceptions of agroecological transitions defined above. This local knowledge offers solutions adapted to soil fertility, crop associations and rotations, the diversification of production, the maintenance of cultivated biodiversity, crop protection, crop-livestock integration, the integration of trees into agricultural production processes, etc.

Table 10.1. Main characteristics of the three conceptions of agroecology.

	Agroecology of practices	Integral agroecology	Agroecological intensification
Type of farm	All	Small family farm	Family farm
Market integration	Maximum	Limited	Variable
Food system	Globalized	Territorialized	Variable
Labelling	No	Possible	No
Scope of change of practices	Plot and herd	From the plot and herd to the landscape	Plot, herd, and farm
Types of inputs	Synthetic	Variable, but in rather small quantities	Variable
Diversification of production	Not sought	Yes	Yes
Type of incentives	Case by case	Mixed	Few until now
Use of GMOs	Yes	No	Usually no

While these debates on the conception of agroecology are global, they also have a local dimension. The possible options vary widely depending on market dynamics and economic and social performance at a national or regional level. They also differ depending on whether the governance of agriculture and the food sector is conducive to implement and support changes effectively, and on how advanced are the Green Revolution processes of artificialisation and specialization (Baret *et al.*, 2013). An agroecological transition is invoked by all stakeholders advocating a change in practices and a break with conventional agriculture, mechanized or unmechanized. When this notion of 'transition' is applied to agriculture in sub-Saharan Africa, it refers to more than the simple injunction to 'go from one state to another'. It encompasses the leveraging of ecological practices and an evolution in the functions that agriculture must fulfil for society. But used in this way, it seems to describe a linear and comprehensive movement, even though the paths of ecologisation are extremely diverse. In particular in many developing countries that have at best only partly implemented structural changes in their economies, it has to confront specific challenges of creating jobs in unprecedented numbers, required due to rapid population growth and because industry and manufacturing still create very few of them (Pretty *et al.*, 2011; Losch *et al.*, 2012).

The 'agroecology of practices' and 'integral agroecology' conceptions refer most frequently to the conversion of post-Green Revolution agricultural models with high labour productivity and intensive use of synthetic inputs, water and land to more environmentally friendly models that leverage natural ecological processes in their technical itineraries and minimize their negative impacts on the nutrition, health and social equilibrium of the populations concerned (Gliessmann, 2015; IAASTD, 2009; IPES-Food, 2016; Griffon, 2017; Duru *et al.*, 2014). But entire sections of

African agriculture have never become part of the Green Revolution's productivist system. They do use agroecological practices but need to increase their productivity and therefore to intensify these ecological processes. In these situations, agroecological intensification is called for more than agroecological transitions. Indeed, in sub-Saharan Africa, the starting point of trajectories of ecologisation is a predominantly 'traditional' family model of farming because it is based on knowledge and know-how often ignored by the proponents of globalized research; the starting point is not an intensive productivist model which would moreover also lead to technological dependence. The drivers of change and the levers of agricultural policies are therefore radically different from those aiming at an agroecological conversion as advocated in Europe or in North America.

In sub-Saharan Africa, research is being conducted on the possible trajectories of agroecology, in particular by the IPES-Food[3] expert panel, the Alliance for Food Sovereignty in Africa (Afsa, 2016), and the ProIntensAfrica and LeapAgri[4] European programmes. Scientific repositories on the various forms of sustainable intensification (at least described as such in the literature) also exist, whether with a global scope such as conservation agriculture or agroforestry, or whether concerning only specific technical elements, such as integrated pest and disease management (Scopel *et al.*, 2013; Pretty *et al.*, 2011; Tittonell *et al.*, 2012). Thus, the ecologisation of agriculture can draw on the results of a growing amount of research and innovation. Proposals, often backed by research studies, focus on technical options for shifting 'traditional' agriculture towards alternative models and principles. These innovations usually combine a small amount of the knowledge specific to local territories and ecosystems with exogenous elements that have been proven elsewhere, most notably during agroecological transitions of conventional agriculture (mechanized or unmechanized) undertaken in industrialized or emerging countries. This hybridization between local knowledge and exogenous knowledge is a veritable scientific challenge because it must, on the one hand, create *ad hoc* statistical tools to take into account the complexity of traditional practices and, on the other, construct new knowledge specific to agroecological intensification of traditional practices in sub-Saharan Africa.

Furthermore, agroecological transitions are often promoted without any specific prior reflection on the conditions required for and the available room for manoeuvre in a true transformation of agricultural and food systems. And yet, any technical change (use of new inputs and materials) or organizational change (emergence of value chains adapted to different forms of agroecology and integration of producers in these value chains, emergence of logistical and organizational chains for supplying planting material or organic manure and for supporting small-scale mechanization) requires physical and cognitive capacities that are not immediately obvious. The emergence of agroecological intensification in sub-Saharan Africa must enable farms to move beyond the defensive logic of adapting to risks and pressures on resources which curbs their ability to innovate (Whiteside, 1998). Technical innovations must be accompanied by favourable changes in the environment not only of family farms but

3. http://www.ipes-food.org/_img/upload/files/West%20Africa%20concept%20note_EN.pdf (retrieved 7 May 2019).

4. www.intensafrica.org, http://www.leap-agri.com/

also of all actors involved in food systems: improving access to means of production and market-friendly public goods (communications, transport, storage, regulations, traceability, etc.), and the structuring of the actors in the various agri-chain and food system segments so that they can influence the definition and implementation of agricultural development strategies and even of the models of development.

Finally, the polysemy, the inaccuracies and incompleteness of the concept of the 'agroecological transition' call, especially in sub-Saharan Africa, for an improved understanding of the aspirations of the different types of actors and of the actual drivers of agricultural transformations at different levels of decision-making and coordination. This understanding applies to production systems and agrifood systems. It also applies to the capacity of States to orient food and agriculture evolutions and to build up the capacities of stakeholders. Before we take a look at the case of the Malagasy Highlands, we will find it useful to discuss the sometimes ambiguous relationships mentioned in the literature between agroecological intensification and agroecological transition.

Old debates partially revived

Agricultural intensification is mainly defined along three main dimensions: higher yields per hectare for a given crop; higher yields per unit of time due to an increased number of crop cycles per year; replacement of low-yield varieties with those that have higher yields per hectare or generate higher incomes per unit of production (Naylor, 1996).

The equating of intensification to an increase in the quantities produced (of goods and/or their value) and to the growth of factor productivity (land, capital, labour) refers to an older and wider debate on the causes and drivers of agricultural transformation. According to Le Bras (2003), despite their divergences, Malthus and Boserup, in their approaches to the links between livelihood production and population growth, both define intensification as the quest for the best combinations of resources and production factors to meet subsistence needs. The requirements of mathematical modelling have led, in the attempts to formalize the work and conclusions of these two seminal authors (from the works of Quetelet to those of Solow), to the simplification of their hypotheses. In this simplification, intensification is no longer a matter of equilibrium but instead a quest for increasing the overall productivity of factors, especially labour and land, in order to generate a higher monetary income at the farm level. The same simplification is at work in the agronomic conception of intensification. Rather than seeking an equilibrium, the quest for a permanent increase in the quantities produced and in incomes leads to the introduction of an imbalance, which then has to be managed over time. This exigency of managing the imbalance forces farmers to shift from a quest for subsistence self-sufficiency to an increased reliance on stakeholders and elements outside their farms and food systems.

In line with the Malthusian and Boserupian principles of agricultural intensification as redefined by Le Bras (2003), we can recast agroecology as the search for a balance in the management of a set of resources. In these authors' framework, this balance is first and foremost a response to increased pressure on natural resources, especially due to demographic growth and the associated need for increased production (Bonny, 2011; Brookfield, 2001). But this reasoning can be extended to monetary needs, climate change adaptation, biodiversity conservation and restoration and, more broadly, the production of public goods benefiting society as a whole. In this more holistic reasoning, the drivers of intensification and agroecological transitions will no longer be solely focused on increasing production in volume and value (Duru *et al.*, 2014).

Therefore, agroecological transitions should be intensification movements aimed at maximizing, for society as a whole, a set of environmental, social and economic services that ensure the sustainability of agricultural production, food systems and the development model. While 'integral agroecology' is in line with this definition, the 'agroecology of practices' – with its more limited scope – is not. It is essential to conceive agroecological intensification in the light of these objectives.

It is important, especially in the context of agroecological intensification for sub-Saharan Africa, to accord value to environmental and social services, either through the prices of goods and services along the agrifood chains or through other non-market incentives. The necessary changes are significant and difficult to imagine without strong public action not only to ease the constraints on actors who want to initiate transitions, but also to promote price relationships that do not penalize these actors in the face of competition from those who do not engage in ecologisation. It is clear that the different agricultural models are not equal in terms of the levers they can mobilize and the support they can expect from public authorities.

The agroecological transition in the context of the major challenges confronting sub-Saharan Africa

Sub-Saharan Africa is the last major world region to begin its demographic transition.[5] The rate of decline is much slower than those experienced earlier in other parts of the world, especially Asia. The current population in sub-Saharan Africa is expected to double to 2.5 billion in 2050, while China and Europe will see their populations decrease during the same period (Losch, 2016b). Africa will account for 53% of the increase in the world population in the next three decades (United Nations, 2017). This is due to the high number of children born per woman on the continent – between four and five for Africa as a whole and up to more than six in some countries in the Sahel.

One of the consequences will be the densification of most rural areas. Sub-Saharan Africa is urbanizing rapidly (between 2014 and 2050, the share of the urban population in the total population will increase from 37% to 55%), but the rural population will continue to increase after 2050. Furthermore, this region will probably not be able to fully benefit from the demographic dividend, the favourable period in a country's history when the economy takes off, during which the ratio of inactive to active workers declines, with fewer dependent youth not yet of working age and as yet few older people

5. This section draws largely on *Une nouvelle ruralité émergente, Regards croisés sur les transformations rurales africaines*, published by NEPAD and CIRAD (Pesche *et al.*, 2016).

(as has happened in other parts of the world). This phenomenon will be weak and dissipated in this region because of the slow decline in fertility while the aging of the population accelerates because of longer life expectancies (Guengant, 2011).

A mass of new workers will struggle to find employment in the poorly diversified national economies where primary and especially agricultural activities still provide the majority of employment. Indeed, another specificity is that the sub-continent is not yet engaged in its economic transformation. Young people entering the labour market are unlikely to be employed by a still embryonic manufacturing sector or a small formal tertiary sector. They will have to find jobs or activities in agriculture or in the informal urban sector, which while dynamic currently offers few decent jobs. Furthermore, while the informal sector can be a source of innovation and creativity, it offers few levers of redistribution because it escapes taxation. More broadly, the dynamism of this informal sector raises the question of a need to renew modes of governance to better recognize it, so that the economy can be modernized and diversified outside the primary sector.

This overview compels us to question the capacities of the agricultural sector to meet these challenges. The rapid modernization of agriculture in 'developed' countries has led to a concentration of the means of production in a smaller number of farms and to a rapid increase in labour productivity thanks to mechanization and, consequently, to a shift of a large part of the agricultural labour force to other sectors. In sub-Saharan Africa, any such process of modernization will be constrained by the insufficient diversification of national and territorial economies.[6] Unable to rely in the medium term on industrial development or on the formalization of the tertiary sector, agricultural models and the various types of intensification will have to offer decent jobs to the majority of the working population which is still in fact, by choice or lack of choice, in agriculture. It is therefore necessary to adopt strategies of economic diversification while maximizing the employment potential of agriculture (as also, more broadly, of the entire primary sector), which requires us to go beyond sectoral reasoning alone (Losch, 2016a).

Sub-Saharan Africa therefore still needs agriculture to be the engine of growth and transformation. But this agriculture needs to be inclusive, anchored in ever-densifying territories, provide increased income and food security for rural and urban dwellers, and generate decent jobs in massive numbers in rural areas. It must do so in a context of high vulnerability of the agricultural world and of climate change that is fast modifying the conditions of production. And it must also do so in a globalized, increasingly competitive market, with volatile national and international prices of agricultural products, and the pressure of prices of conventional inputs (whose production is concentrated in industrialized countries), even as African countries have ever fewer possibilities of protecting their agriculture from outside pressures.

Agroecological intensification as defined above seems to be a promising path for sub-Saharan Africa, especially to confront the challenge of employment (Pretty *et al.*, 2011). The (albeit rare) comparisons in the literature between agroecology

6. Since the urban architecture of sub-Saharan Africa is characterized by the domination of capital cities and secondary towns with weak infrastructure and little economic diversification, the issue of agricultural employment becomes even more strategically important in most territories.

and conventional forms of agriculture in terms of employment and performance confirm this potential (Pimentel *et al.*, 2005; Altieri *et al.*, 2012). In addition, agro-ecological practices seem to be well-adapted to the social, economic and ecological environment of the sub-continent's family farms: they are less intensive in physical and financial capital, and they better leverage *a priori* the social and cultural capital of rural territories and local resources (knowledge, natural resources, etc.) without leading to technological dependencies. Such agroecological intensification would require, as would the generation of decent jobs, the services rendered by a more virtuous agriculture, currently mainly non-commercial, to be remunerated. It would also require far-reaching voluntarist policies to be put in place. Such viewpoints, however, are not in line with the changes in agriculture and food systems currently being promoted in sub-Saharan Africa. Policies oriented towards the quest for competitiveness in globalized commodity markets, modelled on those of the Green Revolution, still dominate.

At the level of the sub-continent, demographic pressure and uncertainty over the availability of productive resources, especially land, drive agricultural transformations and not market signals, the preservation of the environment or the ability to change food systems.[7] Land pressure generated by foreign or domestic corporate investment in agricultural production is another factor contributing to the weakening of traditional agriculture. It should also be noted that national and local public policies have, in the recent times, had little positive impact on transformations of agriculture and the food sector. The most striking innovations are those conceived by producers and food system actors themselves, and they are more in line with a strategy for preserving the means of production and diversifying income-generating activities than an ecologisation of practices. The example of the Malagasy Highlands, which we describe in the next section, is an apt illustration of these constrained mechanisms.

A restricted development of agroecology: the case of the Vakinankaratra region in Madagascar

Our case study takes a look at factors that block transitions in production systems, and opens up perspectives for a better taking of food systems into account to remove these blocks. In the Vakinankaratra region in Madagascar, the favourable natural environment for agriculture production, the diversity of production systems, the farmers' know-how and some more or less well-structured agri-chains involving different public and private actors all constitute a real potential for agricultural development. But agricultural policies have not so far been able to trigger the structural transformation of agriculture and the rural economy, either through conventional intensification – even though widely promoted – or by encouraging the intensification of existing agricultural practices. These polices will thus be forced to evolve given the already high and steadily increasing demographic pressure.

7. For examples, see the case studies describing the drivers and realities of agricultural intensification in sub-Saharan Africa at http://www.intensafrica.org.

The obstacles in the path of agricultural intensification

Over the last 20 years, three major and broadly contrasting orientations have characterized these policies, largely inspired by the major international agencies:
– the withdrawal of the State;
– the desire to increase production not only to ensure the food security of a growing population, especially urban, but also for exports;
– the taking into account of environmental aspects, in particular at the instigation of the major international conservation NGOs, as also with the integration, at least partially, of the concept of sustainable development in the drafting of rural policies (Raharison, 2014; Bosc *et al.*, 2010).

Agricultural policies were essentially aimed at promoting conventional intensification and saw an acceleration during the 2000s. Most importantly, given the limited public funding resources, it became necessary to introduce tax incentives for agribusinesses to establish themselves in the country and set up economically efficient production agri-chains (Burnod *et al.*, 2011). At the same time, aid was provided to facilitate access to inputs for small-scale family farming. These policies have not produced the expected results because of institutional bottlenecks and the inadequate production and market infrastructure. Irrespective of the size and form of the production units concerned (poorly differentiated and poorly equipped family farms, or foreign-funded agribusiness companies), the production and market environments remain extremely unfavourable. More recently and gradually, policies have begun advocating agroecological intensification practices, notably with the promotion of the system of rice intensification (SRI; Serpantié, 2013) and conservation agriculture (Penot *et al.*, 2015), but these practices have not seen any significant adoption so far. For example, in mid-western Vakinankaratra, only 2% of farms use planting under cover techniques, four years after a dissemination project ended (Razafimahatratra *et al.*, 2017). There has been limited and insufficient conventional and agroecological intensification, with farmers having to deal alone with changes in an environment that is not conducive to risk-taking. Agricultural policies are not solely responsible, however. At the national level, the succession of political crises since independence has led to the deterioration of the main socio-economic indicators (see in particular Razafindrakoto *et al.*, 2017) and to a blocking of structural change.

The country remains very agricultural: almost 80% of households have at least one member participating in agricultural activity (Instat, 2011). There is widespread rural poverty because of the low agricultural productivity as well as – and especially so – because the factors of production are not available to families. Even though the population has doubled in a single generation, the secondary and tertiary sectors are struggling to develop and are unable to absorb the young people entering the workforce; the agricultural sector thus absorbs most of the population growth. At the macro-economic level, the net per capita production index is declining as is the ratio of exports to imports of agricultural products. Due to increasing population pressure, productive resources are being exhausted and in most cases no longer allow families to meet their needs.

According to agricultural censuses, in 1985, the average surface area per farm in Vakinankaratra was 1.07 ha. This figure had dipped to 0.55 ha in 2005 (MAEP,

2007) due to population growth and the intergenerational transfer and division of family assets. The proportion of farms that were smaller than 1.5 ha in area was 84% in 2010 (Instat, 2011). The average number of cattle per farm declined from 6 to 4 in 20 years. These continuing trends are resulting in very high land pressure in some areas today, with average holdings of 0.4 ha and only 3.3 heads of cattle (Sourisseau *et al.*, 2016). And yet, there are very sparsely populated areas across the country and even in the Vakinankaratra region, which are potential spaces for the extension of agriculture. But these areas are remote, without infrastructure and suffer from a lack of security. There exist no significant land development policies that could allow the shifting out of small family farms from the most densely populated areas (Bélières *et al.*, 2016). Farms instead rely on intensification strategies that involve the diversification of activities.

The figures cited in the following paragraphs are taken from two studies. The first is on the functioning of farms and the agrarian system in mid-western Vakinankaratra (Razafimahatratra *et al.*, 2017). The second focuses on the trajectories followed by 24 family farms in the region, endeavours to understand the implementation over time of intensification processes (Rakotoarisoa *et al.*, 2016), and then identifies perspectives for enhanced ecologisation of agriculture (in the sense of an improved integration of natural processes in cultivated processes) that could be propitious to development.

Farms with the highest farm incomes in absolute terms and by family worker are those that undertake the most activities: lowland rice, rainfed crops on hill slopes (*tanety*), fruit or market-garden production, dairy farming, small-scale livestock husbandry, combination of on- and off-farm activities, etc. Rice farming, especially in its irrigated or flooded form, occupies a prominent place in the farms' portfolios (42% of the cultivated surface area and 58% of the gross crop production) because it ensures the family's food base and, in addition, because enough production is left over for sales (about one-third of the production). Many other crops are grown: 40 annual or perennial species were encountered in a survey of 240 farms (Raharison *et al.*, 2017). Close to half of the farms include at least four major crops in their rotations: rice, maize, legumes, and tubers. The practice of crop association is widespread: 78% of farms have at least one plot cultivated in association, and a total of 22% of the plots by number and 27% by cultivated area are covered by crop associations, a significant quantity given that lowland rice accounts for 28% of the annual surface area and is cultivated as a pure crop. The associations are very diverse: a total of 44 different ones were encountered. In general, polyculture is combined with livestock farming. Cattle, swine and poultry farming are practised by 70%, 65% and 80% of households respectively. Cattle husbandry is widespread with 56% of the holdings owning at least one zebu, but the distribution of the animals is uneven (4% of holdings own 36% of the capital represented by the animals). Livestock husbandry provides animal traction and most of the manure applied to the fields. The use of purchased agricultural inputs and, in particular, of mineral fertilizers, remains low: 24% of farms use them at a dose of less than 40 kg/ha/year, which works out to an average dose of less than 20 kg/ha/year across the region's total cultivated area (Razafimahatratra *et al.*, 2017). Phytosanitary products are used a little more (40% of farms), but at very low doses because they are mainly limited to insecticides and fungicides to treat seeds (average annual expenditure of 10,000 Ar[8] per farm, i.e. less than 3 €). The use of veterinary products is more widespread (79%) but the average amounts are again small (41,000 Ar/year, or about 10 €). Labour costs (daily labour or paid by the task) account for 90% of the total cultivation expenses. Labour remains mainly manual, although animal traction is widespread (43% of farms). The majority of farms choose to use organic manure originating from livestock effluents. Due to small acreages, farmers prefer to recycle nutrients within the farm to save cost. The saturation of lowlands for irrigated rice cultivation has favoured the cultivation of rainfed crops, especially rice, on hill slopes. The extension of rainfed rice is therefore a form of agroecological intensification through diversification and improvement of the rice systems themselves, for which the research community has provided substantial support.

Diversification of activities is a part of anti-risk strategies for dealing with shocks. Thus, following the political crisis of 2009 – which brought the activities of one of the largest milk processing companies to a halt, led to a sudden deterioration in market conditions, and resulted in the loss of outlets –, some dairy farmers who were engaged in a process of conventional intensification turned instead towards agroecological intensification processes in an effort to reduce their dependence on the supply of inputs. Diversification is a structural element of the intensification strategy itself, which aims at a better leveraging of the farm's resources by relying on the integration of activities and on their complementarities. The most intensive and most productive farms are generally those that are the most diversified. These characteristics, combined with low use of mineral inputs and a virtual absence of motorization, move these farms away from the principles of conventional intensification. Their practices pertain instead more to an agroecology that optimizes resources and local knowledge. The systems are diversified, based on crop associations and rotations, crop-livestock integration, landscaping with mainly manual labour (rice fields and terraces), intensification through labour (manual transplanting, thinning, weeding), etc. There is even some resistance to the adoption of conventional techniques, most often due to difficulties of access or cost considerations, but also sometimes because of cultural references concerning 'respect for the land'. Much more is at work here than just anti-risk strategies, with practices that rely on real know-how and empirical knowledge of agroecology, which could even provide inspiration to the research and development communities (Raharison *et al.*, 2017).

Surveys show that the availability of factors of production and their suitability for economic and social needs are the key elements of evolutionary processes. Imbalances between farm demographics and the distribution of the means of production prevent changes and have adverse effects on farm productivity. The most frequently encountered imbalance pertains to land. A farm that sees its family workforce increase while the already limited land available to it remains the same no longer has the resources to increase family labour productivity on the farm. The family can supplement its income only by looking for off-farm, often low-paying, activities (agricultural labourer, coalman, brickmaker). And yet, productive capacities are sensitive to the fragility of the human capital: diseases and deaths are shocks that sometimes force farming fami-

8. Ariary, abbreviated Ar, is the Malagasy currency.

lies to sell traction cattle or land. The land market is indeed very active in this region of Madagascar, with transactions taking place mainly between family farms. While this phenomenon does not lead to real land concentrations, there are inequalities; the less well-fortunate families work as labourers on the richest farms. These factors restrict investment capacity and limit a family farm's room for manoeuvre in its effort to intensify its agricultural activities.

The trajectories are moreover fragile and sensitive to external shocks. In the sample surveyed, several farms suffered one or more shocks that often contributed to drops in the families' standards of living. The most common shocks result from climatic hazards, insecurity (theft) and pest damage. Some farms have seen their entire herd succumb to disease; others have seen their herds, painstakingly built up over the years, stolen in one night.

At the technical level, access to land, the reduction of arable land and access to agricultural inputs of all sorts remain major constraints. Seeds of improved varieties and agricultural inputs are difficult to obtain due to lack of distribution channels, high transport costs and a weak private sector. Moreover, at present, given the relative prices of inputs (high) and agricultural products (low), it does not make economic sense to use inputs, all the more so since the prices of agricultural products fluctuate sharply.

Price structures are unfavourable to producers, given the fragmented supply, non-existent infrastructures and agri-chains dominated by traders (collectors and wholesalers) who impose prices. The lack of organization of markets and their poor performance, in conjunction with a chronic weakness of producer organizations and the fluctuation of prices, are real roadblocks to improving farmer incomes. The low level of agricultural productivity is also linked to the very limited capacity of farmers to make productive agricultural investments. Only 10% of rural households take loans from financing institutions, and this at very high rates of interest (often around 3% per month). In the sample, farms in a favourable situation were those that have been able to invest recently in production factors (especially land). These investments were made possible by farm or off-farm income, or through risky actions, such as the sale of livestock, especially traction cattle, in order to take advantage of an opportunity to buy land.

Prospects for deriving benefits from agroecological practices

One of the main constraints of the region's family farms is their very low productive capacities (land, animals, material and equipment, land development). Policies that encourage these farms to derive value from existing land reserves will have to be adopted. This requires agricultural policies to be conceived as part of comprehensive territorial planning policies: roads, security, social infrastructure, and aid for setting up farms in new areas. Investments over the medium term in already cultivated areas are also needed: development of terraced or paddy fields; sources of funding to allow the amendment of land; the dissemination of varieties adapted to rotations, associations and double cropping; the development of agroforestry and conservation agriculture techniques; the purchase of animal traction equipment and motorized equipment;

the purchase of improved but sufficiently rustic animal breeds, etc. Combinations of comprehensive territorial planning and investment support for family farms, including for labour, can act as levers, provided that the farms of the most vulnerable receive significant subsidies (HLPE, 2013).

At the same time, innovations must be designed for diversified and highly agroecological systems. The dissemination of very targeted innovations for a cropping system or a livestock husbandry unit, with the application of conventional intensification techniques, leads to specialization and increases the farm's vulnerability. Such targeted innovations can only have limited impacts on the overall productivity of the family farm and, in particular, on income per family worker. The relevance of innovations has to be assessed in terms of the increase in this income per family worker and its long-term stability. Since this income results from complex activity systems, only systemic approaches can be used to understand and improve the processes underway on farms and in the territories to which they belong. A new production, variety, equipment or technique may well be successful in improving agricultural productivity, but to be sustainable, this improvement must be perceived throughout the entire activity system. Given the producers' low investment capacities, the innovations proposed will have to rely mainly on taking advantage of available natural resources and the intensification of natural processes within production systems. But the dynamics of agroecological intensification have to be more in line with the interrelations between the different parts of the systems implemented.

Similarly, it is important to have assured outlets for production and to integrate farms into more organized and better articulated agri-chains. And given the low level of each production, performance must be assessed in terms of the results of a combination of agri-chains and activities. So far, in Madagascar and elsewhere, agricultural intensification has been driven by a specialization of producers and agri-chains, with a gradual vertical concentration by companies seeking to control part of the growing markets of the globalized food system. Agroecological intensification is intrinsically diversified and products can be marketed only through a range of agri-chains and operators, also diversified, which is certainly not conducive to economies of scale and the optimization of technico-economic processes. Under these conditions, agroecological intensification does not lend itself, *a priori* and especially in the Malagasy context, to specialization and the vertical integration of agri-chains. It calls for a more 'flexible' organization of the agrifood system's upstream components – agri-supply, bank credit, and production services – to meet both the demands of the market and the diversity of productions. However, one should not assume that specialization and professionalization go hand in hand. On the contrary, agroecological intensification requires more professionalization on the part of producers and other actors, especially upstream of production.

In this respect, greater coordination between the local authorities and the central State, favouring a territorial and holistic vision of transformations, is desirable and would make it possible for the gains of an agroecological intensification to be perceived at the level of the farms' activity systems. It is also useful to strengthen farmer organizations to fight against asymmetries along the agri-chains, make development actions sustainable over the long term and position them in a systemic perspective. The research and development communities should engage in improving their knowledge of food systems as a whole and of the place of producers and their organizations in these systems.

Policies change regularly, but often promote imported models – or, at best, hybrid ones –, with very little support for investment in family farms, a tendency towards sectoral and specialized visions, and a lack of long-term commitment. The agri-chains suffer from inadequate infrastructure, coordination, and support for value addition. Indeed, the farmers' strategies are already based on the quest for diversity and self-sufficiency of their farms on the basis of processes largely relying on agroecology. In the face of structural constraints and the level of risk, any major artificialisation of agricultural systems appears to be an unrealistic and undesirable objective for family farms in Vakinankaratra, in contrast to a promotion of agro-ecological intensification that creates jobs and which is already emerging in this region's peasant systems.

Conclusion

In the revived debates and wider discussions on the conceptions of agroecology and the nature of the transitions to promote, the example of the Malagasy Highlands shows how important the starting point of the agricultural models concerned is in planning their evolutions. The trajectory of traditional agriculture – the form of agriculture that is most widespread in Madagascar as also in the whole of sub-Saharan Africa – is that of agroecological intensification. It is also, ultimately, the continuation of this agroecological intensification, very different from the agroecology of practices or integral agroecology which are the usual solutions proposed to replace conventional intensification, that appears to be the most adapted to the resources and the vulnerability of these farms.

For this agroecological intensification to be able to take place, it is imperative to take into account the demographic and economic contexts, the factors of production the farms are equipped with, and the availability of and the accessibility to natural resources. It is necessary to start from existing practices and know-how, which in most cases in sub-Saharan Africa can be considered as agroecological. But this knowledge and these practices are part of activity systems that are both complex and more 'sophisticated' than the 'packages of technological innovations' proposed by the agronomic research community. It is also necessary to assess and understand the actual room for manoeuvre of the systems concerned. One must avoid promoting technically solutions that are desirable and coherent solely in a sectoral perspective or an agricultural specialization perspective, but which may simply not be applicable or accessible. In addition, given the diversity of situations, it is essential to design an approach suitable for territorial diversity. An 'intensification through diversification' thus seems to be the solution. It also imparts value by mobilizing various actors and by building up their capacities of innovation in order to help them manage a greater complexity. It shifts agroecological thinking from the plot or the farm to food systems and territories in which farmers operate.

To support these dynamics, it is therefore necessary to revamp agricultural and food policies to make them territory-centric by identifying and leveraging specific territorial resources. As far as agroecological intensification is concerned, it is a matter of defining agricultural and food strategies that rely on these territorial resources. Of course, this encompasses market strategies, in particular the identification and leveraging of quality brands, but the reasoning can be extended also to the management of food systems adapted to local realities: distribution of value, better linkages between the agrifood industry and local markets, redistribution allowing investment in public goods, ensuring greater consistency with the opportunities and practices of agricultural and non-agricultural diversification, etc.

The example of the Malagasy Highlands finally shows that technical solutions alone will not be sufficient levers to significantly and sustainably improve livelihoods and the quality of agrifood systems. The roadblocks are such that it is difficult to imagine any positive development without massive and coordinated public action, not only at the farm level but also at those of agri-chains and territories.[9] It is essential to generate knowledge to evaluate the different options: agroecology of practices, integral agroecology and agroecological intensification. Above all, we consider it important to determine the strategies that can remove the constraints and to estimate the methods to implement in order to seize the opportunities offered by agroecological intensification, an option that we now believe is the most viable, not only in Vakinankaratra, but also for the majority of family farms in sub-Saharan Africa.

More broadly, and irrespective of the option chosen, it is also necessary to document better the economic and social performance of these different forms of agroecology at the level of activity systems of family farms and at the level of food systems. Indeed, a radical change in the power relations currently prevailing in price-setting mechanisms, and a decision to effectively pay for agricultural and agri-chain services (so called ecosystem services) are needed. Without such changes, agricultural systems and food systems will not be able to initiate an agroecological intensification in today stifled situations in sub-Saharan Africa.

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9. In the case of Madagascar, the poorest households do not have the capacity to diversify their activities or to respond to conventional public policy incentives. Other forms will have be considered to trigger a transformation. Unconditional cash transfers and public facilities can be part of a possible toolbox, but specific innovations remain to be invented.

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Chapter 11

From natural regulation processes to technical innovation, what agroecological solutions for the countries of the Global South?

Éric Malézieux, Bruno Rapidel, François-Régis Goebel, Philippe Tixier

Agriculture today is faced with new challenges on a global scale: climate change, loss of biodiversity, increasing scarcity of arable land, and exhaustion of resources. The significant increase in productivity over the past 50 years in the countries of the Global North has resulted in large-scale use of fossil fuels and chemical inputs, and has led to a significant negative impact on the environment. Moreover, the substantial and ever-increasing use of pesticides is leading to deteriorating water quality and proven adverse impacts on the health of agricultural workers and consumers.

Agroecology has emerged within this context despite the fact that its development is still caught up in strong societal debates. It is, at the same time, a scientific discipline, a social movement and a set of agronomic practices (Wezel *et al.*, 2009). Irrespective of the definition selected (the political dimension remains a controversial subject), most of the authors who study it agree on a number of biological principles that must guide the functioning of agrosystems. Agroecology is thus based on a core principle: the use of natural processes, often associated with biodiversity, to ensure ecosystem services, including agricultural production. This emphasis on natural processes requires profound changes in current technical systems. These modifications also entail a radical change in the objectives and modalities of agronomic research, one of which, in addition to the development of innovations, is to support actors in their trajectories of technological change.

The aim of this chapter is to identify the scientific knowledge underpinning the biophysical functioning of innovative agroecological farming systems that are being or have been adopted by farmers at a more or less large scale, or which forms the basis of innovations initiated by farmers. While the agroecological movement concerns agriculture in the countries of the Global North as well as in the Global South, our focus in this chapter is on small-scale farmers. Indeed, the situation of small-scale family farming in the countries of the Global South remains unique: most often it remains untouched by the technological revolution, and its sustainability is often based on biological regulatory mechanisms within agrosystems. We will attempt to identify these mechanisms since such agricultural systems can serve as examples in many cases. Local or traditional knowledge can indeed form the basis of sustainable solutions for crop protection and resilience to climate change, since they preserve biodiversity and rely on natural regulatory processes.

In most cases, it is not easy to convince conventional farmers to adopt agroecological practices. Indeed, this new farming method frequently entails major changes in cropping systems, which could be construed as risks by these farmers. For example, there is some reluctance to move away from an intensive system that uses significant amounts of pesticides to an integrated crop protection system or from a system of integrated protection to agroecological protection of crops.

While we must continue to produce scientific knowledge and take advantage of it, it is not the only source of innovation in agroecology. Innovation relies on the ability of actors to mobilize knowledge from various sources and, based on it, to work together to create new knowledge through organized interactions on challenges, constraints and opportunities faced by farmers and societies. While research occupies a key place in the development of innovations, it needs to be recast in the new agroecological context. The examples provided in this chapter are part of this perspective: to provide the most generic knowledge possible to help co-design innovative agroecological systems that represent a sustainable alternative to conventional agriculture.

Concepts and principles for an agroecological agriculture

Natural ecosystems, agrosystems and agroecology

Natural ecosystems often share common characteristics: a high level of biodiversity, permanent soil cover, the presence of woody species, numerous inter-species interactions, etc. In contrast, intensive agrosystems have systematically eliminated these characteristics: drastic reduction in biodiversity (down to a single plant species in the cultivated field), deep and frequent tillage, removal of woody species, and reduced species interactions.

While agrosystems most often consist of a very limited number of cultivated species, natural ecosystems enjoy a rich biological diversity which provides a large number of ecosystem services. Consequently, the agroecological approach is based on a key hypothesis: it is possible to produce sustainably by relying on ecosystem functionalities and by reinforcing biological regulatory processes that result from biodiversity. The approach therefore consists mainly in introducing – or reintroducing – and managing a functional, cultivated and associated biodiversity into intensive agrosystems (which formerly relied heavily on chemical inputs) in order to take advantage of this introduction or reintroduction in terms of ecosystem services.

This approach can be implemented at several scales, from the field to the landscape. As demonstrated in practice, the introduction of biodiversity has significant implications for the functioning of an agrosystem (Malézieux, 2012). Depending on the species and implementation methods selected, it allows more specifically:
– to use the complementarity of functional traits between different species for a better utilization of resources, and thus increase the cultivated ecosystem's total productivity;
– to ensure a permanent presence of soil cover or even tree cover;
– to increase heterogeneity and thus interactions within the system;
– to promote natural regulation of pests and diseases within food webs;
– to use the properties of plants for pest and disease control (attractive and repellent natural substances).

Incorporating a greater plant diversity in space and over time also increases soil organic matter content and improves the biological functioning of soils. Increasing plant diversity is thus crucial to designing agroecological cropping systems (Malézieux *et al.*, 2009). However, there is no simple solution that can be implemented to manage biodiversity. Indeed, only groups of appropriate species, accompanied by a management favouring all the regulatory mechanisms, make it possible to obtain these benefits and increase production, leading ultimately to more sustainable agrosystems. Figure 11.1 endeavours to summarize all the relationships between objectives, processes and innovations in agroecological systems.

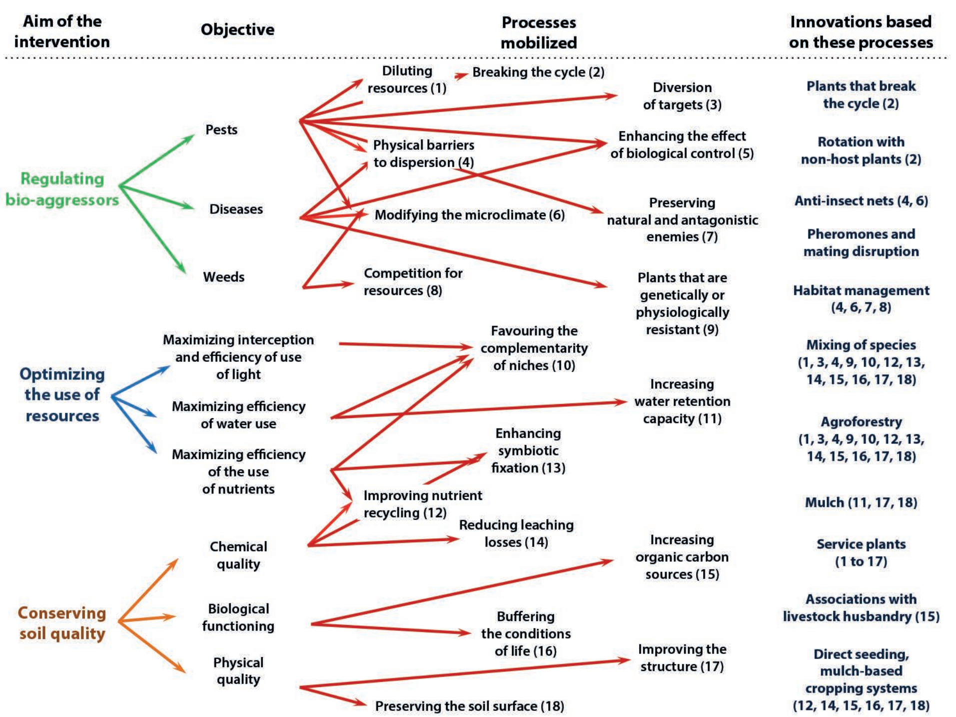

Figure 11.1. Concepts and processes used in agroecology with the aim of reducing the use of chemical inputs (based on Ratnadass *et al.*, 2012; Husson *et al.*, 2015).

The recourse to ecological concepts

As its etymology suggests, agroecology uses concepts from two disciplines: agronomy and ecology. The concepts of ecological niche, species dispersion, biological interaction, community dynamics, multi-trophic interactions, functional redundancy and complementarity are, for example, essential for creating agroecological systems. While these ecological concepts help better understand the functioning of natural ecosystems, their application in agriculture is one of the scientific challenges of agroecology. Examples illustrate how these concepts can be used to design more sustainable agrosystems. Functional complementarity is, for example, an essential element of species association: the association of two species is based on the principle that individuals of one species will be less in competition with those of another species than with individuals of their own species. In ecology, the ability of plants to perform the functions necessary for the survival of the ecosystem is represented by functional traits. This approach has also been recently used in agronomy to study some crop associations (Damour *et al.*, 2018). Aboveground functional complementarity makes it possible to control, or even optimize, the utilization and recycling of resources (see Box 11.1). Functional complementarity has also been mobilized for root systems in order to promote the use of different niches by species with opposing strategies for acquisition, conservation and use of resources (Weemstra *et al.*, 2016).

Plant diversity and control of pests and diseases

By integrating new plant species into the agroecosystem, it is possible to mitigate the impact of insect pests and diseases through several methods which can also be combined (Figure 11.1):

– by using the dilution of resources and diversion phenomena in insects, based on visual and olfactory effects of plants (in-figure nos. 1 and 3);
– by disrupting the pest's life cycle in space using non-host effects (2 and 3);
– by encouraging dynamic allelopathic effects in the soil;
– by promoting specific enemies of the pests and diseases present in the soil;
– by increasing the plant's physiological resistance through an optimized supply of nutrients in the cropping system;
– by stimulating pest control effects through the predation of plant pests, by conserving their natural enemies (7);
– by modifying the architecture of plants to create physical barriers and a microclimate unfavourable to these pests and diseases (4 and 6).

The aim of pest control through 'conservation' is to promote the presence of natural enemies (7). It involves taking the interactions between insects and their natural or cultivated habitats into account in order to then shape these habitats to increase the effectiveness of biological control. These new practices often aim to optimize the conservation of natural enemies in a given area, including in the agricultural plot (Box 11.2; Landis *et al.*, 2000; Altieri and Nicholls, 2004). This requires a knowledge of all the key elements of the landscape surrounding the agricultural plot or farm: the natural vegetation, its location, its characteristics, its size and the plant species present, the fallows, the hedges, the groves, etc. This approach can well be combined with 'traditional biological pest control by augmentation or acclimation of natural enemies of such parasitoids', which favours their artificial introduction in the target agrosystem.

Box 11.1. The association of coffee and erythrina

B. Rapidel

The commonly practised intercropping of coffee and erythrina (*Erythrina* spp.) is a good example of the functional complementarity between species: while erythrina exhibits a strategy of rapid growth, low reserves and induces a very rapid litter decomposition, the coffee plant exhibits a completely different behaviour (in terms of Leaf Economic Spectrum) (Wright *et al.*, 2004), with a dense and decay-resistant wood, and a low specific leaf area (SLA) (Photo 11.1). Furthermore, coffee production is highly dependent on the availability of nitrogen, while erythrina is a nitrogen-fixing legume. The coffee plant is an undergrowth shrub and is adapted to shade environments. While the roots of these two species also exhibit different traits (slow growth and high exploration density for coffee, rapid growth and exploration of a large area for erythrina), they explore relatively similar niches. Thus, these species may compete for water, but since erythrina is much less drought-resistant than coffee, it cannot survive in environments where water availability may be a limiting factor for coffee cultivation.

Photo 11.1. Intercropping of coffee and erythrina. © Bruno Rapidel/CIRAD.

Box 11.2. Push-pull processes in sugarcane cultivation

F.-R. Goebel

Research has identified service plants that can be used or introduced on the border of sugarcane fields in South Africa to boost the natural regulation of the African stalk borer *Eldana saccharina*: wild plants such as *Cyperus*, *Erianthus*, *Pennisetum* or *Desmodium*, and cultivated crops like maize or sorghum, act as parasitoid-attracting or pest-repellent plants (Conlong and Rutherford, 2009; Cockburn *et al.*, 2014). The aim is to increase natural pest control by enriching the biodiversity of sugarcane cropping systems that are often intensive and which have consequently decreased natural pest control (Figure 11.2).

In Réunion, *Erianthus*, a plant similar to sugarcane but which is more attractive to the moth borer *Chilo sacchariphagus*, was tested and used as a trap crop on the border of the sugarcane field to attract and kill this pest (Nibouche *et al.*, 2012). This action can be combined with the release of complementary parasitoids, such as trichogramma, to suppress egg laying by this borer on the border of the sugarcane fields. These service plants can thus be used to develop a push-pull system, which can become a useful part of agroecological crop protection (Goebel *et al.*, 2018).

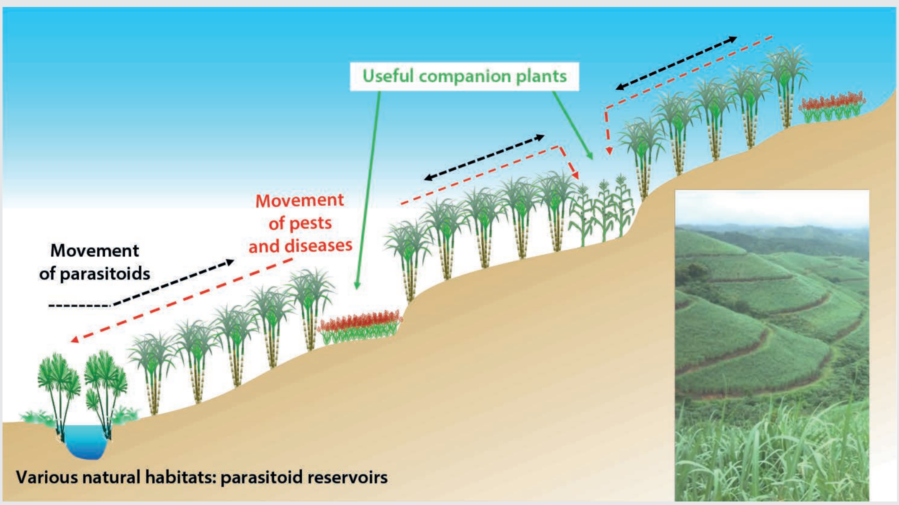

Figure 11.2. Use of landscape elements and introduction of service plants for biological pest control (case of *Eldana saccharina*, a sugarcane pest, in South Africa, Conlong and Rutherford, 2010).

Pest management is based on a broad and in-depth knowledge of interactions in the agroecosystem between insects and their natural enemies (parasitoids, pathogens, predators, etc.), host plants and the natural vegetation that shelters them.

The modification of biogeochemical cycles

The introduction of biodiversity into an agrosystem also affects biogeochemical cycles: water and carbon cycles can become greatly modified (Figure 11.1), in particular by the introduction of woody species, as shown by the agroforestry example in Sudano-Sahelian Africa (Box 11.3).

Box 11.3. Agroforestry in Sudano-Sahelian Africa

B. Rapidel

There are many examples of agroforestry in Sahelian and Sudano-Sahelian Africa. It is, however, often difficult to differentiate between biological and socio-economic reasons to explain the coexistence of trees and crops. Nonetheless, two examples are based on biological foundations which have been studied in depth: the first is the association between crops and the leguminous tree *Faidherbia albida*. This tree characteristically loses its leaves in the rainy season, thus enabling the maintenance of a high level of soil organic matter (a common role of trees in agricultural systems) while not competing for light and water with rainy season crops. Its fast-growing root system allows this species to reach the water table in its early years of growth, and thus maintain its leaves in the dry season (Roupsard *et al.*, 1999). These leaves are harvested based on demand and provide supplementary feed for livestock. This species has been widely used in reforestation programmes in Niger (Garrity *et al.*, 2010). The second example is of the dry-area shrubs *Guiera senegalensis* (Combretacea) and *Piliostigma reticulatum* (Fabacea), grown in the Sahelian area in sorghum and millet fields. These shrubs have deep roots and maintain their foliage in the dry season by capturing water resources inaccessible to the annual cereals with which they are intercropped (Louppe, 1991). Research studies have shown that their root systems redistribute water to shallow horizons from deeper wetter horizons (Kizito *et al.*, 2012). They can also withstand an almost total annual pruning. They are frequently cited as a restoration species for degraded soils because they promote an accumulation of organic matter (Diack *et al.*, 2000).

From ecological principles to innovation

Agroecological principles must be translated into concrete achievements that are implemented by actors at the scale of the plot and cropping system. The questions the agronomist has to ask in order to do so are: Which species to associate? What operational methods to adopt? How to design these new and more complex systems? How to evaluate them? Based on what criteria?

We thus move from the principles of agroecology to innovations based on modalities of action. The principle of introducing biodiversity into an agrosystem may include different modalities of action that stimulate identified agroecological processes (see Figure 11.1). These mainly involve combining organisms (Malézieux *et al.*, 2009): we can combine varieties as well as productive plant species, introduce service plants, and combine non-woody and woody species as well as plant and animal species (see Figure 11.2). Each of these practices initiates several processes. The more the number of possible theoretical combinations, the more difficult the search for efficient systems becomes. Moreover, among the efficient systems, those the farmers find acceptable are even more limited. In addition to the spatial dimension, the temporal dimension is essential: rotations, whether in association with cover species or not, represent an essential agroecological modality of action. The time step can be very variable: to the short time span of the association of vegetable species whose cycle lasts only a few months, we associate woody species whose cropping period lasts several decades. These two time spans can interact perfectly: the farmer must manage both time steps, sometimes on the same plot. It is thus possible to establish a typology of cropping systems based on an increasing complexity of systems and the introduction of woody species.

In the following sections, we will illustrate these different modalities of introducing biodiversity through four successive case studies: service plants in monocultures, mulch-based cropping systems, intercropping of two woody species, and complex systems in humid tropical regions.

A key agroecological example: service plants and weed management

The diversity of communities present in agrosystems is likely to assist the provision of a number of ecosystem services. The control of weeds (i.e. plants causing loss of yield by competing with the cultivated crop) is, for example, directly linked to the plant biodiversity existing in plots. The introduction of a service plant is thus a way of modifying the composition of the plant community in order to promote this service. In our weed control example, choosing the species of the service plant is complicated as it can lead to competition with the primary crop. Service plants must satisfy a set of characteristics, some of which may be contradictory (Figure 11.3).

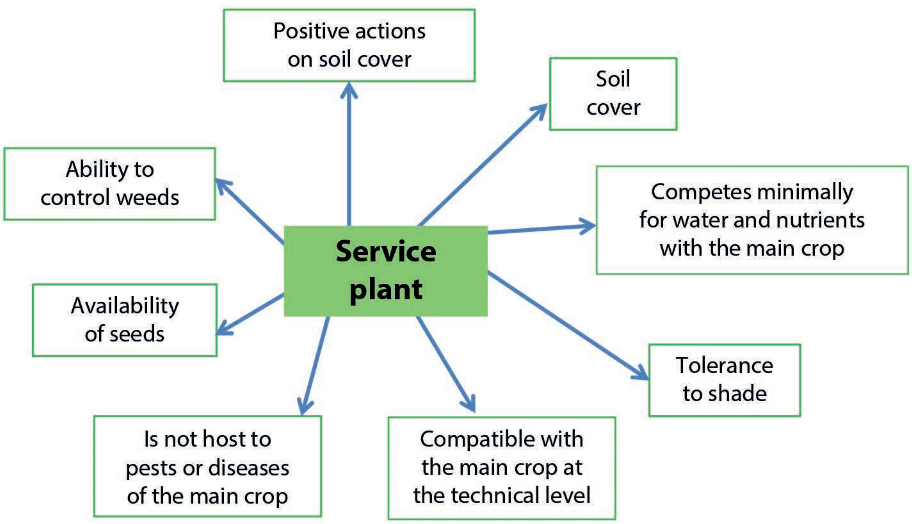

Figure 11.3. The set of services that service plants must be provide.

In general, service plants are capable of providing multiple ecosystem services through the modifications they make to the environment, either physical (physical and chemical structure of the soil) or biological (see Figure 11.1). They are thus increasingly used, for example, in various cropping systems such as banana plantations and orchards to control weeds, and eventually limit herbicide use (Boxes 11.4 and 11.5). Furthermore, the inclusion of a cover crop modifies the system's overall functioning in terms of the water and nutrient cycles (Tixier *et al.*, 2011), as well as the interactions between insect and micro-organism communities (Duyck *et al.*, 2009). The addition of a new resource to the system is a strong lever to modify food webs. Be it aboveground or underground, this new resource can help increase the abundance of herbivores, and thus favour an increase in the number of generalist predators who, in turn, are likely to contribute to improved pest control.

Box 11.4. Service plants in banana plantations

P. Tixier

Service plants have been widely used in banana plantations in the French West Indies, either between cropping seasons or in association with the banana trees. These two options require plants with potentially different characteristics. During the between-crops period (grass fallow), in addition to having a very good ability to cover the soil and control weeds, a service plant suitable for fallows must:

– not be host to plant-parasitic nematodes of banana trees (*Radopholus similis* and *Pratylenchus coffeae*) so that the fallow period fulfils its role;

– improve the physical structure of the soil (organic tillage);

– be compatible with the replanting of banana trees at the end of the fallow period and ensure nutrient restoration following the planting of banana.

The characteristics of service plants associated with the banana tree should be within a narrow range that allows good weed control without competing for resources with it. The service plants must also be flexible enough to adapt to variations in the light resource available during production cycles (closure of the canopy in the first cycle, reopening after harvests). One method for selecting service plants is based on describing the functional traits of potential species as (easily measurable) evaluators of the services they are likely to provide (Damour *et al.*, 2014). To implement this approach, a large number of species had to be collected and characterized, followed by testing of the most promising ones in prototype cropping systems. These steps make it possible to validate the selection by taking into account the technical constraints and by making adjustments to the management of the cover crop.

The addition of a cover crop also helps support a richer food web (predators and omnivores) (Djigal *et al.*, 2012). However, the effect on pest and disease control often depends on the species of the cover plant. Thus, plants of the Poaceae family seem more suited to regulate plant parasitic nematodes than those of the leguminous family. The situation is similar above ground where generalist predators (mainly the ant *Solenopsis geminata*) are more abundant in plots with a cover crop (*Brachiaria decumbens*) than in plots with bare soil (Mollot *et al.*, 2012).

Service plants are also used within annual crops. Annual species are associated using numerous techniques including mulch-based cropping systems. The aim of the direct seeding mulch-based cropping system, a practice linked to conservation agriculture, is to maintain a permanent plant cover and limit tillage only to sowing furrows. This practice reduces erosion and enhances soil biological activity, contributing to the sustainable management of soil organic matter. Direct seeding mulch-based cropping systems have been adopted in many tropical regions (mainly in Africa, South America, Southeast Asia) as well as in France. In the case of rice cultivation in Madagascar, the first trials of direct seeding mulch-based cropping systems date back to the early 1990s. The mulch cover presents several benefits during the cultivation of rainfed rice: it provides a large amount of organic matter, limits direct evaporation from the soil, reduces temperature variations on the soil surface, and has a strong effect on weeds, which results in an increase in yield at the end of the cycle (Ranaivoson *et al.*, 2017) For example, the use of the perennial legume *Stylosanthes guianensis* (Fabaceae) as a cover crop, which produces a high biomass and has allelopathic effects on soil pests like white grubs and even some nematodes, has been proven to be successful (Husson *et al.*, 2013; Husson *et al.*, 2015).

A direct seeding mulch-based cropping system, based on a biennial cereal-cotton rotation, was proposed in the cotton basin of Cameroon after four years of conclusive experimentation (Naudin *et al.*, 2010). In the first year, a cereal (sorghum or maize) is associated with a grass (*Brachiaria ruziziensis*) or a legume (*Crotalaria retusa*) cover crop. The objective is to maintain the cereal yield, the staple family diet, while producing enough biomass to cover the soil after the harvest. Cotton is sown manually the following year in the dead plant cover. Farmers have adopted this system and development agencies have recommended its use.

Box 11.5. Management of natural weed growth in orchards

F. Le Bellec

Citrus fruits are often attacked by various pests and diseases that affect crop quality and the lifespan of the trees in the case of certain diseases. The phytophagous mites and some insects (such as thrips) cause irreversible damage to the fruits when their populations outbreak. Farmers adopt various preventive phytosanitary measures to limit such damage. Mites of the Phytoseiidae family can help regulate the populations of phytophagous mites and thrips. However, phytosanitary protection applied on the latter necessarily impacts the former. It is possible to promote a suitable habitat for Phytoseiid populations in such orchards through a sound management in space and time of natural weed growth in citrus orchards (Photo 11.2).

Studies have thus been carried out in orchards in Réunion (Rothé *et al.*, 2016; Simon *et al.*, 2017). The floristic diversity of the weed cover in these orchards – regardless of the weed management method – ensures an abundance of functional traits leading to a diversity and abundance of habitat and food for generalist predators (ladybugs and Phytoseiidae). Thirteen Phytoseiidae species have been found in the weed cover in these orchards.

Maintaining an almost undisturbed habitat within an orchard can thus potentially increase the effectiveness of biological control while reducing pesticide use. But how can the functional biodiversity within these orchards be increased in order to promote the ecosystem service of pest and disease control? The study of functional traits of species of the spontaneous flora helped predict the composition of different weeds within the natural growth for various management methods, and thus suppress or favour certain plant species in these communities. Nevertheless, in order to ensure the perpetuation of the pest control ecosystem service, the management strategies used must create transitional refuge habitats for auxiliaries. This requires the differentiation over time and space of various weed management interventions. These techniques are thus complex and require a good knowledge of the processes to be implemented.

Photo 11.2. Weed management in citrus orchards. © Fabrice Le Bellec/CIRAD.

Agroforestry systems

Agroforestry systems are cultivated systems that combine several layers (at least one tree layer combined with one herbaceous layer) and which often have a high specific diversity. Agroforestry systems, situated in between the cultivated field and the forest (*ager* and *sylva*), combine annual and perennial herbaceous and woody species, as part of a set of more or less complex practices. Agroforestry systems are not specific to the tropics: they were very common in temperate and Mediterranean areas before the introduction of mechanization, and are currently experiencing a revival. In the tropics, they are very prevalent in many small family farms and the international scientific community is showing an increasing interest in them.

The association of two woody species

The most widespread examples of agroforestry in the world are in fact represented by the associations of perennial plants, i.e. the cultivation of perennial crops (mainly cocoa, coffee, rubber, coconut) in association with other perennial species. There are two broad types of associations: existing shade trees from thinned forests with inter-cropping of the perennial crop – i.e. agroforests – or specific planting of shade trees at the time of, or slightly before, planting the perennial crop in the plot. The specific diversity of shade trees is generally lower when they are planted on bare land.

Two perennial crops can also be cultivated in association. Such associations are made possible by the shade tolerance of some crops, such as coffee and cocoa, that grow from the understory. In other cases, however, these associations take advantage of the delay between the planting of the perennial crop and its entry into production, and the time required by certain perennial crops to occupy the plantation area. For example, there are coffee plantations that come into production three years after planting, with rubber trees in inter-rows that starts production six to seven years after planting. In most cases, agroforestry promotes the provision of several ecosystem services (Box 11.6).

Complex agroforestry systems in humid tropical areas

Based on a multi-layered tropical forest model, agroforestry systems in the humid and sub-humid tropics provide local livelihoods and fulfil key environmental and socio-economic functions. Agroforestry systems in humid regions are characterized by a rich and planned biological diversity (the farmer manages a large number of plant species in a planned manner), a high structural heterogeneity of the system, a significant evolution of the vegetation structure over the long term, and the provision of numerous ecosystem services. They offer are a good example of sustainability based on the role of biodiversity (Box 11.7).

How to turn agroecological principles into action?

Agroecological principles are based on analysing the functioning of natural ecosystems. For scales larger than that of the plot, several levels of organization have to be understood in order to implement these principles in agrosystems. Thus, the agroecological approach must first be implemented at the farm level (choice of species, plant-animal interactions, organization of crops within the farm's production areas and in its agricultural calendar, maintenance of biodiversity islands, etc.). More broadly, the scale of the watershed must also be considered, as also that of the landscape (i.e. landscape ecology), mainly in order to take into account the regulations specific to territory-wide interactions and the habitats of different pest and auxiliary species. But the agroecological approach must also be integrated into the more or less territorialized social systems that make up agri-chains and, more generally, into food systems (Figure 11.5).

Box 11.6. Coffee-based agroforestry and the provision of ecosystem services

B. Rapidel

The association of coffee with trees provides ecosystem services to farmers and to society, but these services are generally not taken into account (Rapidel *et al.*, 2011) (Figure 11.4 and Photo 11.3). Following the classification proposed by the Millennium Ecosystem Assessment (2005), we can list the different services provided by plantations in Central America.

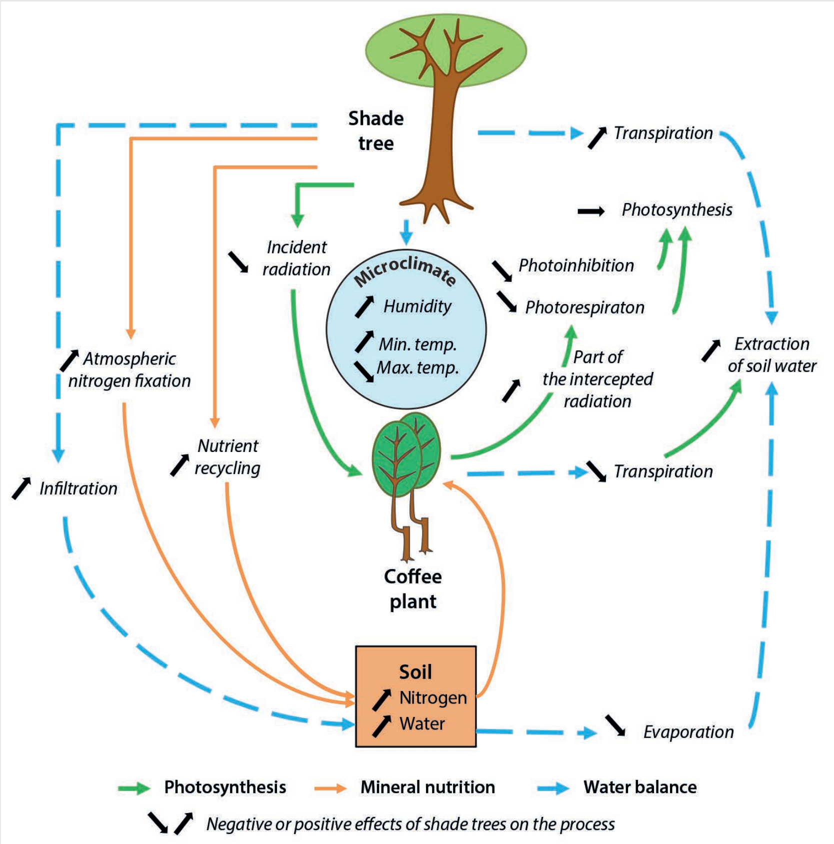

Figure 11.4. Effects of shade trees on photosynthesis, water balance and nutrient uptake of coffee plants (Rapidel *et al.*, 2015).

Provisioning services

It has been shown that simplified agroforestry coffee plantations producing bananas, for example, lead to a better quality diet (Meylan *et al.*, 2013). In more diverse systems, various additional products represent significant additional sources of income. These systems, which have a permanent ground cover, protect the soil surface with decomposing residues, and supply better quality, less sediment-laden water to downstream dams.

Regulating services

These plantations help regulate climate, with better greenhouse gas balances due to the reduced use of synthetic fertilizers (Hergoualc'h *et al.,* 2012). They help control pests, for example by birds controlling the coffee borer, but more generally by enriching aboveground and underground food webs. These regulating services, however, depend on the pests and diseases concerned. Indeed, microclimatic conditions under the shade of trees can, in particular, be favourable to some fungal diseases.

Supporting services

While nutrient recycling has improved in these plantations (a fact that has been widely observed), symbiotic nitrogen fixation (Meylan *et al.*, 2017) and the conservation of soil fertility have also seen an improvement.

Finally, the positive effect of agroforestry systems on the conservation of plant and animal biodiversity has also been positively established on numerous occasions (De Clerck *et al.*, 2010). It is relatively clear that these systems are preferable to plantations that are fully exposed to the sun, especially when such capabilities to provide services are combined in agroforestry systems that are co-designed with farmers (Meylan, 2012). These services can thus provide farmers with higher incomes. However, this is not always the case, especially when the only product valued monetarily is coffee, the production of which, depending on the case, may be lower in an agroforestry system.

Photo 11.3. Coffee plants under shade. © Bruno Rapidel/CIRAD

Box 11.7. Agroforestry systems in humid areas

É. Malézieux

Some coffee and cocoa agroforestry plantations in Central America, Asia, and Africa reproduce the structure of natural forests and thus have biodiversity indices that are often comparable to protected forests, thus representing a significant conservation value (Deheuvels *et al.*, 2012) (Photo 11.4). A high diversity of cultivated or naturally growing plants serves as a refuge and habitat for numerous plant and animal species, thus playing a key role in maintaining the original biodiversity in sensitive areas. At the social level, the multiplicity of sources of income or of services (wood, pharmacopoeia, hunting, gathering, climate protection, limitation of nitrate losses, landscape, fire protection, etc.) offered by agroforestry systems is often considered an important factor of stability, as shown by the example of cocoa farms in Cameroon (Jagoret *et al.*, 2014, and Chapter 3). This helps compensate for the volatility of prices of agricultural products (e.g. of tropical crops such as coffee and copra).

Photo 11.4. An agroforestry plot in Cameroon. © Eric Malézieux/CIRAD.

The agroecological approach also raises the issue of the process of innovation. There is some distance to cover, which can be long and arduous, between the generation of scientific knowledge on the functioning of ecosystems and its use to design sustainable agricultural system that can be implemented by farmers. In other words, there exist many steps between the formalization of principles that could form the basis for an 'agroecological' farming system, and their translation into actual large-scale technical systems. In the domain of agroecology, innovation often requires the

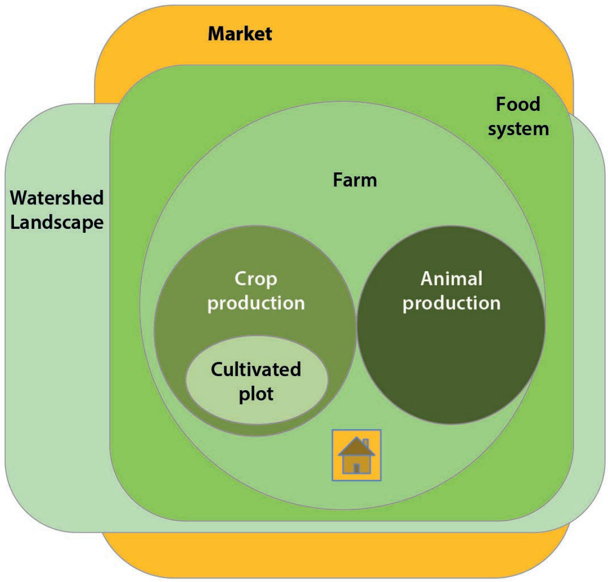

Figure 11.5. Different integration scales (based on Griffon, 2013).

sustainable appropriation and mobilization by farmers of both scientific and local knowledge of processes that are often complex. It also requires a forum for interactions between researchers, development actors and farmers. Several approaches have attempted to formalize these multi-actor innovation processes. Examples include some approaches used for orchards (Le Bellec *et al.*, 2012) and the DATE (Diagnosis, Design, Assessment, Training and Extension) approach, which can be used not only to co-design innovative farming systems in conservation agriculture but also to undertake multi-criteria evaluations (Husson *et al.*, 2015). This latter multi-scale participatory approach brings together several partners and integrates scientific and local knowledge. In general, the implementation of the agroecology paradigm requires the research community to integrate these new elements and to be able to implement them in a broader context for development actors and civil society. Consequently, a key element in the development of agroecology around the world is the adoption of appropriate public policies.

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Chapter 12

Assessment of trade-offs between environmental and socio-economic issues in agroecological systems

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The concept of sustainable development as proposed in 1987 by the UN in its report 'Our Common Future' highlights the notion of inter- and intra-generational solidarity by affirming that 'sustainable development is development that meets the needs of the present without compromising the ability of future generations to meet their own needs' (Brundtland Report, WCED, 1987). Consequently, it becomes necessary to take into account the social, environmental and economic dimensions of human activities (or 'People, Planet, Profit', see Elkington, 1997).

Each of these dimensions includes countless factors of sustainability, which can act in synergy or in antagonism. It is therefore not possible to measure in absolute terms the sustainability of a particular way of exploiting nature. All we can do is to compare different options and, at the same time, accept that this comparison is not entirely free of subjectivity, as found in any 'model', i.e. in all the methods for studying complex systems.

Moreover, the specific objectives of the assessment can be very varied: it could be meant to inform public decision-making processes to enhance the sustainability of production methods, or to help practitioners or others who wish to evaluate their own actions. The assessment often encompasses several types of actors, with differing objectives and viewpoints, with the aim of creating a common vision of the issues within which the different points of view will eventually be identified and recognized as legitimate. The desire to understand the complexity of the problem in all these cases, and consequently to arrive at certain standards that can guide as large a number as possible of them, led to a sustained 20-year effort by the scientific community to devise methods.

At present, there is an abundance of these 'multi-criteria assessment methods'. How to navigate amongst them? Which ones are the most suitable to inform decision-making by actors of development of sustainable agriculture? And more specifically, in the case of family farming in the countries of the Global South? What kind of research is needed to improve our collective capacity to assess agricultural sustainability? This chapter attempts to provide answers to these questions.

The challenges of multi-criteria assessment of sustainability of agriculture in the countries of the Global South

The sustainable development approach based on its three dimensions (social, environmental and economic) has been widely accepted and implemented in different ways. Nonetheless, contrary to the initial holistic spirit of sustainable development, this approach has also led to various rifts between actors concerned by each of these dimensions according to their specific priorities on the basis of the exigencies of a place or time. This is a situation that has largely arisen due to the difficulty of incorporating the necessary trans-disciplinarity in the design and implementation of sustainable development. Indeed, this dimensional rift underlies the difficulty of taking the interactions between these dimensions into account and of their integration. Beyond the complexity of assessing these interactions in their totality, this approach also emphasizes the need for trade-offs rather than for the pooling of services across dimensions (Gibson, 2006). The three-dimensional approach to sustainability is, therefore, not unbiased. It results from different priority-based choices, and inevitably introduces biases in the integration of results.

In industrialized countries, where the concept of sustainability originated and where few environments remain untouched by human activity, the environmental dimension has always been at the forefront from an early stage, with the historic issues of resource scarcity sparking the first interest in the topic. Other societies, where resource scarcity is not as alarming an issue in comparison to their socio-economic development, do not recognize the essence of the three dimensions of sustainability a distinct. This is especially the case in various developing countries in the tropics. Thus, a study of the perception of sustainability by family farmers in Indonesia showed that they did not perceive the three dimensions of sustainability as distinct, but as intrinsically interwoven, non-separable and thus, non-overlapping (Bessou *et al.*, 2017). For these actors, for example, a forest is an environmental, cultural and social common good, as well as an individual source of material, income and other services. This resource is not perceived in terms of biodiversity protection that would oppose economic growth, but as a multi-dimensional whole.

The definition of sustainability, and therefore the need to safeguard future generations, only makes sense when it is considered in a global perspective. In order to reconcile local and global perspectives, it seems necessary to effect a change of scale in the conception of sustainability and sustainable development. This change of scale is understood, at the same time, in geographical terms as a change in the resolution of perceptions, and, in systemic terms, as the taking into account of different levels of organization at different scales (Macary, 2013). This problem of scale is thus intrinsically linked to a problem of inter-disciplinarity and, together, they represent basic challenges for assessing sustainability. As a result, recent conceptual development models address sustainability through the prism of the study of complex systems (Capra and Luisi, 2014; Capra, 1996, 2002) but do not provide a multi-criteria assessment method.

Consequently, there exists no single theory of sustainable development, nor is there any consensus on the relationship between sustainability and sustainable development. Some authors view sustainable development as a means of achieving sustainability (e.g. Diesendorf, 2000), while others interpret sustainability as a prerequisite for sustainable development (Sartori *et al.*, 2014). In any case, sustainable development is not a neutral concept. Assessment methods and sustainability indicators thus incorporate moral and normative conceptions (Thiry and Cassiers, 2010). As a result, despite the urgent need for methods and tools, a researcher involved in multi-criteria assessment must understand that sustainable development is not yet an established discipline; many questions remain unanswered and an awareness of underlying values is of utmost importance.

Standardizing sustainability assessment?

That said, significant efforts have been devoted to create reference methods applicable over as wide a range as possible, thus allowing a comparison of a very large number of farming systems to help inform decision-making by the citizen, consumer or public policymaker. These efforts have resulted in popular and frequently used tools, especially when only the environmental dimension of sustainability is considered.

'Environmental' Life Cycle Assessment

The key example is that of 'environmental' Life Cycle Assessment (LCA). Environmental LCA consists of assessing the potential environmental impacts of a product or service from the stage of the extraction of the raw material needed for its manufacture to its end of life, through all the stages of its journey in the value chain (production, transport, distribution, consumption). Introduced in the 1980s, LCA quickly became an international methodological reference. For example, its use is mandatory in various decision-making frameworks such as the European Renewable Energy Directive (2009) and the European environmental information tool called Product Environmental Footprint. The interest in LCA arises from the extent of the system analysed, i.e. the entire value chain, as well as from its multi-criteria approach based on several environmental impacts (for example climate change, eutrophication, depletion of fossil resources, toxicity, etc.). This makes it possible to identify and potentially control 'impact transfers'[1], when comparing several production scenarios of the same product or when comparing two products performing the same function. This is essential for improving production systems, where less comprehensive approaches may only result in the shifting of problems. That is why this approach has mobilized a large international community, leading to the emergence of specific ISO standards[2] and continuous updating and improvement of the method. In addition, a growing community is also working on proposals for socio-economic indicators in the context of a so-called 'social LCA'.

1. An impact transfer can occur when a process belonging to one production stage of the value chain is improved, but to the detriment of another process belonging to another stage of the chain. Similarly, an environmental impact may be reduced by improving a process, but it may exacerbate another environmental impact. If the analysis does not take all the stages and impacts into account, these transfers may not be identified and the assumed improvements could result in counter-productive effects.
2. ISO 14040 and 14044 (2006).

The ISO standards, which govern the implementation of LCA, define the method's stages of implementation and the modalities of publishing the results. Thus, when correctly applied, these standards ensure a transparent and reproducible assessment procedure. It follows that the existence of such a standard represents *a priori* the hope of arriving at a consensus between decision-makers as well as between consumers. Products and production systems based on this consensus need to be encouraged in order to reduce the negative impacts of human activities on the environment.

The ecological footprint

The concept of the ecological footprint is another example, but it has not been formalized by an ISO standard. This concept is promoted by an independent organization, the Global Footprint Network, which defines and adapts the standard and offers suggestions for the implementation of the concept with the help of experts. The ecological footprint is an indicator expressed in terms of the 'bio-productive' soil surface area required to sustainably meet the consumption of a given population and to absorb the waste generated, as well as greenhouse gas emissions. Applied at the scale of the entire planet, this indicator serves to mark the point beyond which global consumption is no longer 'sustainable', with a global ecological footprint expressed in number of planet Earths greater than 1, and the Earth Overshoot Day, the date – currently occurring earlier each year – on which global consumption exceeds the planet's annual regeneration capacity. The symbolic significance of the concept is convincing and has made it popular, which in turn has encouraged its use as a tool to compare the impact of populations on their environment in different countries. The concept has more recently been extended to the environmental assessment of products and organizations.

A certain relativity of methods

These two approaches to assess environmental impacts are very different and provide results that are difficult to compare. There are very many ways to assess the environmental impacts of human activities and each method requires some simplification of the complex systems under study. The standardization of a sustainability assessment method does not therefore mean that the method is the only way to assess sustainability or that its results are absolute. The assessment remains relative, depending in particular on the objectives of the study, and the knowledge and data available at the time of the assessment.

The objective of standardizing methods is also constrained by the difficulty of defining certain quantities in a mutually acceptable manner. For example, how to quantify the value of a forest as a recreational space? At what scale of time and space should the services provided by a complex agroforestry system be assessed? Can a rural society in crisis, faced with the short-term imperative of survival, and compelled to 'adopt whatever means necessary' to do so, be compared to a relatively wealthy society that has the luxury of being able to spare resources on the basis of long-term goals? How can a broad consensus on these issues be arrived at if it is only the 'experts', very likely lacking any real experience of extreme poverty, who participate in the search for a consensus (Cheyns *et al.*, in press)? Another, perhaps more abstract, example is: Should the value of biodiversity be assigned only on the basis of its contribution to ecosystem services? Or does it not, in a spiritual perspective, also represent a value for humanity that transcends such a narrow view, and is therefore both universal and eminently dependent on individuals?

Recognizing the role of subjectivity in multi-criteria assessments

A large number of methods and approaches explicitly recognize that the assessment of sustainability depends largely on the concerned actors' perspectives. Such methods propose general methodological principles, leaving ample room for case-by-case adjustments, which can be decided jointly by all the actors involved in the assessment, co-constructing in this way a common vision of a system's sustainability.

Many French scientists assume that a multi-criteria sustainability assessment necessarily mobilizes the implementation of what mathematicians call 'multi-attribute hierarchies'. These approaches are based on the identification of a certain number of indicators of the economic, social and environmental performance of the systems being compared, the assignment of values to these indicators for each of these systems, and the application of weighting and aggregation rules to classify different sustainability criteria (for example, see Sadok *et al.*, 2008) (Figure 12.1). All these elements of the method can be decided on a case-by-case basis. The general principles of the methods that make up this group are relatively simple to understand, and easy to implement and discuss (for example, see the MASC method[3]). However, the large number of possible variations in the methods for aggregating criteria and classifying the elements assessed are subtle and complex to grasp, and are the focus of many specialist debates. Indeed, these variations can have a considerable impact on the classifications obtained. More generally, the main criticism directed at these methods is that the classifications they generate are very sensitive to the particular method's parameters, with many threshold effects which also makes it difficult to assess their robustness.

A number of practitioners and researchers prefer not to use the term 'multi-criteria', choosing instead to speak of the integrated assessment of farming systems, thus emphasizing the systemic nature of the approach and complexity of the system studied. Until recently, studies advocating integrated assessment tended to rely less on multi-attribute methods, using instead so-called constrained optimization methods. A key assumption in these methods is that farms represent enterprises that have their own objectives and are managed by rational decision-makers whose role is central to agricultural sustainability. Models have been constructed to simulate the decision of farmers who have to select production techniques from amongst several options, on the basis of their objectives and constraints. These models describe mechanisms that determine the economic and environmental performance of farms in order to

3. Multi-attribute Assessment of the Sustainability of Cropping systems, http://wiki.inra.fr/wiki/deximasc/package+MASC/?language=en (retrieved on 30 January 2018).

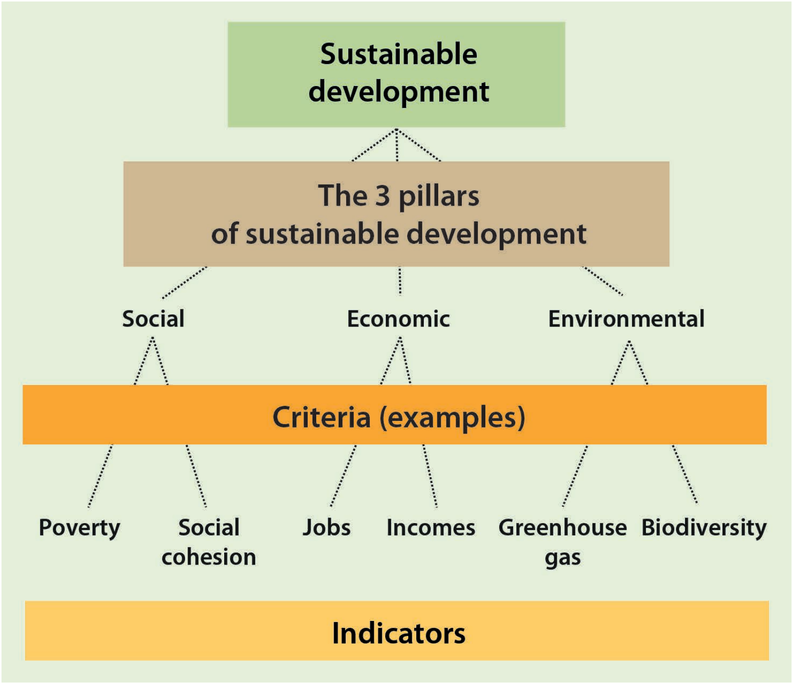

Figure 12.1. Example of a multi-attribute hierarchy representing sustainable development presented as a tree with multiple aggregation levels.

predict deviations as a function of variations in their biophysical, economic and social environments. These models operate in a highly variable and often complex manner, such as changes in scale between the cropping/livestock systems and the production system, or between the farm and the region or the market. These methods are part of the same mathematical domain as multi-attribute hierarchies, or 'operational research', and pose problems that are similar in nature regarding the assessment of their robustness, or the transparency of the methodological choices that arise from the countless possible variants.

This similarity between multi-attribute methods and constrained optimization methods seems to be increasingly accepted by specialists of both methods, who recognize, for some years now, that both methods use optimization techniques and are based on multiple criteria.

However, there are several important differences, and in comparison to multi-attribute hierarchies, it is more difficult to present methods based on mathematical programming to non-specialists and, *a fortiori*, involve them in the implementation of these methods. This approach is sometimes severely criticized for its dependence on an assumption of farmer rationality, especially when it is translated (often abusively) as a reduction of a farmer to a '*homo economicus*' driven solely by the goal of maximizing his income. These methods, however, do allow the taking of the highly varied objectives of producers into account (e.g. see Lozano Vita *et al.*, 2017; Berbel and Rodriguez-Ocaña, 1998; Flinn *et al.*, 1980).

Importantly, many examples have shown the usefulness of these methods in assessing agroecological systems in their economic and social dimensions for family farming (Affholder *et al.*, 2010; Naudin *et al.*, 2014; Alary *et al.*, 2016; Belhouchette *et al.*, 2011). They make it possible to identify clearly the conflict between the short-term economic objectives of farmers and the objectives of maintaining or strengthening long-term ecosystem services other than the service of supply, including for complex farms, with very diverse activities and where simple economic indicators fail to capture the interactions between the various activities that contribute to income generation.

More specifically, it is often possible to use these methods to quantify the optimal trade-offs between the different dimensions of sustainability, using an estimate of short-term income losses of producers who implement agroecological processes, and thus to assess the level of remuneration that should be associated with environmental services in order to reconcile, in an effort to maintain producers' income, their short-term economic objectives and those specific to these environmental services. This function of the method is especially valuable in the context of poor family farms in the countries of the Global South, where producers are constantly confronted by the immediate reality of ensuring their families' survival. When farm income is less than one Euro per worker per day – and this figure includes home consumption – and when each working family member must support two or three unproductive ones (the very young or the aged), as is the case in the overwhelming majority of farms in sub-Saharan Africa, it is especially important to ensure that an agroecological alternative to existing practices does not reduce this income, even marginally, in the short term, irrespective of the promise of an increase in income in the long term if agroecological practices are adopted.

In these integrated assessments, the 'farm models' calculate the aggregate income of different farm activities by taking into account the flow of resources between activities (e.g. organic matter from livestock is used as crop fertilizer). This helps explain how a transition to an agroecological system of a given farm activity is constrained by the changes it induces in the flows of biomass, labour and cash between activities, as well as in the use of the animal traction or mechanized work, with an impact also on the farm's other activities. For example, using mulch to protect the soil from erosion can result in lower livestock productivity since less straw will be available for use as fodder. Or an agroecological practice could result in higher land productivity but lower labour productivity (or vice versa) than with the 'conventional' method, with highly variable consequences on the farmer's income depending on whether the farm is constrained by land or by labour. Multi-attribute hierarchies generally do not explicitly consider these interactions between activities and their impact on farm income in the economic indicators they use.

There thus seems to be some contradiction between the objective of helping the common man understand the assessment of sustainability and the objectives of robustness, consistency and rigour that must be satisfied for such an assessment to be more than merely one point of view (even collective) out of many. Indeed, bringing assessment within the reach of the inexperienced common man involves using methods that are simple to explain and implement, which would require disregarding the complexity of the problem to be tackled and ignoring key interactions between the elements of the system to be assessed.

Assessing agroecology

There does not exist as yet any widely applicable comprehensive and systematic assessment that would allow the comparison of the sustainability of agroecology with that of conventional agriculture. The main difficulty in designing such an assessment is to arrive at a mutually agreeable classification of agricultural practices belonging to agroecology and those belonging to 'conventional' agriculture, from among the myriad practices that exist in sufficiently diverse environments across the planet.

However, when focusing on low-capital family farms in the countries of the Global South, a number of robust facts can be derived from the numerous assessments we already have, even though they may be partial or local in scope. This is especially true for conservation agriculture, which can be seen as a major ideotype of agroecology, particularly adapted in the tropics to climates ranging from the semi-arid to the sub-humid where annual crops rather than perennial ones tend to dominate.

Prevalence of socio-economic issues in family farms in the Global South

It should be noted that poor and very poor family farms in these climatic regions represent the overwhelming majority of the world's agricultural systems, accounting for a very significant portion of its cultivated areas (Hyman *et al.*, 2008; Dixon *et al.*, 2001). While there may be many exceptions, social and economic sustainability is not guaranteed in the majority of these agricultural systems. Indeed, the population that depends on them for a living is most often below the poverty line and is growing so rapidly that if the value of the production does not increase, and the next generation does not find other means of subsistence away from the land farmed by previous generations, and therefore mainly in non-agricultural jobs, poverty will worsen further.

As far as environmental sustainability is concerned, a variety of patterns exist of the use of inputs exogenous to the local ecosystem. Cotton, for example, is widely cultivated by poor farmers in Africa, but with the use of substantial amounts of pesticides, thus posing long-term threats to the environment and people's health. On the other hand, there also exists a majority of cases in which the producers' practices could be described as agroecological, since they make very little use of inputs exogenous to the farm ecosystem, even if this is more due to a lack of finances to procure these inputs than by conscious choice (Feintrenie and Affholder, 2015). These practices are very interesting to assess in their environmental dimension, precisely because they often use the most subtle agroecological levers such as the optimization of nutrient cycles by recycling of livestock effluents and transfers between plant species in association, or the regulation of pests and diseases by rotations and associations of diversified species. But these non-input agricultural systems can have negative environmental impacts, typically in the form of soil erosion, which becomes particularly problematic when demographic pressure results in cultivation expanding to vulnerable soils.

Agronomic and environmental performance of conservation agriculture

Even if there still are, as we shall see, many knowledge gaps to be filled, we have today a certain benefit of hindsight concerning the level of agronomic and environmental performance of conservation agriculture. This form of agriculture can be seen as a way of reconciling increased productivity and environmental sustainability, through the least possible disruption of the soil, enhancement of soil protection using a vegetal cover of dead or living plants, and promotion of rotations and associations of different species. Rather than presenting a battery of indicators with their values and ranges of variation for this kind of agriculture in comparison with current practices of the dominant form of agriculture, we propose, in what follows, to draw a progressive portrait based on published syntheses, starting from the processes implemented in the cultivated ecosystem and leading to a holistic view of its sustainability (Scopel *et al.*, 2013; Giller *et al.*, 2011; Giller *et al.*, 2009; Rusinamhodzi *et al.*, 2011; Pittelkow *et al.*, 2015; Ranaivoson *et al.*, 2017).

Conservation agriculture has proved to be effective, almost everywhere that it is practised, in greatly reducing or even halting soil erosion. It can also be highly efficient in terms of water and nutrient use and in pest control. However, this efficiency is rarely achieved simultaneously for all these functions. And for each of them, what is actually possible to achieve is highly variable, depending on the local environment and the particular conservation agriculture practices used. For example, while a soil cover of mulch residues allows more water to percolate into the soil, thus reducing water runoff, it does not always translate into reduced water stress on crops, as it may lead to an increase in water drainage below the soil zone colonized by the roots, which is likely to increase the loss of nutrients carried away by this water. Only a fairly detailed analysis of rainfall distribution during the cropping season can predict whether or not mulch can help increase yields by reducing water stress (Scopel *et al.*, 2004; Bruelle *et al.*, 2017).

In the same way, the contribution of organic matter rich in carbon from this mulch can paradoxically but not unfrequently provoke nitrogen deficiency in plants; the population of soil microbes – which increases thanks to this carbon source – uses up soil nitrogen, then said to be 'immobilized', at the expense of the crop that has barely enough for its requirements. In general, however, such organic matter inputs lead to a gradual build up of soil nitrogen and carbon stock, albeit in very variable proportions that are not solely dependent on the quantity of biomass returned to the soil, but also on the nature of the soil (its sand and clay content in particular) and the climate (Maltas *et al.*, 2007; Corbeels *et al.*, 2018). The very fact of reducing, or even eliminating, tillage operations is sufficient to promote biological activity, and this is further stimulated by the return of biomass to the soil (Blanchart *et al.*, 2007). This enhanced biological activity, compared to that in 'conventional' cropping techniques, creates a macroporosity that contributes to improved water infiltration (and, consequently, the reduction of erosion).

On the other hand, the other favourable effects often expected from this enhanced biological activity in the soil, such as an increase in soil water storage capacity, mechanisms of soil pest regulation, or improved availability of nutrients during the cropping season have not been convincingly demonstrated. Indeed, we often observe the negative effects on crop growth and yield, at least over a period of a few years following the conversion of the plot to conservation agriculture, because of a relative proliferation of pests that find a favourable environment in mulch. More specifically, the pressure of weeds on the crop is relatively high when the quantity of mulch used is large enough (a threshold of 7 tonnes/ha has been identified, for example, in Southeast Asia). Species associations and rotations do provide the expected benefits in terms of a reduced pressure from pests and, notably, from weeds, when compared to monoculture or continuous cropping, but this advantage is not very significant when the cultivated species – such as maize and other high straw-producing cereals – is itself highly competitive against weeds. For more sensitive species, such as rainfed rice, which are often grown in rotation in a conventional manner precisely for this reason, the advantage of the cultivated diversity through rotations or associations is offset in conservation agriculture by the difficulties in planting the crop across the straw mulch covering the soil. Relay crops have shown they can reduce nutrient losses and pollution from leaching. Nitrogen transfers between legumes and non-nitrogen-fixing plants have been observed, in associations and rotations, with or without conservation agriculture, but again this is a potential that cannot easily be achieved, and one that current simulation models fail to predict reliably (see, for example, Baldé *et al.*, forthcoming; Baldé *et al.*, 2011).

We also note that species associations and relay crops pose risks of competition for access to resources between the cultivated species, which is also difficult to predict accurately as it results from numerous interactions. Any reduction of this competition requires great precision in managing the cropping calendar (see, for example, Silva *et al.*, 2019), often requiring investments in equipment or a large amount of manpower to ensure this precision.

Economic performance of conservation agriculture

The foregoing reveals some conflicts between different environmental criteria, and between these criteria and economic sustainability criteria. Indeed, when we take the processes defined above into account, we understand why reducing erosion through conservation agriculture necessitates, in many cases, a corresponding increase in the use of synthetic nitrogen fertilizers in order to reduce the risk of nitrogen immobilization, if the yield and, more importantly, the economic return to land has to be maintained. This added fertilizer may represent a water pollution risk comparable in impact to that due to erosion, and plays a role in farm economics in a way that runs counter to the effect of the elimination of tillage. And in the same vein, the implementation of conservation agriculture also often leads to the use of additional herbicides to control weeds, this time with greater environmental risks and a corresponding negative economic impact. The alternative of a thick mulch, effective against weeds, would certainly have a better environmental effect but it is, in fact, very rarely used. Indeed it makes little economic sense since straw residues are often more beneficially used in the short term for feeding livestock rather than for constituting a mulch expected to bring long-term positive effects on production through improved nutrient stocks and weed control. An additional factor is the equipment and specific labour-consuming interventions required to produce such a biomass (Naudin *et al.*, 2014).

At the farm level, such conflicts between environmental and economic indicators are generally reflected in a short-term assessment that is clearly unfavourable to the adoption of conservation agriculture by the poorest farmers who have little cash reserves to procure herbicides or urea, and who use biomass more beneficially as fodder, fuel or building material. This is the main reason they do not adopt conservation agriculture (Affholder *et al.*, 2010; Giller *et al.*, 2009) or indeed most other ecological intensification options currently known (Affholder *et al.*, 2015a). And it is also such conflicts that leads wealthier farmers (for example, large family business farms in central Brazil) to implement only some of the principles of conservation agriculture, with relatively little ground cover, high inputs of chemical fertilizers, with rotations with relatively low crop diversity, and with a heavy use of herbicides to control weeds (and often Roundup Ready GMO maize or soya bean). These farmers thus obtain a favourable environmental assessment in terms of erosion and greenhouse gas emissions (thanks to the elimination of motorized tillage), but their practices are *a priori* actually harmful (although, to our knowledge, this has not been quantitatively demonstrated) to the quality of surface water and groundwater, and possibly to biodiversity. They also obtain a rather favourable – albeit only marginally – economic assessment, which is again thanks to the elimination of tillage that generates savings that offset the additional costs of herbicides and fertilizers, even though specific direct seeding equipment must also be acquired (Freud, 2005). Finally, socially, the farmers of family business farms of the central plateau of Brazil – and there exists a similar situation in France (Goulet and Vinck, 2012) – have used conservation agriculture to improve their image with the rest of society, by playing up its agroecological character. It is also possible that this aspect played a key role in convincing family business farms to adopt these practices, by compensating in a certain way the inherent risks assumed by the farms in adopting a technique that is difficult to master, and which is radically new in comparison with their existing expertise.

It is probably also a general property inherent to agroecology, since it is also found in the case of agroforestry, and which emerges from all the rigorous multi-criteria assessments available: from the moment we seek to facilitate relationships between living organisms – the essence of agroecology being to increase resource-use efficiency in ecosystems – we also seem to run the risk of creating competition between species for access to these resources, and that this competition occurs at the expense of production functions. The essence of managing agroecological farming systems will specifically be to attempt to prevent the system from 'tipping' towards competitions that are too disadvantageous for production... and this tipping is especially difficult to anticipate as it is sensitive to the dynamic equilibrium between variables that are in constant interaction.

Avenues to improve multi-criteria assessments

Quantitative knowledge of farming systems

A conceptual difficulty in the assessment of agroecology lies in the need to assess ecosystem functions. To be able to do so, it is necessary either to mechanistically model the processes, or to directly assess the results of these processes assuming that we ignore their determinism. In both cases, the assessment is very complex.

Despite the promise of information technology and the revolution of quantitative systemic approaches over the last half-century, we are far from having models that can provide reliable estimates, of all the variables of the functioning of cultivated ecosystems for all types of agriculture in diverse contexts.

We can assume that, at the scale of cropping systems, we can predict reasonably well the dependence of the yields of primary crops on solar radiation, temperature and rainfall (or irrigation). The prediction of variations in yield based on soil nitrogen availability is however very uncertain, except for major cereals (maize, wheat, rice) in temperate regions. However, the effects of other macro-nutrients (phosphorus, potassium) are currently poorly predicted irrespective of the climatic context. In general, it is easier to predict the agronomic and environmental performance of agriculture in an environment that is highly artificialized through chemical inputs exogenous to the ecosystem, than of agroecological systems that are often dependent on tenuous interactions between living organisms. As such, efforts to model cropping systems in the countries of the Global South, which are often agroecological in nature given the lack of access to inputs, could well lead the way to the modelling of the performance of future agroecological systems in the countries of the Global North. In any case, current modelling efforts at the field scale focus on:

– the long-term prediction of soil nitrogen and carbon stocks as a function of cropping systems, efforts motivated in particular by the challenge of sequestrating carbon in soils to reduce net emissions of greenhouse gases;

– the estimation of nutrient and pesticide fluxes outside the root zone in the soil profile, indicators of water pollution risks;

– the modelling of synergies and competitions between plant species in multi-species systems (agroforestry, associated crops) or for taking the impact of weeds on yields into consideration;

– the relationship between crop species and invasive pests (insects, bacteria, fungi, viruses, etc.), which could require adopting a landscape-scale outlook and focusing on other ecosystem services such as regulation services (Chapters 8 and 11).

At farm scale, we know how to build models capable of modelling farmers' decision-making (in terms of the production system) and, consequently, their incomes and a fairly good number of economic and social indicators, when farms are acutely constrained by their biophysical and economic environment, as is most often the case in the Global South. These models are more difficult to develop and calibrate when producers have more room to manoeuvre in line with their various goals. The development of experimental economics is helping fill this gap, most notably by proposing promising methods for identifying producers' goals (Ward *et al.*, 2016; Jaeck and Lifran, 2014; Louviere *et al.*, 2015). However, the reliability of these models anyway largely depends on the quality of the data representing the performance of cropping and livestock systems, and therefore of the underlying biophysical models (Affholder *et al.*, 2015b).

At the territorial scale, improved hydrological models are now able to predict the flow of dissolved substances such as pesticides (Mottes *et al.*, 2015). In addition to a methodological renewal, we are observing the emergence of a landscape agronomy based on the ecology of the countryside (Chopin *et al.*, 2015; Baudry *et al.*, 1990) that aims to better understand and estimate the interactions between living organisms at this scale, especially relevant for assessing the impacts of changes in agricultural systems on biodiversity. The development of multi-agent models and spatial modelling tools is contributing to this evolution and is also improving our ability to take into account the interdependence of producers and other territorial actors, and thus better assess the social dimension of sustainability (Bousquet *et al.*, 1998).

Finally, irrespective of the scale considered, the processing of big data is opening up new perspectives. The explosion in data being recorded by various sensors, their universal accessibility, and the development of powerful algorithms to connect such data and perform hugely multivariate analyses is offering the hope of identifying simple ways to estimate some variables based on others, without having to undertake new, laborious experiments or the time-consuming route of developing models and comparing them with experimental data. One of the limitations of such approaches is the risk of making serious prediction errors, when the relationships identified are extrapolated by assuming the correlations observed between variables as evidence of causality when it is not. We must also note that farming in the countries of the Global South generates far less big data than in those of the Global North, and that these methods show very distinct biases in favour of phenomena that are important in the contexts of the latter, even though they may not be so for the contexts of the former.

A meta-analysis of the sustainability of organic farming compared to that of conventional agriculture (Seufert and Ramankutty, 2017) provides an example of this risk of bias. In this study, presented as having a global relevance, production systems of the countries of the Global South are practically absent, partly because of the paucity of data available in comparison with those from the countries of the Global North, and partly because the market for organic products is much less developed in the South. While we do find many farmers complying with organic farming specifications, it is not so much by choice as by a lack of access to any external inputs. As a result, there is a virtual lack of interest among producers to certify their products as originating from organic farming. If these production systems were included in the analysis, given the very low average yields that characterize them (Affholder *et al.*, 2013), the conclusions of this meta-analysis would have been, on an whole, extremely unfavourable for organic farming as far as the social and economic dimensions of sustainability are concerned – while, contrastingly, the conclusions of this study were, in fact, favourable in this respect. Indeed, there exists a significant contrast between farmers from the countries of the Global North and those from the Global South in terms of the opportunities opened up by organic farming specifications as they are currently framed, which would undoubtedly have been interesting to identify and discuss in this meta-analysis study.

Methodological research

The third part of this chapter has identified, as the main methodological challenge, the issue of reconciling rigour, transparency, robustness, and ease of implementation, in short a whole list of more or less opposing characteristics that all stem from a necessary reconciliation between recognizing there is a subjective angle of science and striving for maximum objectivity. This challenge seems unremarkable since it has concerned all of contemporary science ever since 20th-century epistemologists discarded the myth of a science that would gradually reveal a unique truth of the world, existing independently of people and their means to discern it (Chalmers, 1976, 2006). However, this epistemological revolution is far from complete, and the very organization of research is broadly inherited from the previous paradigm. Above all, the challenge in question takes on a certain dimension when science needs to be used immediately for collective action, as is the case for the multi-criteria assessment of sustainability. Thus, there exists a certain dynamism in methodological research on multi-criteria assessment.

One focus of such research activities is to compare the mathematical properties of operational research tools using sensitivity, uncertainty and robustness analysis. This is more clearly needed for multi-attribute hierarchies whose properties perhaps pose more problems than for mathematical programming, which formulates dependence indicators of its solutions for each variable considered.

Uncertainty

Uncertainty is the maximum error that can be made in assessing performance and impacts. It arises from an imperfect knowledge of socio-economic and biophysical processes, performance and impact measurement errors, and the variability of the characteristics of the systems being assessed.

The challenge is to quantify the uncertainty, and to take it into account when comparing assessed elements. Multi-criteria assessment methods today have a strong interest in identifying the variables that most influence the conclusions of the assessment in order to measure them more precisely and guide efforts to model the disciplines in which these variables are found. A sensitivity analysis of assessment methods can be undertaken by checking their ability to discriminate between two similar systems. However, the methods must also be robust, i.e. have the capacity to produce accurate results when minor changes take place in the conditions of their implementation.

Robustness and sensitivity

Robustness can be verified, for example, by ensuring that similar conclusions are obtained when the method is implemented in the same production system by different individuals or at different times of the year. Assessment methods that aggregate up to the 'contribution to sustainable development' may lack sensitivity and may have difficulty in differentiating between cropping systems (Craheix *et al.*, 2012). The designers of the MASC method, which is based on a multi-attribute hierarchy, thus carried out sensitivity analyses and identified the need to reduce the number of aggregation levels and balance the number of criteria in each organizational branch of the sustainable development tree considered in their approach.

The ergonomics and transparency of these methods for actors are also goals of research studies with a more specific objective to identify, in the broad range of this set of tools, the branches best adapted to the 'participatory' assessment of sustainability, and to produce overviews and guides to help actors choose a tool based on their objectives and constraints (Lairez *et al.*, 2015).

Integration of the social and economic dimensions

Another major area of research is the integration of the social and economic dimensions in approaches that have hitherto focused solely on the environmental dimension (with, for example, the development of the so-called 'social' LCA) and, more generally, a better taking into account of the multidimensional nature of sustainability.

In the case of poor farmers in the countries of the Global South, the challenge is, above all, to recognize the prevalence of the social and economic dimensions of sustainability, in the short term, in relation to environmental issues, in order to identify trajectories that do not simply add an injunction of environment conservation to the burden of poverty. The concept of the agroecological transition, originating in France and promoted by public actors, itself comes with risk, as long as it focuses solely on environmental issues, in contrast to the ecological intensification concept (Chevassus au Louis and Griffon, 2008; Cassman, 1999), which espouses the idea of reconciling the implementation of agroecological principles with increased agricultural production, seen as necessary to ensure global food security and as an opportunity to help farmers in the countries of the Global South break the cycle of poverty (Tittonell and Giller, 2013; Affholder *et al.*, 2015a).

It therefore seems necessary to create tools for designing agricultural policies that can resolve the conflict between the socio-economic and environmental dimensions of sustainability, for example by providing subsidies for adopting particular practices, for products originating from these practices, or for specific inputs used in these practices or, more generally, by paying for environmental services.

At the same time, if we accept the principle of such policies, we must question ourselves about policies that encourage agricultural intensification. Indeed, why not consider making payments for 'social services' which could result in alleviating poverty for millions in rural areas? Because if their lot does not improve, they may soon be flooding international migration routes in far greater numbers than they have done so far, leading to major social impacts in the rich democracies they land up in, which could even result in a regression of some democratic principles. This issue of support for agricultural development receded into the background during the 30-odd years of liberal globalization, which was finally called into question by international organizations following the global food crisis of 2007. Because the experience of industrialized countries has helped reveal the considerable biases of public policies supporting agriculture in general, we have to propose new tools for *ex ante* and *ex post* assessment of these policies in terms of their impacts on sustainability.

That said, the issue of designing a system at the scale of the cultivated plot, based on multi-criteria assessments at this scale and at higher ones, remains pivotal in the search for techniques corresponding to the most acceptable trade-offs between the environmental, economic and social issues at these different scales. Reasoning here in terms of 'ideotypes of agroecological systems', i.e. ideal agroecological systems, would probably lead to an overestimation of the cost of policies promoting ecological intensification and thus, very likely, delay their implementation. But farms in the countries of the Global South are often very diversified in their activities because it increases their resilience to all kinds of risks. These farms are also very different from one another, each adapted to the constraints of its own biophysical environment, while infrastructure and agricultural support policies in the rich countries greatly reduce the impact of such constraints on their farmers. This complexity and diversity of the production systems of poor farmers in the Global South are such that the individual indicators of productivity of the various activities they carry out are not able to accurately represent their aggregate farm income, its variability due to various hazards, or its dependence on the evolution of their practices, especially towards agroecological techniques. This therefore only reinforces the need to model the economic and social performance of these farms.

Furthermore, agriculture is constantly changing, in the countries of the Global North as well of the Global South, much like the world it is part of. These changes can be extremely slow but also take the form of real technical revolutions that lead to a radical change in a few years of all the variables characteristic of the functioning of the agrarian system. The Green Revolution was an example, and similar revolutions are underway in many countries, most notably in emerging ones that had been bypassed by the Green Revolution in the 20th century. How to avoid assessing agroecological prototypes of cropping or livestock systems that are appropriate for today's farming systems, but which will be of little use in the near future when these farming systems will have been replaced by others? How to design agroecological cropping systems quickly, based on ex ante assessments, when the growing demand for an agricultural product leads farms to rapidly adopt intensive conventional systems? Those intensive systems may indeed be financially more efficient in the short term to generate profits from this emerging demand, but it may make it then more difficult to subsequently transition towards more sustainable practices. Agroecological cropping systems developed by teams of researchers in the mountains of Vietnam, by taking into account the constraints of subsistence farming that existed in these regions at the start of the research and development programme, were found to be inadequate a few years later when production systems had been profoundly altered following an economic boom in this country and the integration of farms into a market that had become more attractive to farmers (Affholder *et al.*, 2008). Similarly, in Brazil, agroecological techniques proposed for maize cultivation that were well adapted to farms created by the agrarian reform (Alary *et al.*, 2016) lost much of their relevance following a considerable reduction of the surface area under maize. This happened because these farms became specialized in intensive dairy production and started buying livestock feed from the market to meet their animals' protein requirements.

Linking the assessment of sustainability with prospective approaches

So how can we avoid implicitly embracing the hypothesis that poor farmers will remain poor when we have to assess cropping or livestock systems? How to instead consider plausible scenarios to help them break out of the cycle of poverty, but which involve entirely different production systems, whose sustainability indicators to be estimated would differ radically from those of their existing farms? And taken to its extreme, the lack of deliberation on the dynamics of production systems will result in a static vision of sustainability, which does not really encourage actors to favour radical changes in production systems. In other words, by assessing agroecological systems for the poor while assuming they will continue to remain poor, do we not run a risk of favouring policies that, at the very least, miss opportunities to lift farms out of poverty and, at worst, help keep them there?

To avoid these major pitfalls, it is necessary to link the assessment of sustainability with prospective approaches in order to identify possible scenarios for the evolution of agrarian and production systems. And we must be able to reason out the choice of indicators, their weightage, and their methods of aggregation by taking these scenarios of evolution into account. For example, in the case of farms set in extreme poverty, which do not use fertilizers or pesticides, key indicators to assess their sustainability would need to pertain to income and food security. But if, within a decade, these farms become part of a market that remunerates agricultural labour well and they begin to use pesticides, the weightage of environmental indicators in assessing sustainability will have to become significantly higher compared to income indicators. If we have not invested in the meantime in estimating pesticide flows in the current setting, we will have to extrapolate from estimates made elsewhere, without any means of knowing how pertinent and accurate these estimates are, and thus be left with no means to ascertain if the relative rankings of sustainability of production systems which use more or less pesticide are reliable or not. In such a case, it will be difficult to convince actors to implement a given technique on the basis of increased sustainability!

More generally, this area of methodological research entails progressing in step with how the disciplines of biophysical sciences and social sciences collaborate, are collectively conscious of the part subjectivity plays in their analyses, and thus jointly subscribe to the results they produce. Contrary to popular belief, this is not particularly based on the amount of goodwill researchers have – which they usually have in ample measure –, but rather on the implementation of certain principles, some of which are simple and have been known for a long time (e.g. recognizing that if it is more difficult, more resources are needed; Naiman, 1999) while others are more subtle (assuming dissymmetry in between disciplines in power relations within a working group; MacMynowski, 2007), but most of which are somewhat constrained by existing modalities of organization and, above all, of the assessment by the research community – not sufficiently multi-criteria, or in any case in which the value of inter-disciplinarity is insufficently recognized!

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Chapter 13

Agroecology and climate change: close links which give cause for hope

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Agriculture is undoubtedly one of the most climate-dependent human activities. Every farmer watches the sky and takes weather conditions (rainfall, temperature, wind, etc.) into account in his agricultural activities. Agriculture's industrial version, which is almost the only form now found in developed countries, has however tried to overcome this dependence. Instead of adapting to environmental and climatic constraints and their variability, this form of agriculture, based on economies of scale, often seeks to modify the environment, for example by irrigating, standardizing the topography, increasing plot size and reducing landscape heterogeneity. The aim is to ensure that high-yield varieties selected for a standard environment find optimum growth conditions at all costs. This approach, which is based on the assumption that it is always possible to control cultivation conditions, finds itself confronting a new factor that has emerged in recent years: climate change.

The relationship between agriculture and climate change

There are several examples of the impact of climate change on agriculture: irregular seasonality, precipitation that is shifted in time or distributed differently, extreme events, temperature changes that advance or delay harvest dates, more active pests, etc. The impacts are varied and also affect yields (Roudier *et al.*, 2011) as well as the nutritional quality of harvested products. Indeed, Myers *et al.* (2014) predict a significant reduction in protein, zinc and iron content in wheat and rice due to an increase in the concentration of atmospheric carbon. In countries of the Global South, climate change impacts the agricultural sector particularly severely because of the high dependence of agriculture on the environment (for example, the vast majority of African agricultural land is unirrigated), which makes it more vulnerable, and because economic conditions do not allow intensive farming to be adopted. In their Nationally Determined Contributions (NDCs), presented by the world's countries in the Paris Agreement of 2015 (COP 21), all sub-Saharan African countries mentioned the agricultural sector among the options selected for adaptation to climate change.

However, the agricultural sector does not just suffer from the impacts of climate change; it is also partially answerable for it. This sector is a massive emitter of greenhouse gases, responsible for about 12% of anthropogenic emissions of these gases, and up to 24% if emissions from land-use changes are included, i.e. essentially tropical deforestation (IPCC, 2014). But there is now a serious effort to understand how agriculture (and more broadly land use, including forestry) can be one of the solutions to climate change because of the potential for carbon sequestration in soils and vegetation and because of the possible reduction of agricultural emissions through the modification of a number of practices such as the large-scale use of synthetic fertilizers. However, it is important to distinguish the increase in the stock of organic carbon in the soil from its sequestration; only the latter corresponds to a withdrawal of carbon dioxide from the atmosphere (Chenu *et al.*, 2018). The concept of 'climate-smart agriculture' tries to take into account the fact that agriculture can be an aggravating factor of climate change, but which at the same time suffers strongly from its consequences. Climate-smart agriculture attempts to respond simultaneously to three issues:
– adapting to climate change (a function sometimes equated – wrongly – to resilience, which is a broader concept that also includes risk reduction);
– mitigating climate change;
– ensuring food security in a sustainable way.

Recent analyses have shown the complementarity that exists between agroecology and climate-smart agriculture, and in particular that the latter would have everything to gain by integrating concepts of the former (Saj *et al.*, 2017).

Agroecology, an integrated solution combining climate change adaptation and mitigation

The principles of agroecology

In its biophysical dimension, agroecology is based on the principles of diversity, efficient use of natural resources, nutrient recycling, natural regulation of and synergy between the different components of agroecosystems, which are most often multi-specific. These principles make it possible to help implement agricultural practices adapted and resilient to climate change. While the concept of resilience has several definitions, we understand it here as the ability of a system to cope with a series of shocks and stresses, in a dynamic and uncertain context.

Resilience is characterized by three capabilities of a system:
– absorption and recovery;
– preparation;
– transformation.

The diversity of agroecological practices helps strengthen each of these three capabilities and thus improves the system's resilience to future climate change. For example, water conservation techniques allow crops to cope better with an unexpected rainfall deficit (absorption); the varietal diversity available to the farmer allows him to choose, before the cultivation season, the optimal varieties to plant (by anticipating medium-term variations); the diversity of varieties and crops and their coupling with livestock husbandry equips an agrosystem with a transformative capacity that allows it to survive long-term major changes such as those modelled by climate change scenarios. Figure 13.1 shows how traditional varieties of millet and sorghum will be less impacted by a +4°C temperature increase scenario than some improved varieties (Roudier, 2012). Agroecology is a viable option to improve the adaptation and resilience of agriculture to climate change because of its inherent characteristics: the diversification of crops and plots, landscape heterogeneity, the use of biodiversity and agrobiodiversity (diversity of useful plants and animals), reduction in use of greenhouse gas emitting inputs, biological pest control, symbioses and various interactions (rhizobia, mycorrhizae, push-pull[1]), etc.

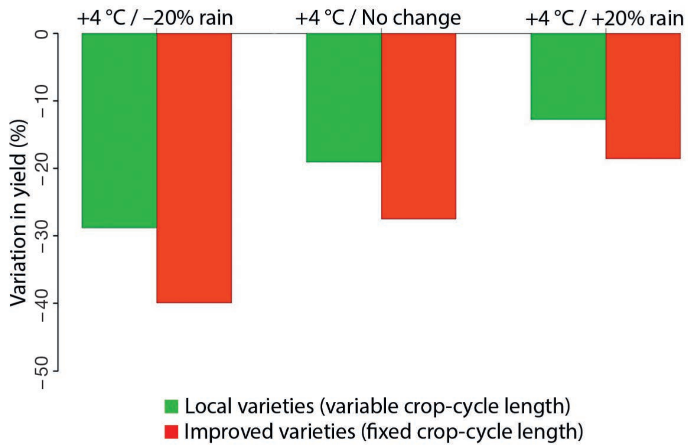

Figure 13.1. Mean yield variations of millet and sorghum in West Africa (35 stations) for local varieties and improved varieties under three scenarios of future climate change (taking the 1961-1990 period as reference). These results are simulations derived from the Sarra-H model (for the methodology, see Roudier, 2012).

Climate risk

Climate risk results from a combination of hazards and vulnerabilities (Gilard, 2015). Vulnerability to climate change depends on exposure to hazards whose probability may vary, as well as the sensitivity and adaptability of the societies concerned. While adaptation can reduce sensitivity to climate change, it is mitigation that can reduce hazards, i.e. exposure to these changes. However, adaptation is localized, while mitigation only works on a global scale, with its effects acting on the atmosphere shared by all. Thanks to its proven properties of enhancing capacities of adaptation, agroecology can have a moderating effect on climate risk and vulnerability. Reducing vulnerability through individual or collective agroecological innovations will often prove to be more effective and no doubt less expensive than reducing hazards through complex technical interventions. In the face of an expected rainfall vulnerability, the spatial and temporal diversification of crops at the landscape scale can, for example, be more effective than the construction of large irrigation structures.

1. See chapter 11.

Mitigating climate change

Mitigation of climate change by reducing greenhouse gas emissions or by carbon sequestration is not an explicit goal of agroecology. Although it can be assumed that in many cases agroecology allows for increased sequestration and lower emissions due to reduced use of synthetic inputs, the precise quantitative comparison in this domain between conventional agriculture and agroecology remains to be done. While there are no regulatory requirements or formal certifications for agroecology, its characteristics nevertheless contribute to mitigating climate change, for example by increasing the total biomass of cultivated plots or by providing soil coverage throughout the year through increased accumulation of organic matter (and therefore of carbon) in the soil. Several cases highlighting the simultaneous potentials of agroecology for climate change adaptation and mitigation have been described in the literature (for example, Altieri *et al.*, 2015; 2017; Paustian *et al.*, 1998) for instance in agroforestry (Photo 13.1), intercropping practices (Photo 13.2), or large-scale heterogeneity maintained in multifunctional landscapes (Photo 13.3). This observation has made it possible to say that while climate-smart agriculture is not necessarily agroecological, agroecology is necessarily climate-smart (Tittonell, 2015).

Agroecology contributes most to mitigating climate change through soil carbon sequestration. This function has been formalized by a recent initiative called '4 per 1000: Soils for food security and climate' (4 per 1000, 2018; Soussana *et al.*, 2018), whose threefold objective is:
– mitigating climate change;
– adapting agriculture to climate change;
– advancing food security.

Agricultural and forest soils contain two to three times more carbon than does the atmosphere, especially in the form of organic matter. Thus, it is estimated that an increase in the organic carbon stock of upper soil horizons at an annual rate of 4 per 1000 could be able to offset annual anthropogenic emissions of greenhouse gases, provided greenhouse gas emissions from deforestation and forest degradation are reduced at the same time. This objective is technically feasible (Soussana *et al.*, 2018) and is a 'no regret' option because an increase in the organic carbon content of soils also increases their fertility, decreases their sensitivity to erosion and increases their water retention capacity. Cases of carbon sequestration in tropical areas at rates equal to or greater than 4 per 1000 per year have been described, for example, through the use of compost or of incorporation of crop residues into the soil (Kenne *et al.*, 2016), in agroforestry (D'Andouss Kissi *et al.*, 2013) and in conservation agriculture (Corbeels *et al.*, 2018).

Positive agroecological feedback

The most promising approach of using agroecology to combat climate change is to look for systems that favour adaptation and mitigation at the same time. This is sometimes referred to as mitigation-adaptation co-benefits or synergy but can be best described as positive feedback between adaptation and mitigation. Adaptation can lead to positive feedback on mitigation, for example, when innovative practices

Photo 13.1. Cocoa trees and fruit trees in an agroforest, Ghana. © E. Torquebiau/CIRAD.

Photo 13.2. Intercropping (maize and beans), Kenya. © E. Torquebiau/CIRAD.

Photo 13.3. Multifunctional landscape (land sharing) with rivers, hedges, fruit trees, human habitation and agroforest, Sumatra, Indonesia. © E. Torquebiau/CIRAD.

designed to improve soil fertility lead to an increase in soil organic matter and thus a reduction in nitrous oxide emissions (N_2O) due to reduced use of synthetic fertilizers. This effect is proven, for example, in the case of agroforestry coffee plantations: even if there is more nitrogen in an agroforestry coffee plantation than in a full-sun one (and therefore potentially more N_2O emissions), its total carbon footprint is lower (Hergoualc'h *et al.*, 2012). In a similar way, mitigation can lead to a positive feedback on adaptation when an objective of increasing soil carbon sequestration results in benefits in terms of soil properties and improved stress resilience, with positive consequences for agricultural production.

Agroforestry provides many examples of positive agroecological feedbacks, such as the one known as 'the regreening of the Sahel' in Niger (Photo 13.4). The practice is based on the assisted natural regeneration of trees in cultivated fields, an old method which was slowly dying out but which innovative public policies (the transfer from the State to farmers of property rights over trees) helped revive (Sendzimir *et al.*, 2011). Tree density has increased dramatically, improving soil fertility and the microclimate (adaptation), favouring aboveground and underground biomass and hence carbon storage (mitigation), all of which is having a positive impact on farmer incomes and food security. Another agroforestry example is the shading of cocoa trees or coffee plants by 'shade' trees, a practice that helps offset losses due to possible increases in temperatures. Agriculture in the Global South provides compelling examples that can be extended to the entire planet.

Photo 13.4. Agroforestry intercropping of maize and *Faidherbia albida*, Dolekaha, Côte d'Ivoire. © Dominique Louppe/CIRAD.

Many other agroecological options can promote adaptation-mitigation synergies: conservation agriculture, intercropping, organic fertilizers, improved pasture management, water management, no-till practices, permanent soil cover, etc. Even livestock husbandry, often blamed for the emission of large amounts of greenhouse gases, can, depending on how pastures are managed and used, contribute to this balance between adaptation and mitigation. In Senegal, a study of extensive livestock farming at the territorial level, a practice that is especially adapted to local conditions, shows that, over annual time steps, greenhouse gas emissions and carbon sequestration balance each other out (Vayssières *et al.*, 2017).

It is indeed only on a scale exceeding the plot, or even the farm, that many approaches can claim to promote the synergy between adaptation and mitigation. In multifunctional landscapes (Torquebiau, 2015; Denier *et al.*, 2015), it is possible to combine objectives of agricultural or forestry production with objectives of nature and biodiversity protection. This concept, known as 'land sharing' (Grau *et al.*, 2013), assigns adaptation or mitigation objectives to neighbouring and often interacting landscape units. It is in direct opposition to the concept of 'land sparing' in which agricultural production and nature protection are spatially separated. Land sparing is a corollary of the Green Revolution and the well-known 'Borlaug hypothesis': maximizing production in agricultural areas with productive varieties, irrigation and inputs in order to protect nature elsewhere. The continued expansion of agricultural lands at the expense of natural environments has proven this hypothesis false. In contrast, land sharing is essentially agroecological and promotes 'climate-smart' landscapes (Harvey *et al.*, 2014; Torquebiau, 2017).

Box 13.1. Agrobiodiversity: a common good for increasing resilience to climate change

E. Torquebiau, P. Roudier, J. Demenois, S. Saj, É. Hainzelin, F. Maraux

The biodiversity of cultivated ecosystems – especially when it is useful for people, including in natural environments – is what is called agrobiodiversity. It forms the foundation of our agriculture but we have forgotten it over time; our agriculture today is based on too few species and a limited number of varieties within these species. Yet agrobiodiversity is an essential lever of agroecology (Hainzelin, 2013) because it is on the basis of this genetic, specific and landscape diversity that it is possible to design new farming systems that are more resilient to environmental and climatic hazards. It is through innovative breeding approaches and diversified farming practices, based on a wide range of species and species interactions, that it will be possible to respond to shifts in climatic and agroecological zones, the emergence of new pests and diseases, and increasingly frequent extreme climatic events. The agricultural and forestry systems that will contribute to mitigating climate change through carbon sequestration are those that are rich in biodiversity and biomass. It is 'perennial' farming (Perfecto *et al.*, 2009) that must be encouraged, based on the use of woody plants, cover crops, roots and tubers, or perennial grasses. The more widespread adoption of these practices, which have historically been used to respond to existing climatic hazards (choosing the variety depending on weather forecasts, for example), is being prevented today in several regions due to the reduced diversity of varieties available to farmers (Maikhuri *et al.*, 1997) as well as the emergence of patents for seeds, which were previously managed as a public good (Brush, 2005).

Prospects and limitations

Although agroecology is a concept that has existed for several decades (Wezel and Soldat, 2009), it is currently used only in the case of traditional agriculture and has not yet been widely disseminated. Even though the constraints imposed by climate change are certainly unwelcome, they can provide an opportunity to accelerate the spread of agroecology. A lack of support from official educational and research institutions may also partly explain this delay. In the past, agroecology has not been included – and often is not so even today – in agricultural education. The lack of reference to agroecology in the majority of public policies must also be blamed. Will the (delayed) inclusion of agriculture by the official bodies of the United Nations Framework Convention on Climate Change (UNFCCC) after COP 23 (November 2017) lead to changes in orientations? Given that agroecology has also been the focus of some development policies for some time (for example, at the FAO with its Symposium on Agroecology for Food Security and Nutrition; FAO, 2015; FAO Symposium, 2018), one can expect the agroecology and climate change themes to build one on the other.

The 'scaling up' of these potentially close links between agroecology and climate change remains a challenge. There is a great need to raise the awareness of farmers in the Global North as in the Global South to the fact that agroecology can represent a solution to the constraints of climate change. But how can we effectively go beyond successful experiments in a few locations to spread this scientific message to the greatest number of farmers when national public policies ignore agroecology or even contradict it with subsidies or various incentives for industrial agriculture? How to raise awareness of these innovative techniques when the staff of services providing technical support to farmers is itself trained in conventional agriculture? While we can now, especially because of the recent work on soil carbon (Soussana *et al.*, 2018), consider using agriculture as a contributory solution to climate change, it is only the forms of agriculture that embrace principles of agroecology that can really play this role.

It is also worth noting that agroecology runs counter to the interests of powerful actors (e.g. inputs suppliers) and therefore the mobilization of political will cannot be taken for granted. While the transition to agroecology can involve all types of agricultural structures, it is particularly well suited to small farms. Indeed, since they are based on the diversification of production and on the ecosystem's biological regulatory mechanisms, agroecological farming systems are inherently less demanding in terms of capital, and enjoy a high agri-environmental and socio-economic sustainability. Such analyses can inform future advocacy efforts essential to the formulation of public policies in the Global North as in the Global South. Finally, agroecology is fundamentally tied to the local context and its large-scale application depends on the dynamism of local innovation systems, not only at the level of agricultural practices but also at the level of commodity chains, and in relation to new links between urban and rural areas. This poses a huge challenge in terms of training and development of skills and redefines the role that the research community must play.

Thanks to its twofold action on climate change, agroecology can help nations meet their Nationally Determined Contributions (NDCs) presented by all the countries of the world at the time of the Paris Agreement in 2015 (COP 21) and which must be revised upwards by 2020. Worldwide, 89% of the countries refer in their contribution to the agricultural sector and the use of land in the broad sense (LULUCF: Land Use, Land Use Change and Forestry). More specifically, 78% of countries include agriculture in their mitigation options and 100% of sub-Saharan African countries cite it as an adaptation option (FAO, 2016). Agroecology is unfortunately mentioned explicitly only very rarely (Rwanda, Honduras) but some of its components do find inclusion: conservatory water management, improved pastoralism, agroecological fish farming, landscape approach, biological corridors, 'low carbon' farming practices, etc. Agroecology can therefore be a path to follow in order to meet national climate objectives.

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Chapter 14

The ecologisation of agriculture through the prism of collaborative innovation

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Calls for collaborative innovation in the agricultural sector continue to grow (Von Hippel, 2005; Swaans *et al.*, 2014; Temple, 2017; Toillier *et al.*, 2018a) with an increasing awareness of the wide range of actors who interact and contribute to innovation: SMEs, service companies, institutions, public actors and even civil society acting through NGOs.

Collaborative innovation can be defined as the creation of innovations outside the boundaries of organizations and through the sharing of ideas, knowledge, expertise, resources and opportunities (Demil and Lecoq, 2012; Ketchen *et al.*, 2007). It is a way of initiating or setting up joint innovation projects through an emphasis on inter-organizational relationships and on the basis of the ability of a diversity of organizations and individuals to progress together, outside of their usual working environments.

Collaborative innovation seems to be especially relevant when looking for ways to support the ecologisation of agriculture. Indeed, it has long been established that an engagement in the agroecological transition cannot be an individual undertaking, since it requires the sharing of resources, knowledge, experiences and spaces, and involves externalities at scales that exceed those of the farm and the production system (Whiteside, 1998; Uphoff, 2002; Oborn *et al.*, 2017; Meynard, 2017). Furthermore, even though many organizations share a desire to find new ways of leveraging natural mechanisms to produce, of respecting the environment better and of meeting the criteria of sustainability in general, it is usually only through multi-stakeholder local mechanisms that solutions are found (Van Mierlo *et al.*, 2017). In the absence of universally applicable solutions, Weltin *et al.* (2018) note that, in all the regions of the world, practitioners have identified the need to co-develop common solutions and actions to implement ecological intensification strategies appropriate to the regional context and local ecosystems. In each case, it is necessary to mobilize actors with different perspectives, to hybridize different types of knowledge (scientists, experts, practitioners) and to anchor the design and implementation of innovations locally (Warner, 2008).

To initiate and organize these dynamics of collaborative innovation, support mechanisms such as innovation platforms and facilitated networks[1] are increasingly being mobilized (Van Mierlo *et al.*, 2017; Beers and Geerling-Eiff, 2014). However, in developing countries in which innovation systems are still highly compartmentalised and where the resources allocated to the agroecological transition remain limited (see Chapter 10), the implementation of such support mechanisms raises real methodological challenges for practitioners of accompaniment. They have to help individuals reorient their practices towards forms of collaborative work they have no training in, and have to catalyse relationships between multiple organizations which may not always be convinced of the benefits of working together. It is a matter mainly of helping these organizations agree on common objectives and produce results that are useful for innovation even though they are used to favouring their own work and to being competitive in order to obtain funding.

How do the mechanisms currently deployed in the Global South help trigger dynamics of collaborative innovation that can be useful for the agroecological transition? What are the difficulties encountered and how can they be overcome?

This chapter throws lights on these questions. The first part justifies the interest in studying the ecologisation of agriculture through the prism of collaborative innovation and of its paradoxes. The second part describes a diversity of collaborative mechanisms mobilized at different levels at which the agroecological transition is organized. Examples from Burkina Faso and Cameroon illustrate the different organizational forms mobilized and the way in which they help overcome certain paradoxes of collaborative innovation in order to make actors move forward. The conclusion provides a perspective for future research.

Collaborative innovation as a way to stimulate the ecologisation of agriculture

A creative bubble within socio-technical networks

The concept of collaborative innovation extends that of 'open innovation', which is based on an organization's ability to open itself up to others in order to innovate, cooperate, and share technologies and intellectual property rights within a given sector and for profit (Chesbrough, 2006; Gassmann *et al.*, 2006). Through his study of innovation communities and their modes of collaboration, Gläser (2001) shows that economic motivation is not always a determining factor. It is instead a matter of voluntary association of actors, not necessarily having the same organizational affiliation but united by a shared objective of creation, adaptation, adoption and dissemination of an innovation.

1. A facilitated network is a business model based on a shared platform that allows individuals to exchange resources and services. Facilitated networks are a means of optimizing collaboration and learning between organizations, most generally by allowing the platform to monetize its resources and services (membership, access and participation rights).

In the movements to ecologise agriculture, different types of actors play key roles at different times to initiate a path of technological or institutional change in agreement with other actors. Genus and Coles (2008) refer to the realignment of networks in the tradition of actor-network theory. Garud *et al.* (2002) have shown that these agents of change are usually 'distributed, partisan and integrated' into technological and institutional trajectories. On the one hand, they participate in pursuit of their own interests. On the other, solutions emerge through partisan mutual adjustments that require an engagement by actors on the very path they have helped to create. In developing countries, actors engaged in agroecological innovation are still not very diverse and few in number, which further limits the range of possibilities. They originate mainly from the public sphere and civil society, intervening according to a project-centric logic, with projects funded by international cooperation entities or public aid. Most often, their relationships are defined by past history and impart predictability to their interactions, leading more to consensual choices and incremental innovations than true revolutions in agricultural models.

Mechanisms to support collaborative innovation attempt to lift individuals from their usual working environments and project them into another dimension, with different metrics, in particular new metrics of time. Blandin *et al.* (2016) speak of the 'creative bubble' in which we seek to accelerate or even 'precipitate' relational and cognitive processes between individuals. It is a matter of saving time by identifying quickly a multitude of new ideas, drivers of solutions, or inter-organizational arrangements to facilitate the emergence of new solutions or the leveraging of opportunities for change.

Collaborating to solve problems

Ecological intensification requires a greater mobilization of natural mechanisms, i.e. those pertaining to ecology, or even their amplification so that they become almost exclusive (or dominant) in terms of agricultural practices, for the ultimate benefit of food production and other societal needs (Griffon, 2013). At the very least, ecologically intensive agriculture aims to maintain the same agricultural yield as a conventional model but with a reduction in the use of artificial chemical inputs. Ecological intensification has to face multiple challenges at the levels of the farm, the territory and the agrifood system as a whole (Meynard, 2017). We can distinguish between simple, complicated and complex problems, all of which call for different mechanisms of innovation and collaboration (Toillier *et al.*, 2018a). These different types of problems require different orders of change. Waddell (2011) distinguishes between three types of change: incremental change, reform, and transformation (Table 14.1), with the latter being the most difficult to achieve. Moreover, simple and complex problems may be a nested or appear in sequence. For example, the apparently simple problem of access by producers to improved seeds – discussed in the case of the Mbalmayo innovation platform in Cameroon (Mathé *et al.*, 2018) and the plantain banana platform in Côte-d'Ivoire (Angbo-Kouakou *et al.*, 2017) – will, sooner or later, raise complex problems of governance in the seed sector that will require a systemic or transformational change, and will therefore need new forms of collaboration to solve them.

Table 14.1. Types of changes that are involved in collaborative innovation mechanisms (adapted from Waddell, 2011; and from Snowden and Boone, 2007).

Problem	Simple	Complicated	Complex
Type of change	Incremental Improving performances	Reform Changing the ways different parts of a system interact	Transformation Creating hitherto unsuspected possibilities, imagining solutions that do not yet exist
Examples	Developing agri-chains that derive value from products resulting from ecological intensification	Creating new rules for the use of resources at the scale of a village territory	Introducing and promoting certified organic farming in a country
Modalities for resolving problems	Changing the ways of acting and behaving	Changing the ways of thinking	Changing the ways of perceiving one's environment
Key questions	How can we do more of the same thing or do it better?	What rules do we need to create?	How can we impart sense to all this?
Learning loop	Single loop	Double loop	Triple loop
When does it take place?	Predictable timeframe for common problems	When we can formulate the problems but cannot arrive at solutions	When we are unable to formulate the problems and unable to find solutions
Who participates?	The actors who formulate the problems	The actors of the concerned system	The actors who help make the system intelligible in its different dimensions
The individual's relationship with the collective	The collective explains the individuals' roles so that everyone acts on the problem	The individual does not feel responsible and believes that it is others who have created the problem	The collective confronts the problem all together and considers itself to be part of the problem and of the solution
Implications for collaborative mechanisms	Can rely on existing hierarchical structures (such as a value chain) to organize collective action Can use a logical framework	Requires the production of a large amount of knowledge because cause-and-effect relationships are not obvious Rigorous planning, multiple types of expertise, poorly suited logical framework	Conducting a number of experiments, generating a large amount of feedback in order to choose strategies that work, learning is achieved through successive failures Change-oriented planning
Examples of collaborative innovation mechanisms	Multi-service innovation platforms guided by agri-chain actors For example, the Mbalmayo platform in Cameroon (Mathé *et al.*, 2018)	Innovation platforms guided by the research community using Action Research in Partnership (ARP) For example, the Abaco platform in Burkina Faso (Dabire *et al.*, 2017)	Facilitated networks For example, the CNABio network in Burkina Faso (Toillier *et al.*, 2017)
Funding mechanisms	Short-term external funding (project)	Long-term external funding (programme)	Internal funding (self-financing)

The paradoxes to overcome

Organization and innovation seem to be two contradictory but inseparable concepts, since the goal of the first is to reduce uncertainty and of the second to take advantage of it. Collaborative innovation must be able to address a set of paradoxes specific to innovation, grouped into three broad categories (Blandin *et al.*, 2016).

Immediate/long term. Innovation is intended to transform practices in a radical manner. This transformation takes time, especially in contexts of agroecological transitions. Different time horizons, beyond just the lifetime of the collaborative mechanism, are involved and have to be taken into account.

Individual/collective. The paradigm of participation in the world of agricultural development has encouraged the systematic inclusion of all stakeholders in innovation support mechanisms, without, however, specifying the details of their inclusion (Schut *et al.*, 2015, or TAP, 2016). Studies on creativity have shown that an innovation collective is not merely a collection of individuals; it also involves a specific kind of management that is necessary for the collective to truly contribute something in addition to the individualities and the ideas of the individuals. On the one hand, the dynamics of individual learning are inseparable from the nature of the relationship with the collective (Hatchuel, 1999) and, on the other, the very composition of the collective influences the group's capacity for innovation (Janssen *et al.*, 2004).

Divergence/convergence. Many mechanisms tend to be divided into two major phases. Such is the case, for example, of a participatory methodology (Duru *et al.*, 2015) designed to promote territorial agroecological transitions. First, we seek and identify problems perceived by the different actors (divergence), then we integrate and evaluate optimal solutions (convergence). In fact, these activities cannot be separated and have to be undertaken in parallel: it is a continuous development-evaluation cycle that makes it possible to take decisions, enrich a proposal or redefine an idea. The challenge is to manage development and evaluation head-on.

Factors of success

There are three known major factors of success for collaborative innovation: the establishment of coordination mechanisms and of protocols for interaction between the different actors; the construction of a common vision; and the mobilization of the resources needed for action.

Coordination mechanisms reduce uncertainty and curb opportunistic behaviour and are thus essential in innovation networks (Dhanaraj and Parkhe, 2006). Indeed, these organizational forms are especially conducive to the exchange of information and the transmission of know-how, but which risk promoting opportunistic behaviour (Goerzen, 2007). Furthermore, the often tacit nature of knowledge and the low degree of predictability of results lead to high levels of uncertainty. The modalities of coordination must make it possible to foster inter-organizational trust, propose conflict management mechanisms, and offer assurances on the use of the results that will be produced (Gardet, 2009).

The interaction protocol consists of selecting the individuals who will collaborate and of organizing the work sequences. Amin and Roberts (2008) show that once the nature of the problem has been identified and the coordination mechanisms chosen, the effectiveness of a collaborative mechanism depends very much on the nature of the actors involved. In a weak context, i.e. when the individuals present have not previously worked with each other, the concretization of ideas and proposals made during interactions will be more difficult than in a strong context (when the individuals present are used to working together successfully). However, this difficulty can be overcome by an appropriate selection of individuals in terms of the complementarity of their skills and their motivations in seeing the problem resolved. If the selection is lenient, as is very often the case in participatory workshops carried out as part of development projects (open to all who are able to attend or according to a hierarchical criteria defined elsewhere), then the risk of the mechanism's failure is higher, unless these individuals belong to organizations already engaged in an innovative community and are able to exceed individuality-related limitations. The organization of work sequences then consists of alternating collective and individual phases, by offering space and time for experimentation, collaboration and comparison. These alternating phases form the basis of collective learning.

Time joins strategy and common sense as an important consideration. Consistency between and alignment of ambitions, strategies, organization and working methods over time will allow the paradoxes of time to be overcome. Successful cases of collaborative innovation demonstrate a collective motivation to address common challenges, going beyond individual issues. Weick (2001) speaks of 'sense making', i.e., of being able to identify problems together and to impart them with a common sense. This requires the creation of common exchange spaces to co-construct a shared vision.

For collective action to even begin, specific human, material and financial resources must be mobilized. The selection of individuals and organizations in particular plays a key role: different skills are necessary, those of content experts (capable of helping develop the product-innovation) as well as those of process experts (capable of helping organize socio-cognitive processes for the design of the innovation). Indeed, the orchestration of collective action calls for facilitators who can coordinate the interactions between the actors, facilitate discussions, promote communications and the dissemination of information, and play the role of translator or 'boundary bridger'. This role is crucial to the proper functioning of an innovation platform and requires specific skills that these facilitators must bring to the table from the very beginning of the process (Klerkx and Leuwis, 2008; Steyaert *et al.*, 2017).

Figure 14.1 summarizes the combination of factors to be taken into account in understanding the scope, processes and benefits of collaborative innovation mechanisms.

Mismatches between promises and results

On the basis of these factors of success of collaborative innovation mechanisms, we explore how the mechanisms currently deployed in the Global South enable and stimulate the dynamics of collaborative innovation useful for agroecological transitions.

Selection of case studies

To distinguish between existing collaborative mechanisms that are supporting agroecological transitions in the Global South, we have adopted two criteria pertaining to the capacities of the individuals and organizations involved (see Figure 14.1): level of constitution of the innovation community that is mobilized in the collaborative mechanism (strong or weak context), and the level of the individuals participating in the mechanism (strict or lenient selection in terms of individual skills, knowledge and abilities) (Figure 14.2).

From a set of case studies to which CIRAD has contributed in the past, four were selected (Figure 14.2 and Table 14.2) to illustrate a variety of initial configurations of mechanisms according to the chosen criteria, i.e. the capacities of the actors involved (context and selection). This exploratory qualitative study aims to highlight the processes through which collaborative mechanisms deliver on their promises. The analyses presented here are based on published literature that describes the scope and the processes of implementation of each of the four mechanisms and the results obtained.

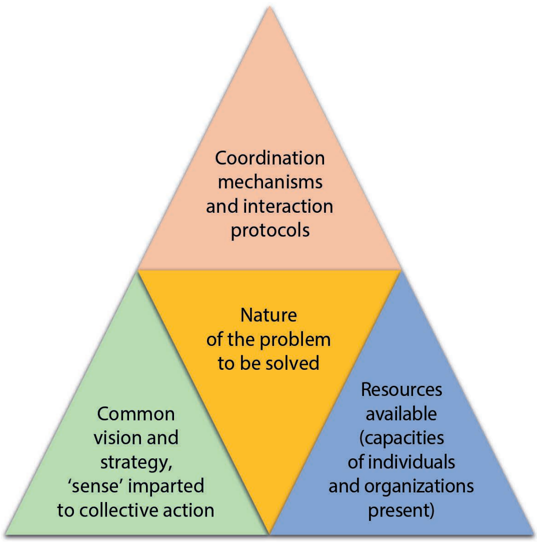

Figure 14.1. Factors of success of collaborative innovation.

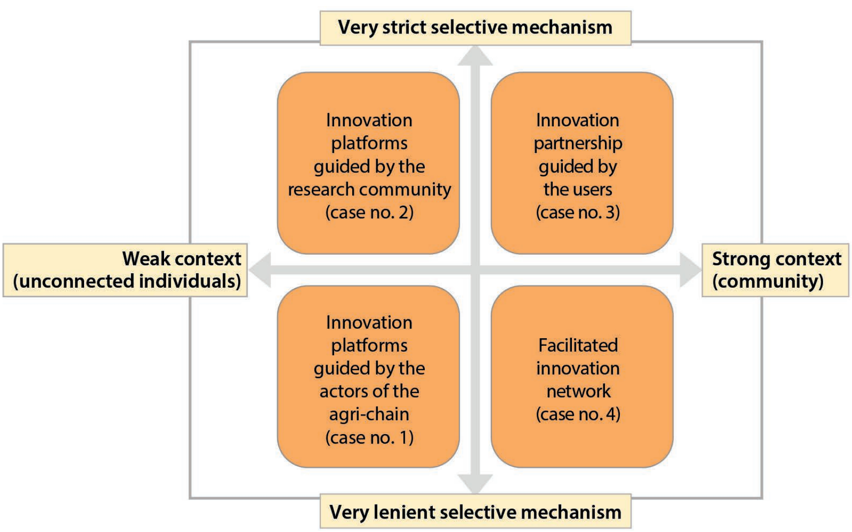

Figure 14.2. Examples of collaborative innovation mechanism according to the capacities of the actors involved: level of inter-organizational relationships and level of selection of participating individuals.

Table 14.2. Examples of collaborative mechanisms for ecological intensification supported by CIRAD in Cameroon and Burkina Faso.

	Aim of the innovation	**Examples of collaborative innovation mechanisms**	**The mechanisms' objectives ('promises')**	**Actors involved**
	Designing and developing new production systems			
Case no. 1	Supporting forms of sustainable intensification using the value chain approach	Multiservice innovation platform guided by the agri-chain's actors: Mbalmayo platform, Cameroon (Mathé *et al.*, 2018)	Identifying local but generalizable technical solutions to optimize crop diversification and enhance soil fertility	Farmers Traders Researchers Agricultural advisers
Case no. 2	Developing conservation agriculture at the village scale	Action research in partnership mechanisms guided by the research community: village platforms of the Abaco project, Burkina Faso (Dabire *et al.*, 2017)	Building technical references adapted to local conditions Changing the rules of governance of common resources (crop residues) at the village level to derive better value from them	Farmers Researchers Traditional village authorities Administrative authorities Agricultural advisers Development NGOs Traders Inputs suppliers Banks Craftsmen, processors
	Designing and developing new services to support transformations on family farms			
Case no. 3	Modifying the approaches used by the producer organization to support its members in order to facilitate ecological intensification	Innovation partnership guided by UGCPA users, Burkina Faso (Toillier and Girard, 2016)	Designing an original communication approach for UGCPA's agri-environmental policy	Producer organization (UGCPA) Researcher (CIRAD) Communications agency (Jade Productions) Facilitating NGO (FARM)
	Developing innovations combining the agriculture and food sectors			
Case no. 4	Introducing and developing organic farming	CNABio facilitated network, Burkina Faso (Toillier *et al.*, 2017)	Developing the first organic farming standard in Burkina Faso Creating the first organic label in Burkina Faso Creating a network of organic farms Developing and organizing support services for organic farms Developing organic agri-chains	Farmers Traders Support and advisory entities (NGO, agricultural adviser) Organic inputs companies Researchers Policymakers

CNABio: National council for organic agriculture (French: *Conseil national de l'agriculture biologique*); UGCPA-BM: Union of Agricultural Product Marketing Groups of Boucle du Mouhoun (French: *Union des groupements pour la commercialisation des produits agricoles de la Boucle du Mouhoun*).

Lessons learnt from these four mechanisms

We illustrate how collaborative innovation was organized in the four selected examples, and examine the functional reasons for the inability of the results to match the promises made. The summary of the analysed cases is presented in Table 14.3.

A lenient selective mechanism in a weak context

As part of a research programme on sustainable agricultural intensification called *Humidtropics*, three innovation platforms were set up at a local level, including the Mbalmayo platform in Cameroon's Central Region (Mathé *et al.*, 2018). The aim was to optimize crop diversification in this region and facilitate sustainable intensification by implementing an agroforestry system. Farmers had to be trained in techniques to propagate local trees, to produce maize and vegetable seeds, and to set up nurseries and experimental plots. They also had to be assisted in implementing more integrated production systems.

All of the local platforms were linked to a national platform that played a coordinating role. Its purpose was also to identify 'meta-problems' – problems that occur at a national rather than only at a local scale –, find generalizable solutions to them and serve as a link to political authorities. The role of the local platforms was to adapt the national framework to their respective contexts. The articulation between these two levels was meant not only to meet the farmers' clearly specified needs in an optimal manner but also to integrate these actions into more global dynamics of the scaling up of adaptable solutions for sustainable intensification.

The results observed after three years of functioning were mixed. For example, the technical responses proposed were ultimately found to be unsuitable because the problem was poorly formulated right at the beginning. The main direct causes behind these identified failures were inadequately used coordination mechanisms, an insufficiently developed common vision, and lack of the appropriate skills of the actors involved. More indirect causes pertained to an intervention that was too limited in time given the scale of the changes that were expected at the individual and organizational levels.

However, Mathé *et al.* (2018) do note that the capacities of the actors involved can be built up:

– by fostering trust with the creation of a space for exchanges between actors who were not used to talking to each other (producers and processors);
– through a better understanding by researchers of the complexity of the needs expressed;
– through the awareness that an improved variety, introduced by the research community, is not necessarily a priority for farmers, since they have other assessment criteria and thus select other, non-recommended, varieties;
– through better coordination between organizations that provide services to producers, such as agricultural advice or access to financial resources, by means of a shared vision of their respective roles.

This case illustrates how a mechanism in a weak context, with an inexact or lenient selection of participants, leads to unsatisfactory results if there is not enough time to deploy the entire protocol of interactions between these actors and if the facilitation is not properly conducted. In this case, the facilitators were unable to get the researchers and farmers to communicate sufficiently so that they could agree on the varieties to choose and on implementing experimental protocols that could be of interest to both parties. The roles of the participants (farmers, advisory service providers, researchers, funding institutions, inputs suppliers, processors, transporters) within the innovation was also not clearly defined or managed, which led to ineffectual individual actions or even conflicting ones. Facilitators should have received more initial training so that they could, at the very least, have been able to analyse situations in the interaction processes in order to use the right facilitation methods at the right time.

A strict selective mechanism in a weak context

As part of the Abaco (Agroecology-Based Aggradation COnservation agriculture) research and development project coordinated by CIRAD, a team of researchers consisting of agronomists, zootechnicians, sociologists and geographers set up and facilitated innovation platforms at the village level between 2011 and 2014 in Burkina Faso. The objective was to co-build, with all the farmers and governance actors in these territories, farming systems based on the principles of conservation agriculture (Dabire *et al.*, 2017).

This objective, initially driven by the research team, was in line with local demand for solutions to reduce soil depletion and to increase productivity, as well as to better leverage crop residues as a source of biomass during the dry season. This collective construction of shared objectives went on for almost a year, with the search at the same time for a mode of operation of the innovation platform that would be anchored in local dynamics specific to each village. Each platform was thus built on a selection of actors to mobilize, based on prior analyses of existing organizations and their roles in managing agricultural resources. The protocol of interactions between researchers and actors was jointly decided upon and led to the validation of an operational framework for experimentation and validation of the results obtained. It brought together a technical body dealing only with the experimental aspects of the project and an institutional body in charge of overseeing relationships between the participants for the proper conduct of the experiments.

At the end of three years of functioning, the results were seen to be positive in terms of the changes in farmers' perceptions, attitudes and practices concerning the implementation of conservation agriculture. Collaborative work allowed all participating individuals to find new solutions at the scale of the village territory to problems encountered at the farm level. The innovation platforms were instrumental in the initiation of the social process necessary for a transition to new farming systems based on principles of conservation agriculture. However, the operational implementation of the collectively identified and validated solutions remains a problem in its own right. It will require new methods since the actors concerned did not make any commitments to undertake changes over the medium and long term. There can thus be no guarantee that the solutions will actually be implemented. Moreover, the platform was not designed to function beyond the design of solutions and did not have funding for continuing operations beyond the duration of the Abaco project.

This case illustrates how double-loop learning has been achieved, essentially allowing people to change their ways of thinking and find new solutions to complicated problems – but without going so far as to actually implement these solutions. The authors highlight two main factors of success:

– the mobilization of existing inclusive organizations, already involved in activities in line with those of the innovation platform, which helped the endeavour gain legitimacy rapidly and convince the farmer audience, in order to promote dialogue around the design of new agricultural systems based on the principles of conservation agriculture;

– the careful establishment of coordination mechanisms and interaction protocols for the various actors to ensure consistency between the exploration of technical issues and of institutional issues in the changes being tried out.

A strict selective mechanism in a strong context

In western Burkina Faso, the Union of Agricultural Product Marketing Groups of Boucle du Mouhoun (UGCPA-BM, in French: *Union des groupements pour la commercialisation des produits agricoles de la Boucle du Mouhoun*) adopted an agri-environmental policy to implement its vision of change in farming practices aimed at ensuring the sustainability of its members' production systems in the medium and long term. This policy encourages the adoption of ecological techniques for soil fertilization (green manure, mulching, improved fallows, legumes), erosion control (stone barriers, agroforestry), reduction in the use of chemical inputs, and the promotion of organic farming. In order to encourage the acceptance of its vision by its members and thus facilitate the adoption of agroecological techniques, UGCPA-BM roped in one of its close partners, the Foundation for World Agriculture and Rurality (French acronym: FARM), to help it design an original communications approach for its agri-environmental policy through the use of innovative technologies. Thus, in 2013, FARM launched an innovation partnership for a two-year period that brought together the producer organization (UGCPA), the research community (CIRAD) and a communications agency (Jade Productions) with which previous collaborations had been successful. The objective of these partners was to design this approach together, with the partners being selected for their complementary skills and viewpoints on the issues of communication and ecological intensification.

The design of the communications approach spanned several months. It was a reflexive, iterative and participatory process and alternated phases of collective work, field data collection and restitution, and internal reflection at UGCPA. The process was guided by the need for the organization to formulate its requirements and expectations from the agri-environmental policy it wished to implement. Each stage was designed to incorporate new elements to help develop the communications approach. The result was an unprecedented approach to support producers which combined participatory video and collective advisory sessions.

While the UGCPA was very satisfied with the result, the fact remains that the innovation produced (the communications approach using the participatory video) was not very original, even if was a novelty for the producer organization. We can therefore question the need to take recourse to such a relatively expensive collaborative mechanism. But there was another result, especially significant with regard to the ecological transition. It concerned the building up of the capacities of the producer organization: capacities to formulate a vision and to organize change; to organize itself to carry out identified actions effectively; to be able to communicate internally, with its members and with its partners; and to adopt a reflexive, step-by-step approach to evaluate its actions. Toillier and Girard (2016) show that it was the protocol consisting of very sequenced interactions between the four partners that allowed this capacity building. Collective designing phases were alternated with internal phases of 'individual' work within organizations, each in its area of expertise: an experimentation phase, adjustment phases between two or three partners, and collective pooling phases. This protocol fostered the partners' commitment and the recognition of the potential of individual initiatives through shared trust, and enabled individual and organizational learning. The collaborative innovation mechanism in itself became a capacity building mechanism for the producer organization. The real internal transformation that resulted represents an asset for accelerating the agroecological transition: UGCPA is now better placed to express its needs to its partners and target its support to its members more effectively.

A lenient selective mechanism in a strong context

The National Council of Organic Agriculture (CNABio, in French: *Conseil national de l'agriculture biologique*) is an association created in 2011 to bring together actors and initiatives to support organic agriculture in Burkina Faso. Its members consist of about 40 organizations: groups of producers, traders, private suppliers of inputs, NGOs and consumers. The strict selection of members is based on their agreement on a vision, a commitment to develop agroecology and organic farming, specific technical skills, and the pooling of resources.

As the umbrella organization of a national network, CNABio's mission is to provide an organized framework to collectively remove the obstacles to the emergence of organic agriculture and agroecology. Thus, a new Burkinabe standard was introduced in 2013, followed by the first certification label in 2016. More than a dozen farms have since been certified, which is contributing to the development of agri-chains and new markets. However, many challenges remain: most notably, promoting access to organic inputs and imparting long-term durability to organic production systems, in particular by using certain agroecological techniques. In order to strengthen its capacity to support these technical and organizational innovations, CNABio has received support from CIRAD in the form of a project, launched in 2016, dedicated to building capacity to innovate. This project has equipped CNABio with the technical, methodological and financial resources required to carry out collective actions of experimentation, consultation and coordination with its network's members. CNABio has found participatory methods of identifying the needs of these members and facilitation skills to be the most useful. By consolidating its interaction framework and coordinating mechanisms, CNABio has, for example, quickly been able to identify new strategies for improving linkages between the production and marketing of organic products. A one-off project was then set up with new partners to implement new short-circuit marketing solutions in a targeted manner.

This case study shows how a facilitated network self-funded over the medium term is in itself a collaborative innovation mechanism. In response to a complex problem, the gradual building of a common vision, the presence of a legitimate federating organization able to mobilize other organizations, the confidence gained as a result of the various collective successes, the regularity of structured exchanges over the long term, and the commitment engendered through the membership of this network appear as factors of success in the deployment of changes at multiple levels (Toillier *et al.*, 2017). These invisible results are forming the basis for setting up well-defined technical projects, to which donors are responding increasingly positively. The network has thus begun to reverse the traditional donor-recipient dynamics by convincing donors to align with its needs and not to respond, on a case by case basis, to its requests for funding. Thus the existence of a common strategy and coordination mechanisms compensate for initially low levels of resources (human, financial, material) by building up the network's capacity to become involved in long-term strategic and political processes. The consequence of these multi-level learning processes (individuals, organizations, inter-organizations) is that the time steps of any action are long (exceeding ten years).

Summary and discussion

Our observations from the four case studies lead us to discuss three ideas: the calling into question of the project-centric approach; the need for a support team instead of facilitators to manage the paradoxes of innovation projects; and the role of collaborative innovation mechanisms in agroecological transitions.

Can innovation be managed through projects?

In all the four cases, the technical results can be considered limited, either not very original or providing answers only partially to the problem posed in terms of the technical issues formulated initially. The bulk of the changes and outcomes concern the improvement in individual skills and collective capacities to formulate problems for progressing together. However, these non-technical functional and cognitive changes are seldom goals in their own right at the time the collaboration mechanism is launched. This leads to results falling short of the promises of change made at the outset.

In three of the four cases, the mechanism is limited to helping the actors develop an idea, and design solutions in an experimental manner until they arrive at a prototype that meets a set of technical and functional criteria, i.e. an acceptable and desired solution that responds satisfactorily to the stated problems or needs. However, this is only a first part of its implementation: in case no. 4, the participatory videos had yet to disseminated and collective advisory sessions had yet to be organized; in case no. 2, the techniques of conservation agriculture had yet to be widely applied and land charters integrating the management of crop residues had yet to be implemented; and in case no. 3, the producers had yet to be supplied with adapted seeds. These unfulfilled goals raise new and complex challenges. Either the participants are sufficiently independent and motivated to act on their own afterwards – as was the case of the UGCPA, which has since implemented its communications approach, or CNABio, which is putting together projects to find the funding necessary for implementing its strategy of rolling out organic farming – or they are not, and the dynamics of innovation fizzle out. The mechanism has thus mainly contributed to the emergence of an innovation community that has to wait for a new project to continue the work, as is often the case in countries of the Global South where actors are used to 'project-centric logic'. Triomphe *et al.* (2016) confirm this observation by tracing innovation trajectories *ex post*. These trajectories are found to be structured mainly by clusters of projects most often focused on technological development issues. They span several decades and it is only at the end of this period that the innovation arrives at a successful conclusion.

Our observations show, however, that it is process-centric logic that really triggers collective dynamics of problem solving and the application of novel solutions adapted to specific needs; development projects are only used in a second phase to obtain the financial means necessary for experimentation or dissemination of new technologies (case no. 3). Lucas *et al.* (2016) confirm, in the French context, that it is the farmers' quest for autonomy and self-sufficiency that enables them to produce agroecological innovations. The problem of implementing solutions does not exist because the process of collaborative innovation is maintained over time, irrespective of funding or external interventions. In case study no. 3, by its very mandate, the lead organization (CNABio) constantly mobilizes resources to ensure the continued implementation of the solutions identified collectively, and to repeat iterations of collaboration, comparison and experimentation phases as often as necessary. This process can take place only over a long period (exceeding ten years) and with a pivotal organization that takes charge of the coordination mechanisms, the interaction protocols and the setting up of projects adapted to the identified needs and which are in line with the action timeframe of the actors involved in the innovation process (Toillier *et al.*, 2017). Lenfle (2004) shows how the management of innovative projects differs from that of development projects, in terms mainly of the nature and skills of the actors to be involved, the temporalities to be considered and the management principles to be used. Thus it is not the project-centric approach in itself that has to be called into question; it is the purpose of the project as well as the management principles and methods that need examination.

In this perspective, collaborative innovation mechanisms should be thought of more as structures able to lead and undertake a long-term innovation process and to manage a portfolio of projects that will strategically address specific problems step by step. In this sense, facilitated networks are more appropriate and effective forms of organization to lead an innovation project than the innovation platforms cobbled together during a short-term development project. The case of CNABio's facilitated network (case no. 4) shows how 'process-centric logic' promoted by collaborative innovation can displace the project approach in order to allow time for an innovation to deploy in all its social, technical, and institutional dimensions. The truly useful projects that bring about effective change then emerge later, at the appropriate times, when the actors have a common purpose and vision, have identified a solution to implement, and have divided up roles and responsibilities.

From the facilitator to the support team

In all four cases, the factors of success of the collaborative innovation mechanism could not be fully materialized, a shortcoming that led to results falling short of the initial intentions and the objectives assigned to the mechanisms. Table 14.3 presents the strengths and weaknesses of the four collaborative mechanisms studied. The two cases with the most comprehensive coordination mechanisms and interaction protocols were the ones whose results came closest to the initial objectives (the Abaco platform and the innovation partnership between UGCPA, FARM, CIRAD and Jade Productions). In one case, this co-ordination and organization role was played by the research community (CIRAD), and in the other by a facilitating NGO (FARM), two organizations which already had extensive experience with this type of approach. In the other two cases, this role was played by *ad hoc* facilitators whose capacities to do so were limited, especially because they lacked an overall vision of the processes at work in the interactions between the different organizations. Many studies (Klerkx and Leeuwis, 2008, 2009) have already stressed the importance and complexity of facilitating collective innovation processes but they pertain relatively rarely to the nature of the particular problem to be solved. Steyaert *et al.* (2017) show that, in agroecological transitions, the problems posed involve contradictions with very high social expectations that make them especially challenging to resolve and carrying out the planned actions becomes difficult. As a result, the facilitator's ability to create an organized but flexible framework for effective collective action is key.

To be able to discuss the need to guide and manage collaborative mechanisms, we designate as 'support capacities' the capabilities required to make these mechanisms function. These support capacities span several different types and can rarely be found in a single individual. In addition to the aspects already identified in the literature, we note that it is also a matter of understanding the technical and organizational challenges of innovation to a certain extent; of knowing the network of actors involved and understanding the interplay between them; of being able to propose experimentation strategies adapted to different situations as well as more or less formalized forms of arrangement that will be acceptable to the actors involved (partnerships, contracts, commitment charters, etc.); and of being familiar with protocols of interaction between different types of organization, with specific monitoring-evaluation tools, and with techniques of reflexive analysis. The challenge is to deploy an approach to support actors in a situation of innovation so that their technical or organizational needs can be satisfied as and when required.

While the figure of the facilitator is considered important by authors across the literature, the empirical results of our case studies show that what is more effective are facilitation teams or, more generally, support teams formed on an *ad hoc* basis that cover all the required skills. These teams consist of researchers, development agents from participating organizations, individuals designated as 'facilitators' for the duration of the project, and farmer leaders who represent the interests of the innovation's beneficiaries. These teams are formed as and when problems of collaboration emerge and end up taking charge of the functioning itself of the collaborative mechanism. More attention therefore must be paid to the constitution of these teams, to the methodological tools made available to them, and to the building up of their technical and functional capacities, all of which will condition the innovation's speed of progress and effectiveness. Toillier *et al.* (2018b) show in particular the diversity of possible postures that researchers can adopt and the capacities required to accompany an innovation process. They can play the role of trainers, experts, communicators, or catalysts who bring together different categories of actors. Their adaptability is essential in order for them to play a supporting role since, by its very nature, innovation is unpredictable.

There exist few projects or training programmes dedicated to creating or building up these skills. Two avenues are foreseeable: capacity building undertaken internally by those organizations that want to be able to lead or manage collaborative innovation mechanisms; and an *ad hoc* capacity building through a project at the time a collaborative mechanism is implemented.

Table 14.3. Summary of analyses of cases.

	Case no. 1	**Case no. 2**	**Case no. 3**	**Case no. 4**
Case study	Multi-service innovation platform Cameroon	Abaco innovation platform guided by the research community, Burkina Faso	Innovation partnership between UGCPA, FARM, CIRAD, Jade Productions Burkina Faso	CNABio facilitated network Burkina Faso
Aim of the collaboration	To initiate collective problem-solving dynamics in an agri-chain	To initiate collective problem-solving dynamics in a village	To solve a one-off problem	To support a complex change over the long term
Main results	Groundwork laid for another, more targeted collective action and for achieving the expected results	Targeted results achieved but they only partially respond to the issues concerned Collective dynamics initiated so that changes that have been started can be continued	The expected product has been finalized but it responds only partially to the issues concerned Capabilities created to continue the changes that have been started	Succession of micro-results that contribute to the overall goal
Coordination mechanisms	– Weak Not formalized	++ Coordination managed by an institutionalized body at the village level	++ Coordination managed by collaboration contracts between partners	+ Coordination managed through a system of membership
Interaction protocol	– Not suited to requirements and too short (3 years)	+ Sequenced and relatively short (4 years)	++ Very sequenced and very short (less than 2 years)	– Not formalized and spanning a long period (exceeding 10 years)
Common vision	– Poorly developed	++ Developed	– Partly consensual	++ Developed
Mobilization of the necessary resources	– Inadequate due to the lack of a strategy	+ Partial	++ Sufficient for the stated goals	– Inadequate due to a lack of financial means

Collaborative mechanisms: spaces for support during periods of transition

Through the capacity building of actors of innovation, the four mechanisms studied offer a space or framework to support changes at the individual and organizational levels that are necessary for an agroecological transition. They intervene at different times, at different organizational levels and at different intensities, none of which we have evaluated. We have simply apprehended them through the magnitude of the changes observed as a result of the collaborative activities carried out.

The selected case studies show that these mechanisms can deal with problems at the farm or the village scales to set up new production systems, either at the level of farmer support organizations in order to provide them with more adapted services, or at the level of the agrifood system as a whole. The goal can be to develop a set of novel solutions to a succession of more or less complex problems, or simply to provide a solution to a well-defined problem. This goal depends on the proponents of the mechanism, the resources allocated and the allotted time frame – short term (project), medium term (programme), or long term (facilitated network).

However, these collaborative mechanisms are often perceived to be time-consuming, expensive and with results not commensurate to the promises made. The ecologisation of agriculture, more than any other form of change of production systems, creates problems of very different types that call into question the ways the actors involved in finding solutions to these problems act and behave, the ways they think and the ways they perceive their environment. Collaborative innovation mechanisms are designed to support these individual and organizational transformations while ensuring the continuous production of a set of technical results that help identify novel solutions to the problems raised. Because of the need to make individuals and organizations collaborate outside of their usual framework, these mechanisms must provide sufficiently robust and long-duration coordination arrangements and interaction protocols so that a common vision can be built and resources necessary for action can be mobilized. Our analysis of four case studies shows how shortcomings in these elements stand in the way of the development of satisfactory solutions. The mechanisms thus initiate dynamics that they do not see to their conclusion, and have to therefore exist beyond project-centric approaches to achieve the desired objectives. One solution would be to rely on established organizations already present on the ground if they are able and permitted by their mandates to take charge of managing these mechanisms over the long term.

Conclusion

The aim of this chapter is to examine the scope, processes and advantages of collaborative innovation mechanisms that appear to be necessary for designing and implementing novel solutions and for accelerating agroecological transitions. The very nature and principles of agroecology preclude the existence of transferable technical packages or turnkey technological solutions. The mobilization of the knowledge of the diverse actors involved and experimentation are necessary to arrive at new and viable production systems and services. Collaborative mechanisms thus provide a framework for exploration, experimentation and scaling up by arranging and organizing interactions between different organizations that do not usually work together.

Using empirical analyses, we have shown the importance of the initial configurations of these mechanisms and of associated interaction mechanisms, which have to be more structured and sequenced the more the initial collaborative context is weak. We have also shown that collaborative innovation has to be based on processes rather than on projects. The discrepancies between the promises made and the results achieved stem from the mismatch between the project-centric approach and the pace of individual and collective learning. It is only because a common vision and strategy is deployed that the actors who undertake an innovation can set up development projects that will meet their needs at the right time. These observations call for a change in the ways of thinking and supporting innovation, one that focuses more on building the capacity of the individuals in charge of the innovation than on the technical results to be achieved. New and more flexible forms of providing support and funding, focused on collaborative processes, need to be discovered to make these mechanisms effective and to thus save time during the different phases of an agroecological transition. They open up new fields of research around issues of managing innovation projects and organizational learning, which are as yet little studied in the agricultural domain in developing countries.

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Chapter 15

What market dynamics for promoting an agroecological transition?

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In his seminal report on the right to food, O. de Schutter concludes that there is a need to change the world's farming systems to devise a more sustainable and equitable diet to feed the world's population. He advocates a transition to a diversified agroecology based on smaller farms that practise a less intensive agriculture and use fewer inputs (de Schutter, 2014). This recommendation is unequivocal: it confirms that agroecology is now recognized, and has moved from just being a model that is opposed to the Green Revolution to one that proposes an agricultural model that could and should be disseminated widely (IDAE, 2015). And yet, this agroecological transition is not easy to implement. Indeed, it calls into question, and even requires the discarding of, existing knowledge on food and farming practices that form the base on which our current agriculture model is developed.[1]

Ecology, the environmental sciences and some agronomy disciplines were the first to devise alternative production methods that relied on ecological processes to provide useful services for agricultural production (Ollivier and Bellon, 2013). Issues pertaining to the marketing of products of agroecology were explored later through the social sciences (economics, sociology, geography). These studies show that agroecology also relies on new market dynamics centred on the relocalization of productive systems and a proximity between farmers and consumers (growth of direct sales and short circuits) and on the development of new standards and certification systems (Allen, 2004; Guthman, 2004). For the last 15 years, sociology and geography studies have also pressed for a better consideration of the different ways food products are consumed and their linkages – or relinkages – with the way they are produced (Delfosse, 2003; Rieutort, 2011; Le Velly, 2017), which David Goodman (2004) describes as the consumption 'turn' in rural sociology. These developments in different disciplines have thus contributed to a gradual transformation of the levels of organization and of analysis of agroecology, going from the plot to the farming and food system (Wezel *et al.*, 2009).

1. In this chapter, we use the term 'agroecological transition' as defined in the book's Introduction.

Several experiments conducted at a local level closely tie processes for the ecologisation of farming systems with specific market dynamics. Identified as alternative food networks, these experiments are harbingers of new development models; they 'promise to make a difference' and propose new values (Le Velly, 2017). While the viability of these alternative systems is not in doubt, questions on their scalability and reproducibility remain largely unanswered. In addition, the adoption of agroecological practices generally entails additional costs for the farmer in terms of manpower, certification and monitoring. These additional expenses drive farmers to seek new and more profitable markets in search of clients who are willing to pay a premium for quality and the sake of the environment (Moustier, 2014). However, the link between agroecological farming practices and specific commercial ones is insufficiently documented.

This chapter aims to explore how agroecological products derive value from the markets, based on which organizational methods and specific market devices[2], and to what extent the latter contribute to the evolution of farming systems. A detailed look at representative cases will highlight the diversity of these marketing practices and draw lessons on the possibilities and limitations of these market devices, of their scaling up, and of the unlocking of existing farming and food systems.

Market devices to unlock farming systems

Studies on alternative food systems demonstrate their dynamism and creativity. The diversity of ways of marketing agroecological products that have been tried out by farmers and consumers, and their capacity for innovation and adaptation allows us to view these processes with optimism. However, these experiments are often accused of being not very reproducible, too restricted, too local, unscalable and unable to respond to the global challenges of agricultural production and food security.

Literature on the theory of socio-technical transition and its multi-level perspective (Geels, 2002; Geels and Schot, 2007) puts these limitations into perspective[3]. It proposes positioning the dominant agro-industrial food system (considered as the socio-technical regime) and these alternative practices (considered as niches) in a common analysis framework (Figure 15.1). The socio-technical regime is stable: it is based on a set of well-established standards, actors, policies, markets and research. Niches are created independent of the rules and dominant actors. In this approach, the niches are not disconnected from the model of transition, they are understood as incubation spaces (Geels, 2002), i.e. places to implement learning processes and to build new economic networks; they are intended to accommodate the creation and establishment of alternative systems (Meynard *et al.*, 2013). In the graphical representation of the socio-technical transition by Geels and Schot (2007), the niches gradually tend to integrate the dominant regime by making its

2. Consequently, we include in the term 'market device' all the trading methods and innovative practices for deriving value from agroecological products.

3. The transition theory focuses on major transformations that involve major breaks, impacting stakeholders, their modalities of engagement, and their practices. This theory emphasizes the social dimension, essential to the dissemination of technical innovations.

various dimensions evolve (standards, actors, knowledge, etc.). This representation emphasizes the transformative or non-transformative nature of these innovations vis-à-vis the dominant model.

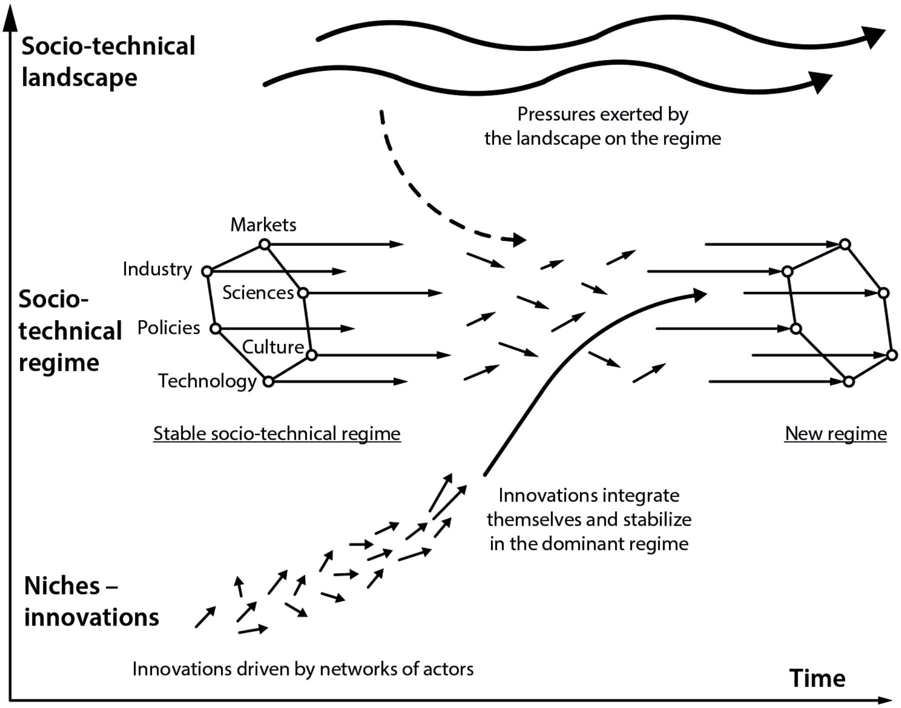

Figure 15.1. Analytical framework of the multi-level perspective of transition (Geels, 2002).

Transitions are considered here as the result of interactions between several levels: the socio-technical landscape that encompasses the environment in which society is situated; a stable socio-technical regime defined by rules, practices and interdependent actors which direct or limit the actions of operators; and niches which are spaces in which more radical innovations are built. The transition from one socio-technical regime to another is the result of pressures exerted by the landscape on the regime or the progressive integration of radical innovations (new rules, new practices) into the regime.

A good example to illustrate these dynamics is the recent institutionalization of participatory certification of organic products. Conceived by actors on the margins of the agro-industrial system (the regime), this practice was seen as an alternative or a counter-proposal to the third-party certification system. It is being gradually recognized by public actors and by consumers as a guarantee of agroecological production. In some countries, this alternative method has found approval in public regulations that oversee the certification of organic products in the dominant model (the socio-technical regime).

In this multi-level perspective of transition, policymakers can also consider several levers for action. Action on standards of the agro-industrial regime can be complemented by specific policy measures targeted at niche innovations: a credit programme for the creation of small-scale processing units in rural areas, for example, or logistical support for establishing open-air markets in urban centres.

Finally, the notion of the socio-technical regime introduces the idea of lock-in of farming systems (Box 15.1). While rules, standards and actors constituting the dominant system make it stable, they also result in its locking-in (Geels, 2004; Vanloqueren and Baret, 2009).

The illustration of this phenomenon in Brazil shows that a successful agroecological transition depends on several prerequisites and different types of innovations and mechanisms for unlocking the socio-technical regime. We can identify at least four of them.

First, a specific event is often seen to trigger the start of a process of agroecological transition. It may be an economic crisis (steep fall in the selling price of an agricultural product), illness of a farmer due to poisoning from the use of phytosanitary products, or the emergence of a socio-economic opportunity in the region: new processes for purchasing organic products, setting up of a public food procurement programme or a programme to procure vegetables grown with reduced chemical inputs, or agri-environmental measures included in an agricultural policy.

Second, consumer interest is another prerequisite. Since the 1990s, a profound change in the relationship between the consumer and his diet is reflected in the demand for agricultural products that are produced in a certain manner (sustainable, organic, farm-to-table, fresh) and/or that originate from specific geographical regions. A consumer's preference for geographic proximity indicates a form of support for local agriculture, a way to meet and come to know farmers or to minimize transport and

Box 15.1. An example of a socio-technical lock-in in Brazil

C. Cerdan

This lock-in effect can be illustrated by an example. In southern Brazil, many family farmers are part of agro-industrial chains to rear poultry or pigs or grow tobacco. A contract binds each farmer to the industry concerned. At the start of each season, these farmers receive agricultural inputs and commit to producing a set quantity of animals or tobacco leaves. The low income they obtain from this activity does not allow them to gain financial autonomy, thus keeping them in a cycle of dependence on the agro-industrial system. Moreover, regional specialization limits opportunities for diversifying activities. Indeed, existing knowledge systems, technical solutions provided by the research community or agricultural development institutions, and seasonal credit facilities are all oriented towards existing industrial production in the region. It is thus difficult for family farmers to break away from this system.

However, different kinds of policies can help unlock these systems. The policy of buying agricultural products from family farms and the programme to supply school canteens with such products represent substantial economic opportunities for some Brazilian farmers. They have thus been able to terminate their contracts with industry and reorient their farms to new products (fruits, vegetables, milk). It is important to note, however, that these reorientations have been strongly supported by social movements (NGOs) and by scientists and technicians seeking alternative development models for Brazilian regions (Mior, 2005).

storage costs for sustainable food systems (Moustier, 2017). Geographical proximity can also be seen as the reaffirmation of consumers' desire to protect food and cultural heritage. These developments are giving rise to the emergence and experimentation of new methods of purchasing food products. The consumer combines a range of methods and places to procure his food, alternating between supermarkets (distant and generic) and outlets that are closer (open-air markets, specialist shops, alternative purchasing networks such as AMAP, vegetable baskets).

Third, in order to practise agroecological or organic farming, the farmer has to involve himself in processes of learning and experimentation, on his own and/or collectively. In order to incorporate agroecological processes in his production system, the farmer requires new knowledge, a keen sense of observation, and a certain sensitivity to his environment. He also has to establish new trading relationships with consumers. Possible options include: becoming a member of an AMAP (community supported agriculture movement in France), delivering baskets of organic products directly to consumers, supplying to public procurement, becoming a member of a collective or a cooperative, selling in open-air markets, and forging new alliances with retailers. All of these require new organizational or institutional learning.

Fourth, and finally, it is not easy to change systems! Even though farmers do transform their farming systems altogether (e.g. tobacco farmers switching to vegetable farming in Brazil), years of specialization usually contribute to a loss of knowledge that has to be revived. This observation highlights how important it is for a farmer to involve himself in collective dynamics. Since the institutional and cognitive context is not always favourable to agroecological transition, the participation in the exchanges between farmers of experiences and knowledge is a key element in this transition. In many cases, the agroecological project in a territory allows the structuring of collective action, and more broadly, of building a vision of a shared future: what landscape, what environmental quality, what type of land use (Lamine, 2017)?

Detailed analyses of some successful experiments have revealed these prerequisites and necessary conditions for change. To further our deliberation on the agroecological transition, we advance the hypothesis that the contribution of these market devices (niches) to the evolution of the dominant system (socio-technical regime) and to the release of certain lock-ins depends on how the actors involved conceive of agroecology. It is necessary to better qualify these market devices and their position in relation to the agroecological transition. To this end, we describe, in some detail, seven experiments which demonstrate the diversity of the initiatives and the dynamics involved.

An overview of market devices for an agroecological transition

The initiatives we analyse here are organizational and/or institutional market innovations that modify the rules governing the trading of products. The case studies span different degrees of use of natural processes in lieu of chemicals, and include models based on organic and reasoned agriculture. Our reflection is based on information gathered from actors in the context of development projects in partnership in several countries of the Global South (South Africa, Brazil, Laos, Madagascar, Morocco, Vietnam) and on the analysis of a diversity of documents (reports, articles, legal or regulatory documents, web sites and communications media). These projects bring together not only farmers and representatives of professional organizations but also representatives of research and rural development institutes.

Ecovida in Brazil: an agroecology network, breaking with the conventional agricultural model

Created in the late 1990s through the integration of local organizations already working to promote family farming and alternative technologies, the Ecovida organization today connects nearly 5000 family farms in 200 municipalities of the three southern Brazilian States. Farmers are divided into nearly 300 community groups, which make up 30 territorialized groups. This network also includes about 40 formal organizations: producer and consumer associations and cooperatives, and NGOs providing technical support.

The designers of the Ecovida network have defined common values that all prospective members have to subscribe to. The first is to promote the collective dimension at all levels, from the local to the regional. To be a member of the Ecovida network, one must be attached to a group in one's village or region. The second is the quest for an alternative to the dominant Green Revolution-based agricultural model, by fostering exchanges between farmers of their real agroecological experiences and their knowledge. The third attempts to bring consumers closer to farmers. While it is commonly accepted that farmers need to modify their ways of producing food, Ecovida believes that consumers also need to evolve by abandoning their 'Fordist'[4] approach and by trying to better understand the realities of the rural world. Fairs and open-air markets are seen as excellent settings to recreate a climate of trust and solidarity between producers and consumers. Prices are voluntarily controlled not only to avoid limiting the sale of organic products solely to affluent consumers, but also to dissuade the entry of new farmers and traders who are only driven by profit.

The promotion of institutional markets in Brazil (programme for the purchase of products from family farms, national school meals programme) and the actions taken by local organizations to increase the number of open-air markets were a first step to consolidate the transition of member farmer groups. This model, however, has its limitations. The local market and State procurement (school meals) cannot absorb an unlimited quantity of products. To address this problem, the Ecovida network created a sustainable road transportation programme with the aim of having trucks with fresh or processed agricultural products circulate between local groups. In this social innovation, all participants are members of the network and commit to buy or exchange (barter) products from other groups. This encourages the diversification of products offered in local markets and lowers transportation costs since trucks never return empty. In the interests of transparency and fairness, the terms of trade and volumes

4. Referring to mass consumption which manifests in the acquisition of a large number of products and goods at minimum cost.

are notified and accessible to all. Eight solidarity marketing circuits are currently in place and transport more than 74 different products, representing a volume in 2012 of 831 tonnes and a turnover of 1.5 million Reals (400,000 €).

Finally, the Ecovida network is best known for its involvement in the institutionalization of an alternative model of certification: the participatory guarantee system. At the very start, it opposed a third-party certification model (intervention of a certifying body) set up by the government of Santa Catarina because it considered that this model ignored the history of pioneering farmers and organizations that had already adopted organic farming methods in the region. Building alliances with partner countries in the Global South helped shape the participatory certification model. This quality assurance system certifies organic products on the basis of the active participation of the actors concerned. It is built on a foundation of trust, networks and exchange of knowledge (May, 2008).

The values of the Ecovida network are embedded in this alternative certification system, in particular the central role of the collective (as a guarantor of quality) and the importance of learning through the sharing of experiences and exchange of visits between peers. Ecovida's representatives were subsequently largely involved in formulating the Brazilian law on organic farming. Their experiences and activities have contributed to the statutory recognition of three organic farming certification modalities: third-party certification, the participatory guarantee system, and the organization of social control of direct selling (Law 10.831/2003).

In Morocco, a participatory system to build and manage an agroecology label

Following the emergence in 2004 of the concept of the participatory guarantee system, and its initial definition in 2008 by members of the International Federation of Organic Agriculture Movements (IFOAM), many local and international actors adopted this tool to promote agroecology. The use of these tools is advocated by NGOs and governments in many developing countries to support smallholder communities and help them obtain additional income through organic markets.

In Morocco, the organic farming label, as defined in Law 39-12 of 16 January 2013, is not yet available for producers since it has not yet been notified. Consequently, farmers who want to showcase the ecological nature of their farming systems currently use European and American labels. The high certification cost of these labels, however, makes the products unviable for sale within the country. Initial deliberations on a participatory guarantee system and the establishment of a local label began in 2011, within the Network of Agroecological Initiatives in Morocco (French acronym: RIAM), which was recently constituted as an association. The active members of this association are primarily agronomists, neo-rural farmers, and informed consumers, from the Moroccan or bi-national middle class. Aware of the environmental and public health problems that conventional agriculture in Morocco is generating, they considered it essential to establish a network to exchange views on agroecological practices and identify such farming systems. Starting in 2016, the network began supporting the establishment of eco-solidarity farmers' markets that promote agroecology in several Moroccan cities (Mohammedia, Casablanca, Marrakesh, Rabat).

Nevertheless, there is an urgent need for consumers to be able to count on a quality label and for farmers to adhere to a common set of specifications. Deliberations on the participatory guarantee system saw little success in 2011 as volunteers in the network could not devote enough time. However, the initiative finally saw the light of day thanks to an opportunity to enter into partnership with CIRAD in 2017, initially in the Rabat region. CIRAD used several participatory methods with the different actors concerned (farmers, consumers, grocers, restaurants, etc.) to help build a common reference base (Lemeilleur and Allaire, 2018). In addition to the creation of the guarantee model itself, which aims to progressively generate technical exchanges within local groups and during monitoring visits, these inclusive methods were used to create the reference base which led to an initial enrichment of collective knowledge and a strengthening of the local agroecology network. Some local institutions regard this tool as an opportunity to develop agroecology while waiting for (or in parallel with) an active public system. However, this interest indicates little about the public support that this alternative could receive in Morocco in the future.

Agreco in Santa Rosa de Lima, Brazil: organic farming aided by a basket of territorial goods and services

Agreco is an example of the success of a collective approach to agroecological production in Brazil based on a basket of goods [5]. This association was founded in 1996 in the context of an agricultural crisis which, combined with the isolation of remote farms, the rural exodus and the resurgence of health problems caused by the use of chemical inputs, led civil society and the local government to deliberate on novel solutions to stimulate the territory. Agreco is the result of a gamble: a supermarket chain owner, originally from the region, offered a few farmers exclusive spaces in his stores to sell their organic honey, fruits and vegetables. The gamble paid off: the move was very well received by consumers. The need to increase organic production pushed the association, initially confined to the Santa Rosa de Lima municipality, to expand into nine other municipalities. By 1998, Agreco included 211 families, 500 people and 26 family-owned small agro-industries (vegetables processing, sugarcane, dairy products, honey, preserves, eggs and bakeries). The strengthening of local institutions and the establishment of partnerships with the government allowed the association to diversify its area of activity.

Three successive periods stand out in the transition process. The first was the introduction of organic farming in the region and the building of a strong territorial identity. The second followed the beginning of organic farming with the development of agro-industries to process organic products. Processing of products was a factor in the viability of the experiment as it helped diversify the marketing of organic farming products. The arrival in retail markets of fresh and organic products from other producer organizations closer to the capital forced the Santa Rosa farmers to invest in processing of their products. Existing road infrastructure (dirt roads) prevented them from delivering fresh produce in good condition. This rapid development was achieved by mobilizing financial resources, accessible through the public support programme

5. Food products, fruit juices, and handicrafts sold in the area.

for family farming, the mobilization of a network of competent people, and the professionalization of farmers. The third period started when supply began to exceed demand. The project leaders had an ambitious and inclusive vision, with the goal of achieving a significant impact in terms of job creation and income for the region. It became necessary to look for ways to conquer new markets (supermarkets, school canteens, direct sales via the delivery of baskets of agricultural products to consumers) and to diversify activities in the region (farm stays, agro-tourism, training).

At the same time, other collective initiatives were being implemented to make the transition process sustainable, including the creation of a credit cooperative, a professionalization cooperative for sustainable development and a training centre. The products were certified by Ecocert-Brazil and bear the label of the Agreco collective. They are available in major supermarket chains in the main urban centres of Santa Catarina, as well as in São Paulo and Rio de Janeiro.

The proponents of the project have diversified their activities and services beyond the technical change represented by the introduction of agroecological (and especially organic) systems to grow fruits and vegetables. Producers and actors in the territory have acquired new skills, and have learned to think at the territorial scale and no longer at the limited scale of their farms. They have also invested in new forms of management and proposed new forms of territorial regulation. Today, they take on many collective responsibilities and play new roles in the public sphere. Two aspects stand out in this development: its inclusiveness, and acceptance of marketing channels and third-party certification. This certification was imposed by supermarkets in the capital, and the farmers chose to accept this imperative in order to maintain their presence in this market. In this case, scaling up resulted in a significant diversification of markets and activities.

‘Clean’ vegetables from the mountains of Vietnam

Since 2011, farmer groups have been created in Moc Chau district of Vietnam, in a mid-altitude zone (600-900 m) 150 km from Hanoi, to grow ‘clean’ vegetables to meet the needs of the capital, especially during the summer when the high temperatures and heavy rain of the Red River Delta no longer allow vegetable production. The city of Hanoi, heeding the demand of a growing urban population with increasing incomes and an insistence on food safety, was looking for new supply areas, since its peri-urban belt had become polluted and converted into a construction zone. An agri-chain for certified clean vegetables was started in Moc Chau under the auspices of a research and development project funded by ACIAR (Australian Centre for International Agricultural Research). The success of this approach was the result of several factors.

To begin with, farmers were trained in the methods of growing clean vegetables compliant with standards in force in Vietnam, either the VietGAP standard (a Vietnamese adaptation of the Global GAP standard) or the ‘Clean Vegetables’ standard (which is less stringent in terms of maintaining records), for growing tomatoes, cabbages, salads, beans, etc. Farmers benefited, in particular, from better quality seeds. The project ensured ongoing field monitoring as well as training in the practice of farm book keeping.

In addition, a market analysis was undertaken and a relationship established between Moc Chau farmers and distributors in Hanoi (supermarkets and specialized shops for safe products). In 2013, about 230 tonnes of vegetables were sold to supermarkets (Fivimart, Metro, Oceanmart) and specialty safe-product stores (BigGreen) in Hanoi (Sautier and Nguyen, 2016).

Moreover, a horizontal coordination was established between producers organized into interest groups and some producers belonging to cooperatives, as well a vertical coordination because of the strong commitment of local authorities in Moc Chau district and in the new district of Van Ho (created when Moc Chau was split into two separate districts, both in Son La Province) to develop this agri-chain. Consumers, collectors and distributors were also involved in discussions on developing the agri-chain, and were invited to various on-site project meetings.

Finally, Moc Chau was promoted as an origin of clean vegetable production by registering a certification trademark that combined the Moc Chau origin with an adherence to the VietGAP agroecology and Clean Vegetables standards. Although Vietnam has legislation on geographical indications and more than 60 GIs were registered in 2018, the absence of a specific sensory quality of vegetables grown in Moc Chau, due in part to the very recent cultivation of vegetables in this area and the large number of vegetables involved (19) tipped the choice in favour of a certification trademark. Indeed, the certification trademark ensures the adherence to the rules of production by a quality and certification system implemented by the owner of the mark, who himself is not a producer. The collective mark, another instrument available in Vietnamese law, requires the existence of a single collective association of all vegetable farmers, which is not the case here since the farmers are organized in several different groups.

In 2017, Vietnam witnessed the registration of 181 certification trademarks by local authorities at the district and provincial levels to promote their products (source: National Office of Intellectual Property, NOIP), such as the certification trademark 'Da Lat Safe Vegetables'. Da Lat is a region of southern Vietnam known for its vegetable production and serves as a model for the development of the vegetable chain in Moc Chau. The mark's owner is the local authority which is responsible for quality control for all the farmers. In the case of Moc Chau's certification trademark, the logo includes the name 'Moc Chau Safe Vegetables' in Vietnamese and English, together with an image of the mountains of this district, best known for its tea and dairy products. Registered in 2016 by the National Office of Intellectual Property in the name of the People's Committee of Moc Chau district, the regulations governing the use of the trademark (Decision 345/2014/QD-UBND of 18 September 2014 of the People's Committee of Moc Chau district) provides that it may be used for vegetables grown in the demarcated area of the districts of Moc Chau and Van Ho and which comply either with the Clean Vegetables standard (circular 59/TT-BNNPTNT of 9 November 2012 of the Ministry of Agriculture and Rural Development) or the VietGAP standard. Compliance with these standards is monitored by the National Agro-Forestry-Fisheries Quality Assurance Department (NAFIQAD), the Department of Agriculture and Rural Development (DARD) of Son La Province (Marie-Vivien and Vagneron, 2017), or any other certification body accredited for VietGAP. The DARD of Moc Chau District is responsible for managing the 'Clean Vegetables' trademark and authorizes farmers in Moc Chau and Van Ho to use it, organizes the random collection of samples for laboratory tests, and monitors the origin of the vegetables to verify that they indeed come from the defined production region.

The logo has already been used on vegetable packaging for several years now. This however does raise the issue of the use of packaging pollution, since vegetables are traditionally sold loose and in bulk. This also explains why the outlets are primarily supermarkets and specialty stores.

The project's second phase got underway in 2017 and aims to expand this certified 'Clean Vegetables' chain to more producers, in addition to the 50 or so producers in three pilot villages who already form part of it, including producers cultivating vegetables using conventional methods and to those shifting from growing maize to clean vegetables. While the latter is turning out to be more remunerative as demand from urban consumers is growing exponentially, it does require a genuine and dual know-how on growing vegetables and on reasoned agriculture. This expansion will help establish Moc Chau's reputation as an agroecology region, developed through the use of a trademark. The agroecological attributes will replace the organoleptic qualities to establish the geographical reputation of an agri-chain.

Developing agroecological farming in Madagascar through home delivery of vegetable baskets

In Antananarivo (Madagascar), peri-urban agriculture supplies the bulk of the vegetables consumed in the metropolis. The traditional food cultivation system dominates and encompasses more than 50,000 family farms in the greater peri-urban belt[6] and a dense network of collectors, wholesalers, semi-wholesalers and retailers supplying urban markets. This model faces the challenge of urban growth: unceasing increase in demand, growing pressure on land use, and urban pollution affecting agriculture. Market garden products are especially affected by health-related quality issues (excessive and poorly regulated use of chemical inputs) and losses due to vegetable spoilage when the supply chain does not work smoothly enough. During recent years, a rare few private agroecological vegetable garden projects have emerged. Their proponents are mainly entrepreneurs from Europe catering to an affluent segment of the population.

For more than a decade now, in order to promote small-scale family farms, which represent the bulk of the farming systems in the Malagasy Highlands, NGOs – most notably Agrisud International, Agronomists and Veterinarians Without Borders, and FERT (Training for the Development and Renewal of the Earth) – have been helping develop and disseminate agroecological practices in the market garden sector. The objective of growing healthy (clean) vegetables is tied to that of increasing the income of farmers, struggling with very low land availability (between 5 and 16 ares for market gardening per farm for the majority of them), and of improving the supply to urban consumers in terms of quality, quantity and diversity.

6. 2004/2005 Census of Agriculture for Madagascar, Analamanga Region.

Agrisud has been involved since the beginning of 2015 in an agroforestry support programme around Antananarivo within the framework of a European funding programme. The process involves educating a thousand agroecological farmer leaders, nearly half of whom have already been trained to pass on these techniques to other farmers in their areas, as part of an effort to train a total of 5000 farmers in four years. At the same time, around 50 local collectors have benefited from support for working capital and management capacity building. One of the downstream objectives is to reduce the number of intermediaries and derive increased value from agroecological products in order to improve the margins of producers. To begin with, two sales outlets were set up to showcase the uniqueness of their products. Very soon, given the low volumes sold at these points of sale, a pilot system of vegetable baskets and home delivery was established.

Moreover, coordination structures (local organizations) are being set up since the end of 2017 to improve the link between farmers and traders supported by the project. The aim is to connect a group of a dozen or so farmers with one or two collectors, in order to ensure a smooth supply chain and allow traceability of product quality. In each of these devices, farmers and traders jointly draw up an action plan with the help of technicians to fix crop schedules for the coming months and the requirement in seeds, small equipment and, where necessary, training. These devices were designed to become pivotal points within a short time between the project and the beneficiaries, and progressively empower farmers and collectors. These collectives are at the heart of technical learning processes, with an increase of the know-how of farmers and trainers and the exchange of experiences between members. These collective-action learning processes, involving farmers and collectors, not only concern agronomic skills but also the capability to take advantage of and develop market opportunities. Thus, for example, based on suggestions by collectors and the possibility of obtaining quality seeds through the project, farmers have introduced hitherto rarely cultivated niche vegetables (e.g. red cabbage, broccoli, Nappa Chinese cabbage) in their cropping seasons.

The issue of qualifying and classifying the products arises during the transition to agroecological production, which requires a progressive mastery of the practices involved. A participatory guarantee system was initiated on the basis of individual production datasheets provided by the farmer to downstream actors. This system is, however, being found to be too complex to implement and is being modified to promote a more general appreciation of quality at the level of local organizations.

The approach was initiated recently and the process is underway. From an organizational point of view, the challenge for the devices is to fine-tune the degree of mutual commitment, in a context in which an overly restrictive contractualization would most likely be impractical, given the numbers and diversity of buyers and sellers. Another challenge is to adapt to local geographical specificities: on the one hand, the priority in the areas closest to the city and the markets is to improve the food safety of the products since the supply chain is relatively smooth and, on the other, the more isolated production areas have fewer problems concerning pollution and urbanization but are hampered by access related issues – which could be eased through a more effective coordination with downstream actors. A third challenge is to adjust the guarantee level and product image based on the degree of technical mastery by farmers and awareness by target markets of the benefits of agroecological products. Indeed, the challenge is not only to provide products that are free of chemical residues, but to also ensure a diversified and widespread supply that is accessible to all, and not solely to the more affluent sections of the population. In a context in which problems pertaining to the health quality of the products are evident, but where the consumer's awareness of them is only gradually developing, the relatively flexible concept of agroecology makes it possible to gradually improve the quality of the products by reducing major sanitary risks while not totally banning the use of chemical pesticides.

The institutionalization of organic farming in Laos

A small landlocked nation included in the category of the least developed countries, Laos is almost an exception in Southeast Asia because it instituted a comprehensive institutional framework for the development of organic agriculture in the mid-2000s. In 2004, the PROFIL project (Promotion of Organic Farming and Marketing in the Lao PDR), supported by the Swiss NGO Helvetas and the Laotian Ministry of Agriculture and Forestry, laid the foundation for organic farming by setting up the first groups of organic rice and vegetable farmers (2004); the first national standards for organic agriculture based on the standards proposed by the International Federation of Organic Agriculture Movements (2005); the first farmers' market (2006); a national certification authority (Lao Certification Body); and the Clean Agriculture Development Centre (2008) which aims to promote different forms of sustainable agriculture.

As far as public policies are concerned, the 2011-2020 Agricultural Development Strategy in Laos highlights the potential of organic farming for smallholders while the 2006-2010 and 2011-2015 national socio-economic development plans promoted sustainable agriculture (good agricultural practices, organic farming) as a way of improving the environmental and social performance of agriculture while integrating poor family farmers into high value-added chains. In 2014, Laos adopted a National Strategy for Organic Agriculture and in 2015 a National Strategy for the Development of Organic Agriculture. This enthusiasm is not exclusive to undertakings by the Ministry of Agriculture and Forestry, but also results from several collaborations between the Laotian government and international organizations (Asian Development Bank, FAO), bilateral development agencies (Japan International Cooperation Agency, JICA), international NGOs (Oxford Committee for Famine Relief, OXFAM) and national NGOs (Sustainable Agriculture and Environment Development Association, SAEDA) within the framework of more or less well-coordinated and articulated development projects.

According to the ministry, nearly 8000 hectares of cultivation surface areas were certified as organic in 2016. Of this, 81% were certified by the Lao Certification Body and 19% by ACT (Thai certification body accredited to provide certification of international standards). Rice accounted for 58% of the certified cultivation area and coffee (the main export crop) representing 9% of the total area certified by the Lao Certification Body, and almost 45% of the total area certified by ACT.

As the national certification agency is not accredited to provide certifications of international standards, the national market is a major outlet for domestic rice production and, in particular, for vegetable production. The Vientiane organic farmers' markets are organized by a committee appointed by the ministry and made up of representatives of organic farming producer groups from several districts of Vientiane (Saysettha, Sikhottabong, Sisattanak and Xaythany). These ministry-certified groups produce and market about 220 tonnes of vegetables per year. They also make organic fertilizer, plant fruit trees and organize training sessions for their members.

Sales of organically grown products in farmers' markets have increased significantly in recent years: the turnover of the market in That Luang has risen from about 25 million Laotian kip (LAK)/day in 2008 (1900 €) to 35 million LAK/day in 2012 (3250 €). In 2016, the total volume of vegetables sold at That Luang market was estimated at 4 to 5 tonnes per day during the rainy season and 8 tonnes per day during the dry season (Manivong *et al.*, 2016). Farmers' markets were also set up in Xieng Khouang Province in 2011, under the auspices of local agricultural services and a local NGO (SAEDA), and at Luang Prabang, on the initiative of the Tabi project (The AgroBiodiversity Initiative) and provincial agricultural services.

In 2015, a FAO-funded regional project promoted participatory guarantee systems to help smallholders benefit more from the growth of organic farming. These systems are intended to help producers build a relationship of trust with consumers, forge links with the local market, and participate in collective selling. The government is offering keen support to the implementation of these guarantee systems, which it has recognized. Farmers were allowed to use the national logo (Figure 15.2) and are supported by an active involvement of ministry officials at the local level.

Figure 15.2. The national logo for organic farming in Laos.

Even more recently, other initiatives such as the direct sale of organic vegetable baskets have sprung up around Vientiane. Such diverse initiatives illustrate the role played by alternative market devices in the development of organic farming in Laos. They are based on a growing demand by the local population for food that is healthy and of good quality and demonstrate that, in the absence of access to export markets, a local market can be developed by strengthening the links between farmers and consumers and on the basis of collective learning processes at the local level.

Rooibos: a geographical indication to derive value from agroecological practices in South Africa

The rooibos case study illustrates how geographical indications (GIs), which are based on a local process of codification of practices, offer tools to derive value from agroecological systems. The rooibos plant, endemic to South Africa's fynbos (a dry savannah ecosystem, rich in endemic biodiversity), generally characterizes the landscape where it is grown and the local economy. The primary goal of creating a GI for rooibos in the mid-2000s was to respond to the threat of misappropriation of its name.[7] Cultivated in South Africa since the 1930s, this plant was initially commonly consumed within the country, but is also being exported since the last 20 years to a growing number of countries. Combining indigenous Khoikhoi and Afrikaner practices, it is deeply rooted in South African heritage and represented an emblematic product for launching GI initiatives in this country. Supported by local and international research actors (University of Pretoria and CIRAD) as well as by Western Cape province's Department of Agriculture, the actors of this agri-chain worked together to establish a GI and to have it recognized by the State as well as by the European Union. The latter indeed constitutes an important market for this product, and a GI recognition there is considered by the actors of the chain as the surest guarantee of protection of their product and its name. A long negotiation process was undertaken to establish its specifications.

Since the GI pertains to the name of a product already sold by all the farmers, the discussion was widened to encompass all the practices concerned. Rooibos, a crop traditionally cultivated extensively has, over the last 20 years, witnessed a significant expansion of its cultivation area in conjunction with a marked intensification of its agricultural practices. In response, external actors devoted to environmental issues are rallying to conserve biodiversity. They encourage farmers to reduce the environmental impact of rooibos cultivation, mainly by labelling their practices. At the same time, negotiations on the GI specifications have shown that, for this agri-chain's actors, the challenge is more than just protecting the name. Indeed, the recent dynamics of expansion and intensification threaten both the quality of rooibos and the biodiversity that is an integral part of its production area. This is resulting in the inclusion of the labelling approach recommended by the environmental actors into deliberations on GI, and the use of the GI to incorporate biodiversity management issues in the practices to be developed and showcased. This inclusion of biodiversity issues in negotiation on the specifications helps better qualify the various practices and their impacts. The position that prevailed initially of adopting a minimal set of specifications, reflecting the desire to include as many actors as possible, was thus abandoned. Various agroecological practices are included in the specifications, contributing to a better qualification of rooibos: e.g. establishment of corridors in the farms for monoculture rooibos farmers cultivating more than 50% of their land, with rows of vegetation dividing the cultivated fields.

The process of establishing the GI as a locally negotiated and market-sanctioned standard is opening up local mediation spaces (Biénabe *et al.*, 2009). Using the local negotiation process, the agri-chain's actors and those promoting environmental issues have explicitly described the links between product quality and agroecological processes in production systems, playing a key role in the recognition and

7. Several South African actors involved in selling rooibos on export markets have reported instances of misuse of the name. An American cosmetics company, Annique, manufacturing rooibos-based goods registered the trademark 'Rooibos' in 1994.

dissemination of agroecological practices, on the one hand, at the time of establishing the standard (socialization of practices) and, on the other, through its implementation following the registration of the GI.

However, two points are to be noted in the process of deriving value from agroecology with the help of a geographical indication. Agroecological practices must clearly be seen as contributing to the quality or reputation of the product developed using the GI in order to be legitimately incorporated in the specifications. That said, agroecology's contribution can vary widely depending on the products and the territories concerned, and that is why it is essential that the standards associated with the GI be drafted at the local level. It is also important to note that the process for creating the GI for rooibos spanned several years and is the result of the effective participation of a wide range of actors involved directly or indirectly in the agri-chain. Indeed, while the rooibos inter-professional body was the driving force behind the effort, it was supported by research actors with expertise in GIs, NGOs providing support to smallholders, and actors involved in environmental issues. The participation of all stakeholders and the availability of settings that are conducive to debate and collective arbitration is important for GIs to be able to incorporate the complexity of the issues involved and to promote specific localized and agroecological production systems over time.

Key lessons from these experiences

The above experiments confirm that agroecology is not a predefined structure but a diversified creation because of its multiple uses and users, as well as its very many variants.

The seven cases studied show the link between agroecological practices (in organic or reasoned agriculture) and commercial value obtained through a variety of marketing channels used to reach end consumers (Table 15.1): direct sales to the consumer, farmers' markets or home delivery, or through quality-conscious retailers such as supermarkets, specialty stores, mass catering, or exporters. These initiatives are also backed by quality certification schemes.

Table 15.1. Commercial value and quality control of agroecological practices.

	Type of production	Marketing	Quality control
Ecovida, Brazil	Agroecology	Farmers' markets, mass catering	Participatory guarantee system
Riam, Morocco	Organic farming	Eco-solidarity markets	Participatory guarantee system
Agreco, Brazil	Agroecology	Supermarket, direct sales, agritourism	Ecocert
Moc Chau, Vietnam	Reasoned agriculture	Supermarkets, specialty stores	Certification trademark
Agrisud, Madagascar	Agroecology	Baskets	Participatory guarantee system
Bio, Laos	Organic farming	Farmers' markets	Laos Organic Certification
Rooibos, South Africa	Reasoned agriculture	Export to Europe	GI

In addition, agroecological approaches are characterized by political discourse, slogans, the ideological positioning of the actors who support it and their practices. Simply put, an initial approach to agroecology rests on principles based not only on the management of ecological processes to produce environmental services, but also on social dimensions (Baret, 2017). This form of agroecology – also called 'strong agroecology' – represents a clean break from the conventional development model as it relies on alternative food systems that are in opposition to the dominant model. In contrast, 'weak agroecology' is often criticized by proponents of the 'strong agroecology' model as they view it as a simple 'greenwashing' of conventional agriculture through the adoption of a few practices, without the adoption of the fundamental principles of agroecology. This adaptive conception of the agroecological transition incorporates practices aimed at greater environmental sustainability, but does not call into question the existing socio-technical regime. The recommendations essentially focus on new or corrective practices aimed at reducing the environmental impact of certain production systems.

The analysis of these different market insertion experiences confirms this diversity of situations in relation to the size and objectives of the groups involved, the values they champion, and their modality and degree of institutionalization (Box 15.2 and Figure 15.3).

GIs are aligning themselves with the changing global context and consumer demand; for example, issues of sustainability are being increasingly included in their own right in the GIs' specifications, as seen in the case of rooibos. In addition to including certain rules in favour of an agroecological transition, GI professionals promote actions that support environmental preservation and that derive value from the local heritage (Ollagnon and Touzard, 2007). More recently in France, in order to support the French national policy on agroecology pushed by the Ministry of Agriculture, INAO[8] and the Institute of Vine and Wine Science have developed a guide for good agri-environmental practices. The guide provides technical benchmarks for all winemakers who would like to, individually or collectively, change their practices in order to initiate or deepen an agri-environmental approach (INAO, 2017). Without taking anything away from the efforts made by the agri-chain, this guide is representative of what is meant by adaptive agroecology or weak agroecology in an agri-chain in which there was a strong opposition between GIs and organic farming. This approach is aimed primarily at organizations that manage GIs.

We can also identify, in this typology, the market devices used by farmers and public actors and/or NGOs. We can note here the recent phenomenon in many countries of more and more local authorities, cities and urban areas investing in the food and agricultural sectors. The challenge for these administrators is to ensure food security for their populations (urban as well as rural) and to improve the sustainability of the urban or regional food systems by taking the environmental, social and economic impacts into account. The most commonly used levers for action are a support for

8. The National Institute for Origin and Quality (in French: *Institut national de l'origine et de la qualité, INAO)* is the French government organization responsible for regulating French agricultural products with Protected Designations of Origin.

Box 15.2. Diversity of marketing devices claiming to be part of agroecology

C. Cerdan, E. Biénabe, H. David-Benz, S. Lemeilleur, D. Marie-Vivien, I. Vagneron, P. Moustier

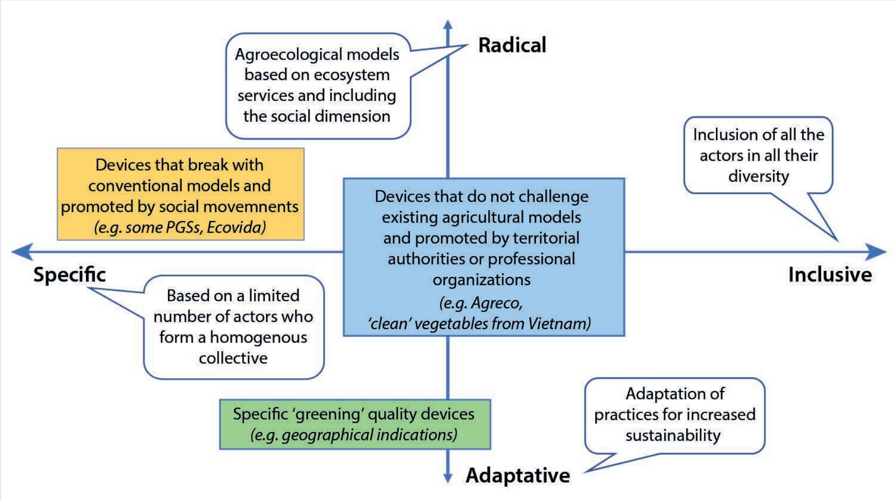

Figure 15.3. Diversity of marketing devices claiming to be part of agroecology (based on Baret, 2017).

In the 'radical and specific' quadrant, we find market devices used by a relatively small group of homogeneous actors. These actors' approach is based on a serious challenge of existing production systems and the promotion of new interactions between farmers and consumers. These devices call for a total break from conventional agricultural development models and the distribution channels associated with them. Their proponents include social movements and activists (the Ecovida network).

In the 'adaptive and inclusive' quadrant, we find devices that do not fundamentally challenge existing agricultural development models. We first classify the methods adopted by producers and private actors. In order to build and expand their range of organic products, supermarkets come closer to producer organizations. This alliance with the distribution sector represents an economic opportunity that motivates farmers to initiate an agroecological transition. The Agreco association in southern Brazil is an example.

The final case belongs in the **'specific and adaptive' quadrant** and concerns geographical indications (GI). In their original conception, GIs do not, in themselves, aim to promote agroecology. They are intellectual property rights that value and protect local products. However, they can also be tools for governance, exercising a significant influence on local innovation processes (Belmin, 2016) and can have a significant impact on agricultural transitions through the development of specific local resources in certain territories. GI and organic farming, or other types of eco-friendly certification, have long been regarded as quality indicators that can be complementary. A farmer can sell his product under a GI tag along with an organic label, adapting his production system to meet both specifications.

wholesale and open-air markets and their logistics (new regulations, infrastructure), catering programmes, and relocation policies for food supply (planning of peri-urban agricultural areas, establishment of rules and contracts, information systems). Procurement platforms for local products (virtual or otherwise) facilitate meetings between public actors and suppliers of local organic and non-organic products. The development of institutional markets and school meal programmes is also part of these dynamics. New policies, such as those concerning Brazil's Zero Hunger programme or those in several African countries, are examples of how to include organic products in school meal menus.

Conclusion

This chapter has shown the importance of market dynamics in the agroecological transition. The search for new markets, the willingness of producers and the evolution of their production systems are some elements that we have been able to identify through the experiments described here. It is important to highlight the wide range not only of market insertion modalities but also of the projects that the promoters of agroecology have used as vehicles for their experiments. Resituating these initiatives in the design of a socio-technical transition and its multi-level perspective (Geels and Schot, 2007) reveals three elements for further reflection.

First, an initiative's scaling capacity or the ability to evolve depends on the underlying project. Different types of situations have been observed. Initiatives (niches) evolve towards the dominant socio-technical regime and contribute to its evolution. This is the case of the institutionalization of agroecology or participatory guarantee systems (Morocco, Laos, Agreco Brazil, Rooibos GI). In other cases, the promoters maintain a strong opposition to the dominant regime. These experiments can evolve and can scale up (move from the local market to the national market) but remain distinct from the dominant regime. Ecovida is a niche that is becoming stronger and spreading out without integrating into the dominant system, while maintaining these values (break with the conventional model, refusal to enter into alliances with large retailers).

Second, the institutionalization of quality labels is based on the establishment of rules that structure social interactions, 'defining who can participate in the market, what goods are part of the transactions, how trading should take place, and what are the rights and obligations of each economic agent' (Niederle and Gelain, 2013; with reference to Hodgson, 2006, see Marie-Vivien and Biénabe, 2017). The institutionalization of agroecology or quality assurance modalities and the role of the State in the process play an important part in stimulating innovation and offering opportunities to territorial and producer organizations to explore new forms of production.

Third, the study shows the linkages between agroecological practices (in organic or reasoned farming) and market value that seek to build a relationship with the end user. These initiatives are also backed by quality certification schemes.

Finally, we note that the presence of different models of agricultural development and the coexistence of a plurality of trading devices based on different rationales and political projects favour agroecological transitions and transformations of food systems.

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Chapter 16

Territorial mechanisms: common goods for undertaking the agroecological transition

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The Green Revolution transformed agricultural production systems in a profound manner in the 20th century (Mazoyer and Roudart, 2006). Based on the use of petroleum products and increasing capital investments, the agricultural models of the Green Revolution were and still are being promoted by proactive public policies, and have become part of complex industrial, commercial and territorial organizations.

The technical and economic efficiency of these models helps them meet the challenge of population growth by offering a wide range of products at low cost to a 7-billion strong population. The lobbies advocating these models have helped make them a pan-global phenomenon and they dominate markets, territories, agri-chains and institutions (Ploeg, 2008).

However, their limitations are becoming increasingly visible. There are negative impacts on the environment and its balance (adverse impacts on biodiversity, land and water pollution, etc.), and the quality of food they produce is being called into question. Furthermore, capital and income are becoming increasingly concentrated, and preventing poverty alleviation (Griffon, 2006).

The agroecological transition positions itself in the backdrop of these effects and negative externalities. It proposes, among other aspects, technical alternatives that mobilize the ecological functionalities of agrosystems to guarantee agricultural production while ensuring a contribution to sustainable development (Gliessman, 2015). Various technical principles and content are being proposed, social groups are adopting them for organizational and policy purposes, agri-chains are being structured, markets are being created, and incentive-based policies are being formulated and implemented. However, such initiatives remain scattered and few in number. They need political and institutional consolidation. Numerous public and private development actors are rallying around this objective (Wezel *et al.*, 2009). This book bears witness to the diversity and multiplicity of the actions being undertaken.

This chapter analyses, in greater detail, the territorial arrangements and organizations needed for this transition. It shows what are their possible contributions, explains methods and limitations, and describes reflections through concrete examples from territories where CIRAD, with its partners, is engaged in pursuing agroecological transitions.

Why talk about territories and mechanisms?

In order to contribute to sustainable development, the agroecological transition cannot be limited to a set of individual transitions in innovative farms, even if they are numerous, for two reasons. The first is technical in nature. The landscapes, where agroecological transitions of agroecosystems take place, are continuous. Thus, a single farmer using pesticides can pollute an entire watershed, making agroecological certification impossible. The second reason is organizational and institutional. The territorial and collective footprint of agricultural activities, the externalities and services, the functioning of markets, the management of resources and ecosystems, and the innovation networks all presuppose a coordinated collective and institutional action (Griffon, 2013).

Thus, agroecology encompasses more than just certain technical changes, spatial perimeters of fields and farms and sectoral spheres, agri-chains or categories of farmers (Petersen *et al.*, 2012). The processes of agroecological transition are anchored in territories because they depend, on the one hand, on a coordination between local actors and, on the other, on social and institutional changes that support and encourage learning and the co-creation of knowledge and innovations among farmers and in agri-chains (Piraux *et al.*, 2010).

These processes take place in institutional contexts that are often unfavourable (Knox and Meinzen-Dick, 1999; or Whiteside, 1998). To begin with, conventional agriculture dominates agricultural land, institutions, social networks and mindsets. Furthermore, the agroecological transition is diverse and not very centralized. Projects concerning agroecology come in multiple forms, both from a technical point of view (from reasoned agriculture to permaculture) and from a political one (from a market-integrated agroecology to one that primarily promotes the autonomy of rural communities).

To respond to these imperatives, local actors can rely on 'territorial mechanisms', creating them if necessary. Based on Foucault (1975), we define a territorial mechanism as an institutional arrangement and an intentional assemblage of heterogeneous elements (standards, discourses, practices, instruments, tools, organizational structures, knowledge, etc.). The whole is designed to meet a common territorial goal, in our case that of reinforcing agroecological transitions.

A territorial mechanism is based on participatory and negotiated actions, and its uniqueness lies in its systematic attempts to regulate the social domain (e.g. inclusion of actors) and the political domain (e.g. access to and usage of land). In this case, the creation of standards is intended to manage behaviour and promote the consolidation of new agroecological practices. The mechanism thus formulates the rules of appropriation and use of resources and space, and also defines the conditions of economic, social and political consolidation of the agroecological transition. To this end, the territorial mechanism mobilizes tools, organizations and specific instruments (charters, certifications, development plans, etc.), designed to first create rules and standards and then to apply them. In so doing, it stabilizes a governance framework for agroecological actions, linking individual, collective and public action. It thus leverages the territory, an institutionalized space that makes sense for local actors in terms of identity and organization, both of which are necessary to mobilize energies for transformation and to define a collective project.

Territorial mechanisms are extremely diverse since the conditions that lead to their creation are always unique. The issue of their specificity arises, nevertheless, with regard to the agroecological transition. Do they possess the same characteristics as mechanisms with other territorial objectives? How are they different from other mechanisms, such as innovation platforms or those for managing common goods? These questions will help us better delineate the territorial mechanisms adapted to the agroecological transition.

This chapter presents an analysis of the objectives, the diversity, the characteristics and the conditions required for the success of such territorial mechanisms. The reflection, intended to be generic, is based on case studies from several countries in the Global South. These cases are presented in text boxes to support and illustrate our observations.

Creation of territorial mechanisms: principles and specificities

Specific standards to ensure the agroecological transition

Territorial mechanisms most often play a key role in regulating local actors, by setting standards for the appropriation and use of territorial resources. While these standards primarily concern renewable resources, they also touch on land use. Indeed, the implementation of more ecological agricultural practices in a territory is often conditioned by the acceptance of new rules governing the use of space and resources, which must be better preserved. These rules and the associated ecological processes are intended to serve as the pillars and drivers of ecological intensification (Gliessman, 2015). For example, Box 16.1 describes the creation of a municipality-level land charter in Burkina Faso necessary for implementing more agroecological rules in a territory. Box 16.2 describes a similar process in villages in Laos. In addition to pertaining to natural resources, this work of formulating standards also concerns markets (e.g. public market for agroecological products), the production of ecosystem services (e.g. water quality, air quality) and the rules for collective action. These standards create local value. The notion of a specific quality of a product or process becomes central.

To guarantee the success of this regulation, a territorial mechanism ensures coordination between the local actors involved in the transition. It has links to the market, the State and civil society (Figure 16.1).

Box 16.1. Land charter and the agroecological transition

É. Vall (see Chapter 1)

Territories in the cotton cultivation zone of western Burkina Faso have undergone significant changes over the last three decades, largely due to a population that has almost tripled. This demographic explosion has been accompanied by an increase in herbivore livestock, clearing of land for agriculture, and extractive activities for natural resources. In fact, the increased pressure on land makes it impossible for customary rules, which were previously adequate, to manage competition and conflicts over space and resources (agricultural land; pastures; watering points; forest, fish and wildlife resources). The issue of their exploitation and sustainable management has thus become vital. In Burkina Faso, local administrative bodies, which were formed following decentralization, must rework the mechanisms to manage the natural resources of their territory in order to use them sustainably, control competitions and manage any conflicts between users. Since 2009, the evolution of the land law has allowed them to implement local land charters. These charters, inspired by local customs, usage and practices, but in conformance with the laws and regulations of the State, determine specific rules for the proper management of territorial resources at a clearly defined scale.

From 2008 to 2012, the Fertipartenaires project[1] supported the Koumbia municipality in designing and implementing a local land charter to establish rules for the use of resources and space that are compatible with the sustainable management of resources and an agroecological transition (Vall *et al.*, 2015). Given the number of actors involved in the municipality (14 villages, 1358 km^2, 36,000 inhabitants) and beyond (province, country), a relatively complex mechanism of actors' representation was set up to establish the charter. Transitional consultation frameworks were first mobilized in each village to take stock in a participatory manner and pre-identify resource management rules. Subsequently, a more close-knit *ad hoc* consultation framework helped fine-tune these rules in accordance with the legal framework and formulate a draft charter that was adopted by the municipal council. The aim of the third phase was to set up the commissions responsible for applying the charter. The end of the project in 2012, the wait for decrees on implementation, and the events of 2014 have prevented the charter from being implemented so far.

(1) http://food-fertipartenaires.cirad.fr.

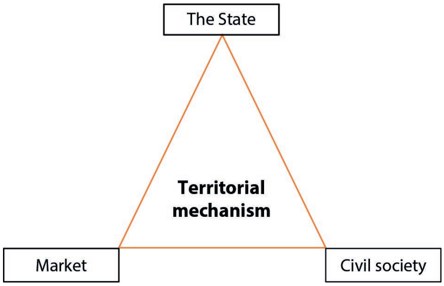

Figure 16.1. Schematic representation of the coordinating role of territorial mechanisms between different kinds of actors in a territory.

Box 16.2. Territorial mechanisms to consolidate the landscape approach in Laos

J.-C. Castella, P. Lienhard, J. Bourgoin, G. Lestrelin, S. Phimmasone (see Chapter 5)

Many villages in the mountainous areas of northern Laos are engaged in a process of agricultural transition that marks the switch from subsistence farming to commercial agriculture. The conversion of traditional slash-and-burn systems – rapidly becoming obsolete due to the contraction of fallow periods to accommodate intensive monoculture of cash crops such as maize and cassava – is contributing to the disappearance of forest-agriculture mosaics and the degradation of agricultural land, and is increasing the vulnerability of small farms. These changes in practices and in the spatial and temporal organization of farming is leading to adverse impacts on the economic and environmental viability of local ways of life.

Since 2014, the EFICAS project (Eco-Friendly Intensification and Climate-resilient Agricultural System[1]) has engaged with village communities in the provinces of Luang Prabang, Houaphanh and Phongsaly to support and help implement territorial mechanisms aimed at an agroecological transition (Castella, 2009). The first step in the collective learning process was to co-design a village-level land-use plan. To this end, a land-use management village committee met for several days with representatives of agricultural extension services and land-registry officials. Together, they marked the boundaries of the village territory on a three-dimensional model of the locality and, wherever necessary, they used GPS readings to locate areas under inter-village disputes and to resolve the issues with representatives of neighbouring villages. Once the boundaries of the village were clearly established, these actors mobilized the socio-economic and environmental data necessary to establish a land-use plan (PLUP or Participatory Land Use Planning). This data was initially used to set up a role play (called PLUP-Fiction) that engaged village participants and local government officials in negotiations on objectives of agricultural production, ecosystem services, preservation of forest resources, etc. Common management and collective actions rules were negotiated between participants as part of the role play, and were then tested and adapted to the three-dimensional model of the village territory (Bourgoin *et al.*, 2013). This helped visualize the territorial components concerned by the issues of agroecological management of resources, and engage the participants in creating a land-use plan adapted to local constraints and opportunities. The plan thus conceived was then implemented by the same groups of actors.

Annual renegotiations of the management and implementation of rules of action were part of a collective learning path that seeks to move towards the land-use plan that was initially mapped. In reality, getting down to action requires a regular renegotiation of the initial plan, which, when implemented, becomes the ultimate objective of the collective action process. The results obtained within the framework of the EFICAS project call for a major transformation of agricultural extension services in Laos, which would give local agents the role of facilitators in collective learning approaches at the scale of the village territory.

(1) www.eficas-laos.net.

Their interests are diverse and sometimes contradictory: the State's mandate is to satisfy the general interest (maximizing public goods, ecosystem services and not just production); markets seek to maximize private benefits (e.g. profits, reputation); and consumers and citizens can also demand the provision of private and public benefits (e.g. health, biodiversity).

Ensuring coordination amounts to generating coherence between market forces, public policies and community projects. To this end, territorial mechanisms structure specific institutional arrangements, which we consider to be the 'rules of the game', and their conditions of use within these mechanisms. This coordination objective is well illustrated by local productive arrangements in Brazil (Box 16.3). Set up in the context of rural territories policy in 2010, local productive arrangements sought to consolidate the productive inclusion of family farmers and to reinforce the agroecological dimension of these processes. Defined at the level of local productive agri-chains (milk, pineapple, guava, etc.), the local productive arrangements promoted the creation of local networks organized around public agents and social movements. New coordination efforts have been put in place to ensure greater coherence in public action and to orient the financing of productive investments.

In order to create the normative frameworks to structure agroecological transitions, territorial mechanisms propose specific instruments (charters, certifications, specifications, public policy tools, contracts, etc.) that reflect the will to change, and which involve various actors at different levels. These frameworks result systematically from a participatory process to formulate these standards, as shown by the different case studies.

Finally, the territorial mechanisms are part of the politics of agroecological transition, by virtue of their territorial and normative function of regulation. Territorial mechanisms linked to agroecological transitions are still rooted in power relationships, in terms of their attempt to modify the relationships and strategies of rural actors, including of those connected to markets. Power relationships favourable to agroecology must be established to stabilize and reinforce this transition. This is illustrated by the territorial certification process in Paragominas, in Brazil (Box 16.4).

A diversity of conceptions depending on the context

Like any territorial mechanism, those promoting agroecological transitions involve various actors. Indeed, they are the focal point of local inter-relationships between the State, the market and civil society. However, the weightages and roles of different kinds of actors vary depending on the context. Most often, the mechanisms are created by actors who have a high social capital, but who vary from one case to next. However, other actors are mobilized too in every case. Territorial certification in Paragominas claims to involve actors from both the private and public spheres. Other territorial mechanisms, such as the Borborema pole (Brazil, Box 16.5) have greater civil society involvement (union, university, NGO).

Territorial mechanisms address various objectives in order to have effects of regulation. Defining new rules for the use of territorial resources, formulating public policies, creating new markets, and bringing together actors in associations or cooperatives are essential steps in the agroecological transition. But each mechanism implements them in its own way and at its own pace, by mobilizing specific instruments (territorial or product certifications, charters, land-use plans, etc.).

Box 16.3. Local productive arrangements in Brazil to promote agroecology

É. Polge

Local productive arrangements are defined as a territorial collection of actors focused on a specific set of interlinked economic activities. They are similar to industrial districts or clusters but are adapted to emerging countries as they take incipient interactions into account that can benefit from forms of collective action, and thus contribute to creating local externalities or foster the emergence of development processes. Local productive arrangements have been promoted by the Brazilian government as institutional arrangements structured around specialized production poles. It is a matter of identifying the beginnings of collective actions around a given production, with the aim of structuring the productive landscape. The concentration of institutional efforts is meant to lead to the emergence of an agri-chain, and help create a territorial administration mechanism for it.

Thus, in the agricultural domain, the local productive arrangement promotes the organization of producers and the emergence of a cash crop, in addition to food produced for home consumption. Thus, the challenge of a local productive arrangement that supports agroecological transition lies in its capacity to utilize a primary production as a development lever, even as it increases farm diversity and marketing opportunities for other productions. This was the objective of local productive arrangements created in the eastern Amazon through the territorial development policy launched in 2008, which had the intention of promoting agroecology through, amongst others, the production of dairy, guava, pineapple, and acai. Local productive arrangements were organized with the help of State agencies, the Colleges of Territorial Development (CODETERs), set up at the level of inter-municipal territories, which themselves are consolidated through arrangements and contracts signed with federated States, especially Pará State.

And yet, their implementation, as shown by Polge *et al.* (2016) and Polge and Piraux (2017), has faced several difficulties in balancing the need for specialization and the agronomic and economic need for diversification. Indeed, while territorial governance mechanisms and local and regional institutions that constitute them promoted agroecology, local productive arrangements promoted a specialization in conventional farming with an excessive use of inputs, thus increasing the vulnerability of farms, now dependent on the production of a single marketed product, and with a reduced home-consumption capability, at least initially. Nevertheless, in a second stage, the organization of producers into cooperatives, and the consolidation of commercial channels, encouraged them to diversify again, albeit with more difficulty as they had adopted a conventional farming method. In other cases, the territorial mechanisms' focus on a large diversity of productions discouraged farmers from producing surpluses of any one production, which resulted in a reduced interest by processing and sales collectives. New coordination efforts have been put in place to ensure greater coherence in public action and to orient the financing of productive investments.

Box 16.4. Territorial certification in the Amazon at Paragominas

R. Poccard

The Paragominas municipality, in Pará State in northern Brazil, has managed to reverse its development trajectory within the space of a few years – from being an acknowledged destroyer of forests to a model of 'green' territorial management in the Amazon. Paragominas was, until the early 2000s, the capital of forest logging, after having been that of beef production, the two main causes of deforestation and forest degradation at the time. It was then, during the tenure of President Lula, that Brazil saw the institution of a battery of repressive measures throughout the Amazon to halt deforestation. This had major consequences. In general, rural producers, prevented from accessing new spaces and forest lands, were forced to abandon their extensive and extractive production methods in order to manage the available natural resources. The emergence of this agricultural transition could well be the first step towards an agroecological transition. The Paragominas municipality was the only one to react proactively to these measures by the central government, and proposed a territorial action plan to the Brazilian government: the *município verde* (green municipality). It guaranteed a zero deforestation objective for the municipality, and also engaged producers in an environmental regularization process while consolidating the municipal tools for forest protection, in exchange for a progressive abolition of repressive measures.

By accepting this decentralization of environmental responsibilities, through an appropriate territorial mechanism, the municipality opened itself to new and more responsible ways of development. This new trajectory could ultimately result in a certification for the territory, based on specific sustainability criteria that is, above all, defined locally.

The territorial mechanism put in place in Paragominas in 2008 relies to a large extent on the municipal council, as local institutions are still at an embryonic stage in these pioneering territories. The local civil society is not very structured (apart from due to the main conflicts dating back to the pioneering phase of occupation). Consequently, to bring these disparate local actors together around a social pact and a territorial development project constitutes an innovation of strategic importance since higher authorities, whether federal or federated, are unable to promote sustainability. Even by limiting themselves to 'command and control[1]' actions, these higher authorities seem constrained by the sheer extent of their jurisdictions, the diversity of situations, the lack of structures, and the still precarious functioning of their own institutions.

The municipal council is currently trying to reformulate its territorial mechanism, since the goal of complying with environmental legislation is no longer sufficient to generate development and sustain everyone's commitment. In addition, concerned about their image or that of their products, agri-chains and, in particular, banks are ready to support territorial projects as long as they are convincing and clear about addressing local challenges of sustainability. Fighting forest fires – a new environmental threat –, greater participation of farming families in public choices, carbon sequestration in soils and vegetation, reconstruction of forest belts and efficient landscapes, and education in rural areas are a few of the priority issues in Paragominas. The agroecological transition is still little mentioned, but the structuring of the territorial mechanism constitutes, in any case, a significant base for promoting or intensifying this transition when it does take place.

(1) These actions are based primarily on satellite monitoring of deforestation, with accompanying control and repression systems.

The system of governance of these territorial mechanisms generally consists of a mix between public and private actors. It can change during the process of its creation as well as during the phase of application of standards. In the case of Burkina Faso, transitional governance bodies were observed. These bodies sometimes remain unchanged until the implementation phase of the standards, as in the case of local productive arrangements in the Amazon. Whatever the case, the system of governance aims to stimulate dialogue and construct shared visions made possible by territorial proximity (Torre and Rallet, 2005). It is also a matter of imparting and building up skills for using information and ensuring territorial management among actors who often have low levels of education.

The mobilized territory is an additional factor of diversity. It appears as a propitious place for a new form of public action, the result of a dialogue between the public and the private sectors (State, market and civil society actors) (Tonneau *et al.*, 2017). The spatial boundaries of the territory, however, vary depending on the mechanisms. Most often, but not always, they correspond to existing decentralized administrative and political levels (municipality, district, etc.) in order to exert a real power of regulation between the actors. Sometimes, as is the case of the Borborema pole, the territory was created by social movements and rural communities. In every case, it is essential to ensure a coherence between the different levels of farms, landscapes, watersheds, municipalities and regions. This is a key element of agroecological transition. We will discuss it in more detail later in the chapter.

Finally, the diversity of territorial mechanisms is the result of specific narratives and intentionalities. Territorial mechanisms are the result of processes of complex interactions between contexts (ecological, social, institutional, political) and between actors mobilized for the transition. The 'initiating' actors are diverse: public bodies for the local productive arrangements in the Brazilian Amazon; local, public and private decision-makers in Paragominas; researchers in Laos and Burkina Faso; social movements in Borborema in Brazil, etc. In each case, the initiator develops a social representation capable of influencing the decision-making, i.e. a political representation of the region, and of setting up standards promoting the agroecological transition.

Transitions rely to a very large extent on local production conditions and their socio-economic and institutional environment. Some contexts are evidently more favourable than others, depending particularly on the social influences involved, the degree of resistance of conventional systems to an agroecological transition, the associated economic and political powers, and, more generally, institutional contexts and policies. In Paragominas, Brazil, the mayor and local elites were able to launch the bold 'green municipality' initiative in response to the federal imposition of very restrictive standards (zero deforestation, stringent regulations in major agri-chains, closure of illegal sawmills), which led to an unsustainable economic and social local crisis, a context that benefits the current certification experiment. The Borborema agricultural union pole was created in an area in which family farming has historically developed, and now represents the territory's lifeblood. Local productive arrangements have benefited from a specific and very proactive political environment. While these contexts do not determine the range of possibilities, they do constrain – or facilitate – the agroecological transition, and therefore condition the effectiveness of territorial mechanisms.

All the specificities (objectives, intentionality, types of actors, instruments, system of governance, mobilized territory) impact the methodologies used, the standards created, the range of actors and the various balances of power achieved.

Box 16.5. Borborema's agricultural union pole: a political actor in the service of the agroecological transition

M. Piraux

Many experiments of agricultural transition appear to have been consolidated in the semi-arid areas of Brazil. In fact, for more than two decades, local organizations have been experimenting with a development model based on agroecology and living in harmony (*convivência*) with drought. The Agreste region in Paraíba State, a transitional region between the coastal wetland and the drier hinterland (Sertão), has always been a driving force in these processes.

In the 1990s, the NGO AS-PTA (Assistance and Service for Alternative Agriculture Projects) initiated a process of experimentation with alternative techniques together with agricultural unions in three of the region's municipalities (*municipes*). Assessments of the technical, economic and social functioning of productive units were conducted by promoting intra- and inter-regional exchanges between farmers. A review of the functioning of each agroecosystem in the region sought to identify the major problems, and then to formulate hypotheses to solve them. In the early 2000s, local experimenter-farmer networks disseminated experimental methodologies in the communities of their respective municipalities.

Starting in 2002, the unions and the AS-PTA expanded the scale of intervention of the experimenter-farmer networks. This directly called for a regional actor capable of articulating the social dynamics of the innovation underway, in order to give the family farmers' organizations in the region a socio-political legitimacy. To this end, the Borborema agricultural union pole was created, bringing together the agricultural union and family farming organizations from 16 municipalities. This territorial mechanism was structured in thematic commissions, each responsible for the design, execution and monitoring of the progress of the experimental work, their systematization and the organization of exchanges. It was also legally institutionalized so that it could manage its own financing. Its regional development promotion strategy was based on a training programme.

The agricultural union pole was also established as a decentralized management unit for public policy programmes in Borborema. Its challenge was to maintain the institutional, administrative, financial and political conditions to ensure its position as an agent stimulating the social dynamics of agroecological innovation, while asserting its role as a political actor capable of publicly promoting various family farming proposals for the development of the area.

We note here the importance of the agricultural union pole as a territorial mechanism to anchor innovations in the territory, seen as a space for creating a collective identity, fostering debates and the institutionalization of agroecological transition processes. It has thus supported learning processes, consolidated social networks and changed the conditions of territorial governance to promote the social and political integration of farmers. It is deriving value, in this manner, from a multi-level process for administering the agricultural innovations that are necessary for the agroecological transition.

What are the concrete contributions of territorial mechanisms in the agroecological transition?

Territorial mechanisms contribute to the agroecological transition in different ways.

Mobilizing territorial assets

Territorial mechanisms mobilize, in particular, the assets that result from the activation of the territory's own resources, reflecting its uniqueness, and the different forms of territorial capital (Chambers and Conway, 1992). Inasmuch as a locality-specific science, agroecology mobilizes knowledge on the potentials of local agroecosystems, the assets of the territory and on territorial anchoring (linked to local, natural, social or symbolic resources).

This produces the tools and methods that structure the mechanisms' activities. A diagnostic phase assesses the state of the environment's resources (ecological, edaphic, etc.). It characterizes the social forces present, their interests, divergences, and points of convergence. It also describes local practices and deduces from them the potentials of the territory. For example, the development of the land charter in western Burkina Faso was only possible because of a better understanding of the local rationales underpinning the use of fodder resources, revealed through the identification of functional categories of forage plants that livestock farmers use, based on knowledge they alone possess. In the Brazilian Amazon, the creation of local productive arrangements helped identify agri-chains present in the territories, and also to better understand them in order to better support them. Indeed, the agroecological transition is contingent upon the organization of markets and agri-chains.

Territorial mechanisms contribute to the creation of suitable markets and agri-chains. Supplying products of the agroecological transition to traditional markets in fact presents major difficulties in terms of preservation and speed of transport. Moreover, distributors demand large volumes and regular supply, conditions that are problematic for the still-emerging agroecological systems. Finally, certain quality criteria, such as a less homogenous appearance of agroecological products, may constrain their marketing. Furthermore, the production costs in agroecology are sometimes higher than in conventional production. The agroecological transition thus requires access to specific kinds of markets: short circuit, niche or institutional.

For example, local institutional markets, first created in Brazil but now present in several countries, are indeed an effective option. Contractual access to these markets stabilizes practices, funding and collective organizations in the medium term. The territorial mechanism allows these markets to be created and facilitates the adaptation of the actors to particular requirements. This is the case in Paragominas, where, as part of Brazil's National School Meal Programme, the municipal council regularly wins national awards for the best initiatives to supply municipal schools. Short circuits for direct sales to the consumer are also alternatives for marketing agroecological products more effectively. The territorial mechanism contributes to the holding of agroecological markets (e.g. booths were financed in the Borborema territory) and, in this way, imparts legitimacy to the products, and helps build up trust between producers and consumers.

Another possible contribution of the territorial mechanisms to the marketing of products of the agroecological transition is to introduce marks of specific quality that are built locally and which leverage territorial assets. The territorial mechanisms' responsibility includes collective work on quality marks or health criteria related to local practices. Thus the municipal council, livestock farmers, inspection systems and dairy cooperatives have, together, formulated municipal legislation in Paragominas, making it possible to recognize and thus impart value to family livestock farming products in the municipality. The mechanisms can also facilitate more elaborate approaches to promote local products, such as labels.

Managing multi-scalar and hybridization processes

Another contribution of territorial mechanisms to the agroecological transition is the promotion of multi-scalar processes. To manage collective resources, organize actors and govern agroecology-specific processes, it is necessary to link different scales.

The landscape is the most suitable scale to think about the functionalities and the protection of natural resources. However, this scale is inadequate to manage them: most often, landscapes do not correspond to any decision-making structure. The new agroecological rules of resource use are thus multi-scalar. They are legislated at encompassing decision-making levels, such as local authorities, and implemented at lower, operational decision-making levels, such as farms and communities. These frameworks are often legislated at the municipal scale as it corresponds to the most decentralized level of the State. But other territorial mechanisms may concern smaller regions, as in the case of the Borborema agricultural union pole, or the inter-municipal scale in the case of local productive arrangements in Brazil. All these schemes are possible if regulatory frameworks exist and are recognized, allowing decentralized bodies to exercise regulatory powers.

Thus, reconciling local uses with existing regulatory frameworks and combining local or innovative practices with established laws form the essence of action through territorial mechanisms. In this way, they facilitate hybridizations between external standards (established by the State, markets or public policies) and endogenous standards, leading to their mutual recognition and legitimacy. This process also improves the adaptation of public policies to local realities, as has been the case with the Borborema pole which has implemented national programmes ('P1MC' or 'One Million Tanks'; 'P1+2' or '*Uma Terra e Duas Águas* (One Earth, Two Waters)').

Long-term perspective and managing the coexistence of agricultural models

Territorial mechanisms have to embrace a long term perspective as far as agroecological transition is concerned, not only because of the pace of innovation and learning, but also because the impacts of agroecological practices appear more slowly than those of conventional system. However, territorial mechanisms are not immune to the rapid pace of political situations, especially electoral ones. For example, in Pará State in the Brazilian Amazon, local productive arrangements, encouraged in 2010 by a political alliance between the federal State and the federated State, were profoundly altered after the 2014 elections. The opposition won in Pará, replacing the incumbent disposition, and discontinued the technical and financial support to local productive arrangements. The territorial mechanism ended in failure due to a lack of continuity of public policies.

Another characteristic of territorial mechanisms is that they sometimes seek to ensure the conditions of coexistence between the various methods of agricultural production. Agroecology is introduced to territories in which the forms of agriculture and production techniques are very varied, from the most conventional to the most organic. However, in order to consolidate a real transition over time, the entire territory will have to collaborate. A transition would be incomplete, or even encourage conflict, if it relied on a single farmer category. To this end, information, learning, the creation of standards, the search for compromises and synergies all constitute opportunities for territorial mechanisms to bridge differences. In Laos (see Box 16.2), coherence is built through a village land-use plan that is arrived at in a concerted manner. In the case of Paragominas municipality, presented in Box 16.4, the territorial certification experiment is based on municipal zoning and a coherence between different agricultural systems.

The conditions required for a proper functioning of territorial mechanisms

Similarities with the management of common goods

Can we consider territorial mechanisms to be common goods? Taking the qualities of non-exclusivity and rivalry that define common goods (Ostrom, 1993), the negotiating spaces constituted by the territorial mechanisms are characterized by open access (everyone can participate) but whose resources are limited, especially in terms of funding and projects. These must necessarily be negotiated between the stakeholders. Thus, Ostrom's framework of sustainability criteria for local institutions is also valid for a proper functioning of territorial mechanisms. Let us recall briefly some of these criteria: adaptation of rules governing the use of common goods to local conditions and community needs; right of those affected by rules to be involved in their modification; respect by external authorities of the rights of community members; self-monitoring of the behaviour of community members; multi-level governance of the common resource; and dispute resolution through accessible and inexpensive means.

These precepts are, however, not enough in the case of the agroecological transition. Our conception of territorial mechanisms involves a broader reflection on actors, instruments, learnings, innovations and the nature of the information to be mobilized to help decision-making. The rationale behind the action of territorial mechanisms centred on agroecological transition mobilizes, in particular, very different actors, with interests that are even more disparate than those of communities governing a common good. This transition has to take place in a context of a strong asymmetry of powers and of the abilities of collective organization. Creating a common good around territorial mechanisms is a complex process, but one that should be undertaken. In particular, forging relationships with local elected representatives is crucial. In Paragominas, for example, the involvement of the municipal council is a decisive element of the process, as the council ultimately holds the power to change key standards.

A necessary accompaniment and support

The innovation capacity of the territorial mechanism, which is itself linked to the quality of support the mechanism has received, is another essential factor for success, as it is in the case of innovation platforms. The support received allows territorial mechanisms to organize the transition on the basis of suitable responses to the needs of local populations. This is essential for their appropriation within their territories. In these circumstances, the mechanisms also favour processes for the co-building of knowledge, technical and social experimentation, and co-designing in partnership. Over the long term, these processes aid in raising awareness, appropriation and training. Support by specialists can facilitate, encourage, and promote interrelationships between actors and lead to the building up of social and institutional capital. However, it is this quality of social links, including those established between the private and public sectors, which drives territorial mechanisms on a daily basis. These links help governance processes run smoothly and the mobilization of actors. They contribute to improved decision-making, more balanced power relationships and a genuine involvement of elected officials. Governance structures must therefore function in a clear and transparent manner, where these links can be identified or even encouraged.

The quality of information

Territorial mechanisms depend on the structuring of information and knowledge necessary for the transition, including in their social and political dimensions. They must produce information that is useful (relevant to the questions asked), usable (appropriable by the actors) and actually used (thanks to the actors' learning processes). Communication and transparency of information are important. Pedagogical resources and suitable media must be made available. It is essential to produce summary documents in formats that are easy to understand, for instance as maps. In Burkina Faso, the existence of a simple document explaining the rules governing the use of resources was a determining factor in the appropriation of the land charter. In Laos, 3D representations allow a detailed visualization and perception of landscapes. Production of information and organization of accompaniment and support processes for local policy actors remain specific to territorial mechanisms.

Learning

That said, in addition to the tools, it is mainly the quality of the process of creating the territorial mechanisms that conditions their success, even in contexts that are constraining. Not skipping steps, giving oneself time and creating real learning processes are all factors that influence the degree of appropriation of the mechanisms, and consequently their legitimacy. This is considered a 'social relationship that gives an actor a recognized capacity to engender a harmonious togetherness' (Lévy and Lussault, 2003). Harmonious togetherness reflects a society's desire to turn conflicts of interest into productive, mutually beneficial cooperation. This significant challenge links territorial mechanisms to the municipal approach. The phase of diagnosis and creation of territorial mechanisms must systematically engender reflections on current productive practices and put them into perspective, whence the obligation and the ability to avoid sanctuarizing discourses, to question, to deconstruct certainties, to transcend rhetorical discourses or partisan politics, and to manage the sometimes numerous conflicts. It is a matter of putting in place a genuine management capability for development and mobilizing the required skills.

The role of mediation and research

In this perspective, the territorial mechanisms could be likened to Living Labs. A Living Lab regards users as key actors in the innovation process (Niitano *et al.*, 2006; Schumacher and Niitano, 2008). This is a generic concept: it has many theoretical and methodological variants, which can be observed in a wide range of experiments.[1]

Living Labs organize user communities in order to bring out, co-create and experiment with innovations that address societal issues. Strongly identified by innovation in business, they act mainly in local ecosystems, on specific innovations and on sectoral projects that prevent them from mobilizing communities in a truly comprehensive way. Some Living Labs claim to have have a territorial scope (Doyon *et al.*, 2015; Scaillerez and Tremblay, 2017). They are more ambitious, refer to territorial development approaches and adopt a more integrated view of societal issues.

Moreover, Living Labs have often proposed tools, especially from the information and communication technologies, that have overestimated the role of information at the expense of management and facilitation. And yet, this aspect is, in fact, crucial for territorial mechanisms. Indeed, the transition from reflection to action can only be effective when resources are allocated to territorial engineering (the set of human resources, methods and tasks that contribute to the development and conduct of a territorial project, as well as to the definition, assembly and implementation of actions, according to Rey-Giraud, 2012) in order to ensure appropriate management. This management is based on a working method that can be summarized by a few key phrases, characterizing as many stages: starting from past experiences, mobilizing skills and knowledge, managing and disseminating information, defining frameworks for deliberation and for references, formulating specifications, implementing, supporting, and assessing. The role of mediators is crucial here to create learning situations in which the actors can define or redefine their practices, their values and overcome defensive attitudes (Argyris and Schön, 1996). Management techniques can also check the domination of certain groups or people and harmful political influences. Tools are available for facilitation and management.

These tools are more or less sophisticated. In Laos, for example, role plays and work with three-dimensional representations were used to define management rules, providing support for negotiations between villagers and local administration objectives concerning agricultural production and ecosystem services. In Paragominas, a substantial amount of discussions, mobilizations, and capacity building was necessary

1. Living Lab was invented in the late 1990s, at the Massachusetts Institute of Technology's Media Lab, and then developed in Europe with the creation, in 2006, of a European network of Living Labs: European Network of Living Labs.

in order to engage family farmers and their representatives in a learning process. This was necessary to establish relationships based on a balanced partnership with the municipal council, and thus contribute to the territorial certification project.

Adaptability

The long-term success of a territorial mechanism largely depends on its ability to adapt to internal and external changes in the territory concerned. Assessment processes (especially the impacts of standards) need to be implemented to ensure that constraints and standards do not outweigh benefits, and that the diversity of the actors' forms of action is not restricted. It is therefore necessary to conceive of the implementation of a territorial mechanism as a continuous process of assessment and of the creation of common references and flexible standards, underpinned by a 'vision' of the territory's sustainability. This notion of assessment does not pertain to an *ad hoc* judgment of the choices made, but rather to the meaning and import of the actions, which requires the critical analysis of these choices and an understanding of the situations of which they are made part. Training and learning are essential to carrying out this critical analysis. The mechanisms can then evolve towards territorial observatories to constitute what are called 'smart territories', which bring together knowledge-engineering and the mobilization of information technologies, capacity building, public-policy assessments, and the constitution of these observatories. The territory is then established as a permanent construct, constantly being appropriated since the conditions of the environment and collective action are not static over time.

Efficiency and legitimacy

Finally, to ensure the conditions for the proper functioning and success of territorial mechanisms, the institutional arrangements and instruments put in place must be recognized as effective. Does territorial certification make the territory more attractive? Have land charters really led to more efficient management of resource uses? Do land-use plans ensure better adaptation to local potential and uses? Do the standards created make sense for the actors, and are they eventually respected and effective? Do the skills resulting from these processes help create new power relationships that are favourable to agroecology? The issue in question here is the legitimacy of the tools and products in relation to the facts on the ground.

Conclusion

The agroecological transition is a complex process that involves technical, social and institutional changes. Collective and public actions anchored in rural areas have to be strengthened because this transition mobilizes a diversity of actors and social groups at different scales and because the technical changes primarily concern farms even though the impacts are felt at other levels because entire agri-chains are impacted. This is the objective of territorial mechanisms that occupy a predominant place in the process of the agroecological transition.

We have shown that these territorial mechanisms constitute a complex assemblage of interacting elements. They combine both material elements (governance structures, instruments, practices, etc.) and immaterial ones (standards, ideas, knowledge, objectives, etc.). This assemblage must make sense for the actors in terms of the stated objective of an agroecological transition. It must also lead to a coherence with regard to territorial challenges in time (sustainability), in space (landscape organization, city-countryside relationships) and between activities (agriculture and other uses of resources, etc.).

Despite their necessary diversity, four generic elements emerge from the analysis of territorial mechanisms. They are territorial normative systems; they result from an intentionality and have a political dimension; they tend towards a progressive institutionalization; and they want to transform activity systems, collective action and the territory. Let us describe these generic elements.

From a regulatory perspective, territorial mechanisms structure territorial normative systems. For this purpose they determine arrangements between actors (rules of the game) and regulate alternative production systems (rules governing the use of resources). The former decide how the actors organize themselves and how they manage their interactions in order to define resource-use standards and a collective project; the latter correspond to these standards and to the project, and to the results of the organizational process. These normative systems, once established, 'constrain' action through specific instruments.

Territorial mechanisms are based on intentionality and have a strong political dimension where the objective is to involve different kinds of actors, including elected representatives. These two characteristics of territorial mechanisms – normative and political – differentiate them from innovation platforms.

Territorial mechanisms tend towards a progressive institutionalization. They follow a phase of creating standards, and then of their application, by framing and channelling the actors' actions through a process for creating standards and shared values. This progression makes it possible to channel energies, create common reference bases through experimentation, and assess standards. The quality of these processes contributes to the legitimacy of territorial mechanisms, and thus to their level of recognition and appropriation.

Territorial mechanisms endeavour to modify actors' practices and promote collective action. They encourage debates on the functionalities of agroecosystems and associated practices. The analysis of practices remains a basis of debates and negotiations. This makes it possible to construct an agroecological transition project that transcends rhetorical discourses and partisan politics. Territorial mechanisms finally acquire a territorializing dimension (Girard and Rivière-Honeeger, 2014). They empower each user of the territory's space according to his own practices, which helps re-appropriate the space, its resources, and its constraints. In this way, they modify relationships with the territories and bring a territorialized vision of the problems and solutions. This is also the case of public policies for the agroecological transition: they will be better adapted to local realities, and capable of making better technical, financial, economic and logistical choices.

However, beyond these generic elements, the trajectories of each territorial mechanism are very diverse, thus emphasizing the fact that the agroecological transition is not unidirectional, that it is necessary to continually experiment and undertake assessments from a technical, organizational and institutional perspective. Agroecology-promoting territorial mechanisms are therefore not transposable as such, since they result from a localized innovation process, defined according to territorial problems and potentialities. In order to propagate them, it would be better to organize a process of exchange and translation (Callon, 1986) between territories, so as to promote learning, and thus initiate the emergence of a local project.

These considerations reveal a dual reality: 'soft' and 'hard' territorial mechanisms, to use the terms employed by Pasquier and Weisbein (2007). On the one hand, 'soft' mechanisms imply flexibility, continual adjustments, ongoing social experimentation, and flexible perimeters, space and actor sets. On the other hand, the 'hard' in 'hard' mechanisms refers to their instrumentation (Lascoumes and Le Gales, 2004), based on standards and rules. These two realities exist and enrich one another. A judicious balance is one that ensures the conditions of institutionalization and efficiency of the mechanisms. An excess of the 'soft' aspect in mechanisms encourages the dilution of responsibilities and the lack of a framework for action; an excess of the 'hard' aspect in mechanisms closes off the process and limits, or even prevents, change.

The social and political construction of an agroecological transition is the outcome of efforts to share and consolidate a collective identity, forging an alternative territorial development project. The efficiency of territorial mechanisms depends on a profound change in the actors' mindset, especially those of conventional agri-chains, as also of local elected representatives. This change must lead to new societal values and new territorialities. This is the difficult but promising path that will ensure that territorial mechanisms are perceived as a common good, generating confidence and solidarity between territorial actors.

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Chapter 17

Public policies supporting agroecology in Latin America: lessons and perspectives

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Latin America and the Caribbean are regions especially interesting to analyse the emergence and development of alternative food and production models with the aim of addressing environmental, social, economic and public health issues.

Since the 1960s, this wider region has been threatened by the excesses of the conventional agriculture based on the Green Revolution, whose agro-industrial production models are not concerned with environmental issues and which have taken advantage of an institutional framework that is much less strict than in Europe and North America. This conventional agriculture, intensive in chemical inputs and water, produces pesticide-laden food that is potentially harmful for public health (Segrelles, 2001; Carrasco *et al.*, 2012; HLPE, 2015). Moreover, such systems are frequently set up on land grabbed from indigenous and rural people (Borras *et al.*, 2011; Baquero and Gómez, 2014).

In such a context, alternative farming and agrifood models have been proposed by producers, researchers and social movements, and, in some countries, even by public authorities. Some of these actors are advocating for an agroecological transition supported by a new generation of public policies (Collado *et al.*, 2013; Sabourin *et al.*, 2017).

This chapter proposes to examine the policies that favour the agroecological transition in Latin America and the Caribbean. It aims to understand how these policies have emerged and what are their challenges and opportunities.

This chapter is based on a study conducted in 2016 and 2017 by a group of researchers from the Network of Public Policy and Rural Development in Latin America and the Caribbean (PP-AL), which undertook case studies in eight countries: Argentina, Brazil, Chile, Costa Rica, Cuba, El Salvador, Mexico, and Nicaragua)[1]. While

1. These case studies are presented in Sabourin *et al.*, 2017.

conducted at the national levels by different researchers, these studies followed a common analytical framework, which included the analysis of five components:

- the use of environment-friendly agriculture concepts in policies;
- the trajectory of social movements and policies;
- the content of the current policies;
- their effects at sectoral or territorial levels;
- the main challenges and perspectives.

In order to discuss these issues, these studies applied bibliographic analyses (research literature and policy documents) and conducted interviews with representatives of social movements and with policymakers in the each country.

Concepts used and their integration into policies

The agroecological movements in Latin America propose a radical transformation of food systems in order to address environmental and social issues (Altieri, 2017). They oppose a conventional and primarily export-oriented agriculture (Toledo, 2012). Agroecology was popularized due to the work of researchers such as Miguel Altieri and Stephen Gliessman, and was championed by coalitions of social organizations that are pressurizing governments to formulate public policies to support it. The policy instruments that contribute to agroecology are varied and often part of programmes that also support organic and sustainable agriculture.

Main conceptualizations of an environment-friendly agriculture

Various actors and public policies in Latin America and the Caribbean are pushing for a transition to a more environment-friendly agriculture by promoting three main agricultural models: organic agriculture, agroecology, and sustainable agriculture. These models, which coexist in different countries of this region, emerged at different times (Figure 17.1).

Organic agriculture

Organic agriculture is the oldest of these concepts as it dates back to the 1920s (Vogt, 2007). The organic agriculture (*agricultura orgánica* in Spanish and *agriculture biologique* in French) movement aims at establishing production systems that conserve the soil and ecosystems, preserve human health, and are based on ecological processes, maintenance of biodiversity, and the specificity of local conditions (Ifoam, 2008). This agricultural model is today defined by national and international standards that are associated with certification processes. Standards regulating organic agriculture prohibit the use of non-organic inputs (chemical fertilizers, synthetic phytosanitary products and genetically modified organisms). However, as it permits the use of certified organic inputs, this model is often associated with the idea of a substitution of chemical inputs by non-chemical ones, without calling into question the modern and globalized agrifood system. In Latin America, organic products are generally oriented towards export markets.

The institutionalization of organic agriculture began in the 1980s with the promulgation of regulatory standards promoted by the International Federation of Organic

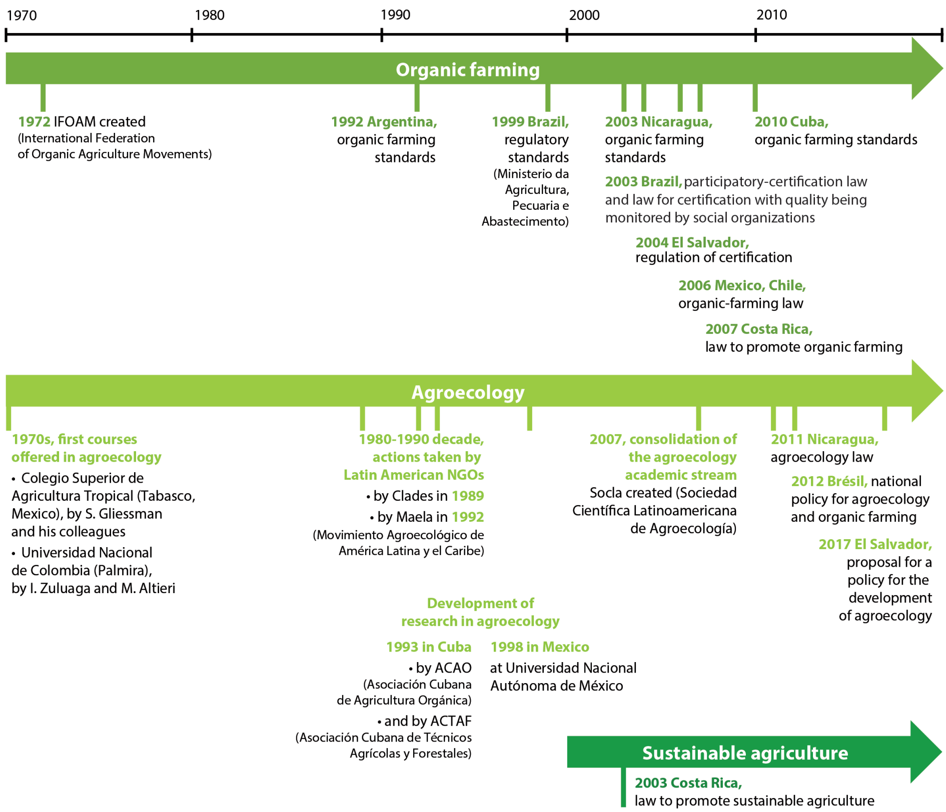

Figure 17.1. The dynamics of the emergence and institutionalization of different environment-friendly agriculturalconcepts in Latin America and the Caribbean. (Based on Altieri, 2015 and Sabourin *et al.*, 2018).

Agriculture Movements (IFOAM). Organic agriculture was then incorporated into the normative regulatory framework of Latin American countries in the 1990s: organic agriculture regime of Argentina in 1992; organic agriculture standard of the Brazilian Ministry of Agriculture, Livestock, and Supply in 1999; organic production standard of Nicaragua in 2003; organic certification scheme of El Salvador in 2004; organic production standard of Cuba in 2010, etc. In addition to these normative frameworks, some countries have also developed specific policies promoting organic agriculture such as the laws on organic agriculture in Chile (2006), Mexico (2007) and Costa Rica (2007).

Agroecology

Latin American agroecology (*agroecología*) is a more recent proposition, dating back to the 1970s, centred on the idea that environmental challenges cannot be disconnected from the profound transformations taking place in the industrial agrifood system. Just like organic agriculture, agroecology is averse to the use of non-organic inputs and espouses the importance of production systems based on principles that conserve ecosystems. Nevertheless, it also advocates a greater autonomy for producers with respect to upstream and downstream markets and emphasizes the principle of recycling within cultivated ecosystems (Altieri and Toledo, 2011; Gliessman, 2006). Accordingly, it proposes a profound modification of the agrifood system and of the relationships between farmers and consumers by supporting short circuits (direct sales, local markets) and food security and sovereignty at the territorial scale. In addition to specifying aspects pertaining to the technical dimensions of farming, agroecology proposes an integral vision that combines social, environmental, economic and cultural characteristics, defining a new model of sustainable rural development (Maela, 2017). It is thus opposed to the mainly export-oriented business model based on principles of the Green Revolution (Toledo, 2012).

The institutionalization of this concept in Latin America did not imply the emergence of specific standards in response to market demands even though its incorporation into policies took three forms. First, in the emblematic case of Cuba, before it became a proactive system driven by a group of researchers and academics, as well as by rural movements and urban agriculture, agroecology was a response to the crisis of conventional agriculture resulting from the US embargo and later from the dissolution of the Soviet Union. While the term 'agroecology' does not appear explicitly in existing policies, the principles of agroecology have been incorporated into policies for food security and sovereignty, nutrition and health – especially in public programmes for organic pest control, urban and peri-urban agriculture, and experimentation and technical assistance (Vázquez *et al.*, 2017).

A second case is associated with countries in which institutionalization has been reflected in the formulation of national policies that are explicitly dedicated to promote agroecology, such as the 2012 National Policy on Agroecology and Organic Production in Brazil, or the 2011 law on agroecology in Nicaragua.

Finally, the concept of agroecology is also present in other countries, such as Mexico and to a lesser extent Argentina, Chile and Costa Rica, associated with the revitalization of smallholder agriculture and the conservation of indigenous traditions and practices such as crop associations (e.g. maize/bean called *milpa*) and social forms of production (mutual support, *tequio*, etc.) and living (*buen vivir*). In these cases, agroecology is not subject of specific policies.

Sustainable agriculture

Sustainable agriculture (*agricultura sostenible*) emerged even more recently, in the 1990s, in some countries of Latin America. This concept proposes *ad hoc* adjustments to the conventional production systems through the adoption of specific techniques aimed at providing or conserving environmental services. It does not call for a halt to the use of chemical inputs or GMOs, nor does it call into question the main principles of the industrial agrifood system.

The concept of sustainable agriculture emerged from the heightened awareness of environmental issues following the Rio de Janeiro Earth Summit in 1992, and of the dangers of excessive use of chemical inputs in conventional agriculture. This concept has been mainly mobilized in three of the countries studied (Costa Rica, Chile and Mexico). Until now, it has resulted in policies promoting environmental services and the introduction of financial incentives to encourage conventional farmers to adopt environment-friendly practices.

Analysis of the three concepts

While all these three concepts propose a transition to a more environment-friendly agriculture, they demonstrate different degrees of integration and institutionalization in each country. Furthermore, they fundamentally differ in the way they incorporate environmental issues into production systems (modalities of 'greening') and in the types of farmers, food systems and market insertion they support (Table 17.1). Nevertheless, in our analysis of policies supporting agroecology, we will include all those that refer to any one of these three concepts, given that they contribute to the agroecological transition to the extent they promote 'agroecological practices' – even if they do not necessarily encompass all the dimensions of the agroecological concept supported by social movement in Latin America.

Table 17.1. Main characteristics of the three agricultural models that incorporate the environmental dimension and are promoted in Latin America and the Caribbean.

	Indicators	Agroecology in Latin America	Organic agriculture	Sustainable agriculture
At the level of the production systems and farming practices	Scale of changes of practices	Plots, farms, landscapes, territories	Plot or farm	Plot
	Inputs	Limited recourse to inputs and originating from organic processes (recycling principle)	From biological and certified processes	Reasoned use of chemical inputs
	Genetically modified organisms (GMO) seeds	No	No	Yes
	Diversification of production	Yes	Not necessarily sought	Not necessarily sought
At the level of farm types and food systems	Types of farms	Family, peasant, indigenous farming	All	All
	Market integration	Limited	Variable	Maximum
	Food system	Territorialized	Globalized	Globalized
	Labelling of products	Possible, but not necessarily sought	Yes, via certification, especially by third parties	No

Processes for formulating policies that favour agroecology

Three main complementary processes favour the construction of agendas and formulation of policies for agroecology.

Mobilization of social movements

The main process that enabled the setting of agendas and formulation of policies favourable to agroecology has been the mobilization of social movements pushing for organic agriculture or agroecology, in association with representatives and advocates of family or peasant farming, and with the support of international technical cooperation entities. This process has been decisive not only in formulating specific agroecology national policies (Brazil and Nicaragua), but also in incorporating the concept of agroecology in programmes at either the local or the regional levels (Chile, El Salvador).

In Brazil, the formulation of the National Policy for Agroecology and Organic Production in 2012 resulted from the influence of a broad 'pro-agroecology' network that was active during the two terms of former president Lula (2003-2010). The confluence of family farming, agrarian reform, and agroecological movements (with scientists and NGOs also participating) shaped the core of this network. It also benefited from the existence of participatory forums such as the National Council for Sustainable Development and Family Farming, and the National Council for Food and Nutrition Security, which enabled dialogue between government and civil society representatives. Finally, the involvement of rural women was decisive in convincing President Dilma Roussef to create the National Policy in her first term (2011-2014) (Schmitt *et al.*, 2017).

In Nicaragua, the promulgation of the law to promote agroecological and organic agriculture in 2011 was the outcome of ten years of mobilization of a broad coalition of social movements and activist unions advocating for agroecology, organic agriculture and the defence of rural people. This movement also worked in association with academics and civil servants, and had the support of international cooperation entities (Fréguin-Gresh, 2017).

In Chile, an agroecology committee coordinated by the Agrarian Development Institute was created in response to the demands of agroecology movements formed mainly by farmer organizations (Martinez *et al.*, 2017).

In El Salvador, the policy for the promotion of agroecology presented to the government in 2017 resulted from the mobilization of a coalition that brought together NGOs and other groups advocating for agroecology, in association with the Rural Dialogue Group and the National Committee for Family Farming (Moran, 2017).

Response to geopolitical, economic or environmental crises

The second process that facilitated the emergence of policies favourable to the agroecological transition is associated with responses to geopolitical, economic or environmental crises. Indeed, some countries (Cuba, Argentina, Nicaragua) initiated an agroecological transition as a result of crises that affected conventional agriculture. In Cuba, agroecology constituted a response to the geopolitical crisis of 1993.

In Argentina, the financial crisis of the late 1980s, characterized by hyperinflation, encouraged the adoption of policies to support poor people and those living in rural, peri-urban and urban areas. Initiated in 1990, the *Prohuerta* programme aimed to disseminate, through a participatory approach, production of vegetables for self-consumption by facilitating access to seeds, water and markets (farmers' markets) for urban and peri-urban producers. More recently, following the 2000-2001 financial crisis, this programme has been extended to rural areas (Patrouilleau *et al.*, 2017).

Agroecology was adopted in Nicaragua, as it was in Cuba, not only as a response to the shortage of chemical inputs during the period of conflict in the 1980s, but also as an alternative to the domination of the agro-industrial capitalist model between 1960-1970. Agroecology was also promoted in response to severe environmental crises that affected the cotton agri-export production model, as well as to climate-related crises, such as the one caused by Hurricane Mitch in 1998, which completely cut off many regions of the country, preventing a large number of farmers from obtaining chemical inputs (Fréguin-Gresh, 2017).

Public initiatives

The third process refers to initiatives launched by public authorities. In some countries, such as Mexico, Chile and Costa Rica, agroecological transition policies emerged mainly because of government efforts to encourage sustainable agriculture, even though this generally happened in response to pressure from social movements and due to exigencies of meeting international environmental standards. This was the case of the Sustainable Rural Development Act of 2001 in Mexico, and the Sustainable Agriculture Promotion Act of 2002 in Costa Rica.

Similar was the case in Chile, where technical assistance and investment subsidy programmes where incorporated into the policies of the Agricultural Development Institute. Complementarly, the incorporation of an alternative certification system into the organic agriculture law allowed small family farmers to access different markets for their organic products (Martinez *et al.*, 2017).

In Costa Rica, following the initiative of a parliamentary deputy, a law promoting organic agriculture was formulated in 2007 by the Organic Agriculture Movement, with the support of officials of the Ministry of Agriculture. This law facilitated the establishment, in 2013, of a programme to recognize environmental benefits – a sort of payment for environmental services in agriculture –, encouraging the adoption of agri-environmental and organic agriculture practices (Sáenz *et al.*, 2017).

Diversity of policies and instruments for promoting agroecology

Formulating policies to promote agroecology

The processes mentioned above resulted in the introduction of various forms of support for the agroecological transition in all the Latin American countries studied. Four national policy configurations to promote agroecology can be identified.

The first type corresponds to countries with existing regulations for organic agriculture, but without any specific policy instrument for this system, even though they have policies pertaining to environmental issues and the management of natural resources, biodiversity or food security, which encourage a change in practices towards sustainable agriculture. Thus, Mexico has a law to manage organic agriculture (Organic Products Law, 2006), the Law for Sustainable Rural Development (2001) and the Law on Biosafety of Genetically Modified Organisms (2005). Chile has a law for organic agriculture (2006), which, as part of its policy of supporting family farming and promoting sustainable agriculture, incorporates agroecology principles. Finally, in addition to a law promoting organic agriculture, Costa Rica has implemented agri-environmental measures as part of its programme to recognize environmental benefits.

The second type of configuration is found in countries that already have regulations and instruments to promote organic production. They also promote agroecology with policies for food security and support for family farming (e.g. *Prohuerta* programme in Argentina).

The third type corresponds to countries that have specific policies promoting both agroecology and organic agriculture, which is the case of Brazil with its National Policy for Agroecology and Organic Production (2012) and Nicaragua with its law for the promotion of agroecology and organic agriculture (2011).

Finally, some countries support agroecology without a dedicated policy, but with policies or programmes that include support for rural agriculture or family farming (Argentina in 2001) or peasant or urban agriculture (Cuba in 1993).

Diversity of instruments for agroecology

Instruments conducive to the adoption of agroecology were introduced in all the countries studied through specific policies and/or policies for supporting family farming, urban or peri-urban agriculture, food security, natural resource management, agri-environmental issues or climate change response strategies. Four major types of instruments are currently found in Latin America.

First, instruments to manage innovations and knowledge systems for an agroecological transition. The aim of such cognitive instruments is to build farmers' capabilities to manage their farms and territories using agroecological principles. These instruments are present in most of the countries studied, along with networks for knowledge dissemination – such as 'farmer-to-farmer' (*campesino a campesino*) networks in Nicaragua – in which farmers test new techniques together and exchange and preserve them. In Chile, programmes of the Institute of Agricultural Development not only have the goal of strengthening these exchange networks but also to impart value to products from peasant production systems through the 'Farmer's Hand' (*Manos Campesinas*) label (Martinez *et al.*, 2017). Similarly, in Mexico, programmes such as the Sustainable Modernization of Traditional Agriculture (Masagro) have been launched and implemented since 2010 (Pulido and Chapela, 2017).

Second, instruments that facilitates access to land and water. They are present in varying degrees of intensity in the countries of the region and have taken the form of land redistribution and legalization programmes. Even though they no longer exist in most countries, the ongoing Brazilian and Cuban programmes are noteworthy.

Third, instruments concerning regulation and promotion of products and market insertion. Present in most of the countries, they help to promote organic agriculture and agroecology by means of two mechanisms: on the one hand, regulations and standards, and, on the other, programmes for the promotion of outlets for organic and agroecological products. The former are present in all the countries studied, in the form of organic agriculture regulations that determine product specifications and certification rules. While in the majority of countries, most third-party certifications are oriented towards international markets, some countries have implemented alternative certification processes for national markets, such as participatory certification in Costa Rica or certification with quality being monitored by social organizations (Brazil). These certifications provide a framework for organic production and, in some cases, agroecological production (Brazil). Such regulations differentiate certified organic production from uncertified agroecological production.

Instruments for the promotion of markets for organic or agroecological products encourage the establishment of local markets and short circuits/food chains: fairs, vegetable baskets, consumer cooperatives. In Latin America, they also consist of preferential public procurement programmes for family farming products with a premium price for organic or agroecological products, such as the Food Acquisition Programme (PAA) and the National School Feeding Programme (PNAE) for family farms in Brazil. While these programmes have been replicated by several countries in the region, they have suffered sharp cutbacks in Brazil under the Temer government (Schmitt *et al.*,2017).

Fourth and finally, environmental regulation instruments and agri-environmental incentives, which also take the form of a variety of mechanisms. On the one hand, environmental regulations prohibit or regulate the use of certain phytosanitary products and GMOs (e.g. Decree-Law no. 153 of 1994 regulating plant health in Cuba, the Law on Biosafety of GMOs of 2005 in Mexico, etc.). Even though they do not focus on the promotion of organic agriculture or agroecology as such, and may face difficulties concerning effective enforcement, they are a key element in the adoption of agroecological and organic practices. On the other hand, regulations on land use prohibit farming or certain practices in certain areas, for example in water recharge zones (Costa Rican Soil Decree, etc.), forcing farmers to adopt more environment-friendly practices.

In addition to these regulatory instruments, positive and direct economic incentives have been put in place in the context of environmental, agri-environmental or climate change policies (Recognition of environmental benefits in Costa Rica, environmental law in Cuba, biodiversity protection in Mexico, etc.). Whereas these instruments are not necessarily targeted at peasant or family farming, they encourage the adoption of specific practices based on the principles of agroecology.

Review and perspective of current policies and instruments

Although the last decade has witnessed the emergence of policies and instruments that favour agroecology, they remain fragile and few in number in comparison to mainstream policies that support large-scale conventional agricultural practices. Their implementation largely depends on the balance of power existing in each country between the proponents of the conventional model and those who support alternative forms of agriculture.

Progress and limitations

Our analysis of the policies that favour alternative forms of farming shows good progress. First of all, over the last decade there has been a progressive consolidation of networks of farmer groups, support organizations (NGOs, trade unions), researchers and public officials sensitive to environmental dynamics. Together they have been able to incorporate agri-environmental transition instruments into agricultural policy agendas and in specific or general policies. In fact, there is a growing recognition by a segment of public administration of actors of agroecology and organic agriculture, resulting in the opening up of spaces for institutionalized participation, consultation and negotiation

(Argentina, Brazil, Chile, Costa Rica, El Salvador, and Nicaragua). In addition, we note the incorporation of the principles of agroecology in policies concerning food security and sovereignty, as well as in those supporting family farming.

Nevertheless, the development of agroecology faces several limitations and difficulties. In most of the Latin American countries studied, agricultural policies are primarily oriented towards agribusinesses and exports, since they are aligned with the interests of large landowners and companies selling agricultural inputs. Furthermore, they are supported by officials of public agricultural departments that still embrace the Green Revolution paradigm. There is a vast power asymmetry between the movements and associations in favour of agroecology (and/or organic agriculture) and those favouring conventional agriculture, which often becomes an obstacle in the taking of environmental issues into account. Moreover, this imbalance is exacerbated in most of the Latin American countries studied because there is little coordination between movements advocating agroecology and those advocating organic agriculture. Tensions over the differing orientations of these movements hinder their ability to maintain or apply the policies they were able to shape through their joint struggles. Finally, the agroecology sector remains relatively unknown due to a lack of information and statistics on its farmers and markets.

In addition, although they exist in all the countries of the region, the policies and instruments that favour agroecology often lack visibility, and the responsibility for their implementation is shared amongst various public actors. Moreover, there are gaps in the research on agroecological practices or extension tools adapted to their characteristics (taking of local agroecological conditions into account, adapting innovations to the socio-economic contexts of farmers, their labour requirements, etc.). A paradigm shift in training agricultural technicians and civil servants of agricultural administrations (which is already taking place but with different intensities depending on the country) is necessary to remove this obstacle to the development of such research and support systems for producers.

Perspectives

Despite current limitations and difficulties, some elements support the agroecological transition in Latin America. In addition to the existence of policies and the creation of coalitions for the advocacy of agroecology, there is a demand in all countries for products of alternative systems (organic or agroecological) that are perceived to be healthier and less polluting. This demand reflects a willingness to pay a premium for such products if guarantees are offered through certification or through relationships of trust between farmers and consumers. Furthermore, this demand is seeing a structural growth based on a growing level of education, information and awareness among consumers on health and food quality. It constitutes an important potential driver for the development of agroecology. The second favourable element originates from the international context. Indeed, pressure from social movements and producer organizations in favour of agroecology can help forge alliances within the United Nations. FAO has, for example, mobilized government support, since 2015, in conferences hosted by 'agroecology-friendly' countries (Declaration of The International Forum for Agroecology, 2015).

Conclusion

An increasing number of specific public policies supporting agroecology and organic agriculture have been adopted in Latin America. Moreover, several instruments supporting agroecology are already included in various sectoral policies (food security, family farming, indigenous communities, biodiversity management, climate change, etc.). A historical review of these policies' trajectories highlights the importance of the crises at the origin of the emergence and dissemination of agroecology. It also highlights the role of coalitions of actors in favour of agroecology and organic agriculture through the convergence of social movements originating from family farming and those defending alternative production models for environmental and health reasons.

Despite this progress, agroecological transitions and policies supporting agroecology face several difficulties, including the focus on conventional agriculture in public policies and administrations, and the promotion of agri-export models, which reproduces an asymmetrical balance of power. Issues of access to land and technical advice, problems of implementation of and coordination between existing instruments, and the divergence between social movements promoting alternative production models also form serious barriers.

Nevertheless, perspectives that favour the agroecological transition are emerging based, on the one hand, on the growing recognition of agroecology as a viable alternative in terms of sustainability and resilience to the challenges that humanity and the planet will have to face and, on the other, on the growing demand from local markets for healthier food.

In this context, several recommendations could be made in order to strengthen the agroecological transition and the implementation of policies to support it in Latin America. As far as research is concerned, the benefits and limitations of the two existing approaches need to be analysed: specific policies oriented toward agroecology versus combinations of instruments within existing sectoral policies. In addition, it is important to fill the gap concerning the thorough analysis of the impacts of specific policies or combinations of existing instruments on agroecology dynamics in territories and at national scales. It is also important to gather data on different policies (in particular the allocation of budgets dedicated to the promotion of conventional agriculture versus alternative systems) as well as concerning the situation of agroecology (number of producers, level of production, of productivity, of income generated, labour force involved, etc.). In fact, no statistics or large-scale studies exist beyond the narratives of local agroecology experiments to assess the import of alternative farming systems in terms of production, economic results and environmental benefits.

Several avenues should be considered to strengthen existing policy frameworks and implement instruments conducive to the adoption of agroecology. In order to influence policy choices, actors in favour of agroecology and organic agriculture have to overcome their differences and, more importantly, create coalitions that transcend the agricultural sector by teaming up with consumers and urban populations who wield a growing influence on political choices. Furthermore, it is important to territorialize these public policies given the problems of segmentation and coordination in the implementation of policies and instruments conducive to agroecology. Indeed, agroecology is embedded in particular territories and takes advantage of specific physical and human conditions. Transitions are difficult without the involvement of local actors.

Finally, the experiences analysed here can inspire policies for agroecology in Africa and Asia, and encourage a reframing of intervention strategies towards an agroecological transition. Indeed, looking beyond the technical aspects of agroecological practices, they show the importance of mechanisms for dialogue and participation involving governments and social movements that support alternative agricultural models which are more environment-friendly (sustainable agriculture, organic agriculture) and also take societal issues into account (as agroecology does in Latin America). These mechanisms can lead to the creation of coalitions of actors that are essential for influencing policymaking in favour of agroecology. They also advocate for agricultural extension and advisory systems that leverage local knowledge and territories. Finally, they highlight the importance of marketing and supply systems that impart value to their products, through certification by social monitoring, support for short circuits, public procurement instruments, and differentiated and guaranteed prices.

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Chapter 18

Agroecological transition of agriculture in the countries of the Global South: taking stock and perspectives

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Agriculture around the world is being called upon today to adapt in order to meet societal demands, environmental challenges, and climatic disruptions. Agriculture in countries of the Global South is, in particular, facing specific and often unprecedented challenges of population growth, rapid urbanization, globalized markets and macro-economic structures still dominated by the primary and informal sectors. In recent decades, agriculture in these nations has evolved in contexts that have complicated the task of negotiating solutions with the actors concerned: the withdrawal of States from agricultural and rural sectors; the emergence of new actors with contradictory interests and strong asymmetries between, for example, producer organizations and globalized agro-industries; low levels of public sector intervention resulting in a lack of quality public goods, especially in the areas of infrastructure and services.

In a context of intense transformations, the actors of the agricultural world must therefore innovate to adapt, ensure resilience and inclusivity, reconcile productivity and environmental sustainability and, at least in sub-Saharan Africa, join other development actors in creating jobs in massive numbers for an increasing number of young people entering the labour market.

Agroecology offers a new paradigm of sustainable agricultural and food systems, which we believe are better able to address societal expectations, global environmental, nutritional and health emergencies, the political orientations of different countries, international initiatives, in particular those of FAO (2018) and Sustainable Development Goals (Caron *et al.*, 2018).

More than 20 years of research, experimentation and support for projects in agroecology, carried out in Africa, Madagascar and the Indian Ocean, Southeast Asia, Latin America and the Caribbean, constitute a significant capital of results and knowledge that CIRAD and AFD have wanted to share through this book.

Two thematic fields stand out from these experiments and experiences:
– what are or could be effective and adapted agroecological systems, through an application of design and evaluation approaches to these systems;
– the manner in which these innovative systems could be deployed through a strong reliance on the human and social sciences.

This summary chapter provides a brief overview of the previous chapters, before proposing, on the basis of these experiences, paths to better support, extend and accelerate the crucial process that is the 'agroecological transition'.

Agroecological transition for agriculture in the Global South: what exactly do we mean?

Many alternative production systems have been proposed in the past several decades in an attempt to respond to the challenges posed by global changes for the countries of the Global South. Some of these systems (organic farming, conservation agriculture, agroforestry, ecological intensification, etc.) have some aspects in common in varying degrees: the optimization of biological and ecological regulation processes, the frugal management of resources, and the sustainable management of nutrient cycles. These systems can be considered as agroecological systems or variants thereof. They have the aim of ensuring agricultural production at the same time as environmental sustainability, and of contributing to a healthy and diversified diet.

Agricultural systems in the Global South are highly diversified. The varied climate, soil and altitude conditions form a matrix of this diversity. The type of production, the modalities of access to land and inputs, the links to markets, the capital invested, the level of intensification and the different modes of production come together in an infinite number of combinations. As a result, each rural society has its own dynamics and the choices it makes in terms of production methods or structuring of agri-chains have specific environmental, economic and social impacts. Consequently, agroecology cannot be promoted as a single model to be followed, but instead as a process of transformation, taking place each time in a specific situation and along a multitude of possible trajectories.

In its founding principles, agroecology not only is based on the management of ecological processes in order to produce environmental services, but also often involves a social and political dimension in the transformation of production methods and, more generally, of food systems in their entirety.[1] This form of agroecology, with a social and political dimension, which can be called 'strong' agroecology[2], runs counter to the conventional intensification model. In contrast, 'weak' agroecology is often dismissed by the proponents of strong agroecology as a mere 'greening' of conventional intensive farming through the adoption of a limited number of agroecological practices. To further clarify these differences, we can refer to the three pillars of the concept of sustainable agriculture for development, as defined by the High Level

1. For a review of the different definitions of the concept of agroecology, see Altieri (1983), Altieri *et al.* (2017), Gliessman (2014), Wezel *et al.* (2009), and Stassart *et al.* (2012).
2. Referring to the distinction between weak and strong sustainability introduced by Daly (1990).

Panel of Experts on Food Security and Nutrition of the UN Committee on World Food Security (HLPE, 2016):
– improve the efficiency of production resources, natural resources and the environment;
– strengthen the resilience of systems (ability to react and adapt to shocks);
– ensure equity and social responsibility.

In this context, the definition of weak agroecology mainly pertains to the first pillar, whereas strong agroecology encompasses all three.

CIRAD and AFD together advance the hypothesis that, given the scale and urgency of the challenges of global change, the majority of production methods in countries of the Global South, irrespective of their degree of intensification, will have to base themselves on the concepts of agroecology in order to become part of a process of economic, environmental and social progress.

Regardless of the type of agriculture considered, two main types of fundamentally linked levers for an agroecological transition are identified in this book's various chapters.

The first is of a technical nature and is based on a better mobilization of functional biodiversity in order to improve the performance of cropping or livestock systems, naturally regulate pests and diseases, and reduce the use of pesticides. It also takes into account the objective of maintaining or improving, including in the long term, the efficiency of use of natural resources (water, energy, soil, etc.) and of managing biogeochemical cycles in order to cut down on the use of nutrients from outside the ecosystem and to reduce the risk of water eutrophication caused by the leakage of nutrients out of the farming system.

The second lever is of a cognitive and organizational nature and relies on the importance of concerted dynamics between producers and all the other actors of agricultural development in the implementation of agroecological systems at the plot scale, the territorial scale and even the national scale. This lever pertains to how and how well actors work together (diversity of actors and power relationships, of strategies and capacities) and to support services for innovation. It takes the political dimensions (roles and forms of public action required) of the transition into account.

The agroecological transition thus appears as a set of linked technical and organizational processes through which new production models based on the principles of agroecology progressively replace the systems based on conventional intensification – or allow very low productivity farmers to intensify their production without adopting the conventional intensification model. In either case, it is important to arrive at a form of agriculture that is able to ensure global and local food security sustainably in all possible dimensions. These transformations are most often accompanied by the quest for greater autonomy for the systems, and therefore of the actors, as far as inputs and services required are concerned, which are generally controlled by large economic actors. Transition therefore inevitably requires strong political choices – inescapable sources of tension – and therefore negotiations.

For CIRAD and AFD, the agroecological transition encompasses both ecological intensification (Griffon, 2013) of low-input agriculture and reduction in the use of inputs in conventional intensification agriculture. However, in the latter case, we think it only appropriate to reserve the term agroecological transition to profound changes in these systems, involving both a reorientation of the way of producing and a focus on the economic and social sustainability of the territories in which they are located. Table 18.1 summarizes what agroecology could contribute to different forms of agriculture in the Global South.

Table 18.1. Potential contributions of agroecological solutions to different forms of agriculture in the Global South.

Expected functions	Forms of agriculture		
	'Small' family farming with no or low levels of chemical inputs use	'Medium-size' agriculture based on principles of conventional intensification using chemical inputs	Industrial agriculture: highly intensive and mechanized
Maintaining or increasing production	++		
Improving farmer incomes and increasing farm resilience	+++	+	
Reducing negative environmental impacts	+	+++	+++
Promoting non-production services	++	++	+
Favouring decent rural employment	+++	++	+
Adapting agriculture to better cope with climate change	+++	+	+
Help mitigate climate change		++	++

The number of crosses denotes the potential of the contribution of agroecological solutions.

Food systems are also evolving in response to the challenges posed by global changes. Agroecological transition is not the most appropriate term to describe the transition of these systems since agroecology is based on the bringing together of agronomy and ecology, whose concepts are only very partially used in food processing systems. However, objectives of improvement of food systems are common and complementary to those of the transition of the production sectors: promotion of a healthy and varied diet; more efficient use of water, energy, and other natural resources; a reduction of losses and waste; and promotion of short circuits and participatory certifications. The agroecological transition of farming systems and the transition of processing and distribution systems are therefore two inseparable and essential components of the implementation of sustainable food systems.

Technical levers based on the mobilization of functional biodiversity

From the feedback of experiments reported in this book, four main types of biological and biophysical levers of the agroecological transition can be distinguished. Their main functions are summarized in Table 18.2.

Using functional biodiversity to help fight pests and diseases and favour processes of natural regulation

A common result of the studies reported in this book concerns the regulation of pests and diseases using techniques that mobilize functional biodiversity and, consequently, the avoidance or reduction of the use of pesticides. The use of this biodiversity makes it possible to reduce the dynamics of pest development through various competition and predation processes (Chapters 6 and 7) and, additionally in some case, through physical barriers such as anti-insect nets (Chapter 4). The structure of the plant and animal communities present in the agroecosystem also influences the nature and intensity of biological regulation (Chapters 2, 7 and 11).

The experiments presented also confirm an improvement in the use of natural resources, in particular light energy, nitrogen, air carbon, water and nutrients, in systems based on the principles of agroecology. This objective is attained by maximizing biomass production by using service plants, crop associations and rotations, and enhancement of soil biological functioning (Chapters 2, 5, 6, 7 and 11).

A judicious increase in functional biodiversity thus favours production as well as stability and resilience of the system in the face of hazards (drought, invasive organisms, etc.). It is also possible to improve the stability of agricultural production by increasing interspecific genetic diversity (associated crops, diversified rotations, introduction of pastures) and by associating several vegetation strata as in agroforestry (Chapter 1, 2, 6, 9 and 11). Increasing intraspecific diversity (populations or mixtures of cultivars) increases production and the system's resilience (Chapters 2 and 6). Biocontrol techniques target host-parasite interactions or vectors, and act directly on some biodiversity components (Chapter 7). The diagnosis of functional soil biodiversity helps improve its management and thus enhances its ecological services (Chapters 2, 5 and 11).

Functional biodiversity is managed at the level of the plot and at its periphery (hedges, ditches, grass strips, etc.), and also at the watershed and territorial levels (Chapter 5). While the mobilization of diversity is not in itself a universal solution, the experiments described in the book testify to the very important progress made in the mastery over multi-species systems and in the engineering of service plants (Chapters 2, 5, 6 and 7). The use of the concept of functional traits has, in particular, made it possible to characterize the potential of cover plants to render a set of services on the basis of some of their characteristics and to work out their optimal deployment in space and time (Chapter 2, 5, 6 and 11).

Managing the nutrient cycle in a sustainable manner

Agroecological practices have the goal of conserving water and nutrient resources quantitatively and qualitatively, avoiding, for example, erosion and soil compaction through permanent soil cover. They also aim to promote the infiltration of water and the recharge of aquifers, while limiting nutrient losses through runoff and leaching (Chapters 2 and 5). During the nitrogen and phosphorus cycles – the very basis of crop production –, there may be losses of elements in the environment, resulting in the waste of nutrients, organic matter and energy, as well as water and air pollution, and greenhouse gas emissions (Chapter 13). To avoid these negative consequences and to improve production efficiency, the agroecological transition leads to the 'closure' of major cycles (i.e. to prevent the escape of nutrients from the farming system) through the combination of a series of practices: biological fixation of nitrogen, storage of carbon and nutrients in soil organic matter, recycling and use of farm fertilizers, combination of cropping and livestock systems, selection of animal breeds and plant varieties on the basis of their efficiency of capture and exploitation of resources, and crop rotations and technical itineraries favouring a temporal matching of the availability of resources and the demand by plants (Chapters 1, 3, 5, 6, 8 and 11).

Managing landscapes

The judicious arrangement of plots and their environment in space (landscape mosaics) can strengthen the control of certain pests, extend the habitat of certain regulating organisms, and promote pollination services (Chapters 5, 6 and 7). Incorporating agroecological management into the development of a landscape mosaic within a territory also helps to better preserve crucial resources (water and soil) and limit the flow of nutrients or pesticides to the natural environment. This management of the spatial organization of plots involves the use of grassed elements and hedges (Chapters 5, 7, 8 and 11).

Redefining the goals of plant and animal genetic improvement

The agroecological transition brings new challenges in terms of breeding (Chapters 2 and 9). The knowledge of ecological functioning transforms the objectives of plant and animal breeding and selection and affects the choice of new characters and ideotypes in order to take the potential interactions of plants and animals with each other and with their environment better into account.

The optimization of biological and ecological interactions requires, in particular, the contextualization of varietal solutions, i.e., a better integration of the local constraints of and expectations from farming systems, crop successions and combinations, available biodiversity, etc. This approach means broadening the range of objectives and selection criteria, the consideration in some cases of longer time scales and of spatial scales exceeding those of the plot and the farm, and the taking into account of local knowledge and local uses in selection processes. The diversity and speed of ecological, technical, economic and social changes are raising new questions about the strategy of varietal deployment specific to each species. The goal has now become to design genotype mixtures that encompass a wider range of optima, rather than aiming for an ideal all-purpose genotype. New ways of managing genetic diversity are being explored in a quest for this better adaptation, in particular through participatory selection methods (decentralized dissemination, open-access varietal formulas, identification of mechanisms underpinning plant interactions, multi-genotype selection, local 'refining' of varieties, etc.).

The changes induced by promoting diversity within systems by mobilizing and managing a greater functional biodiversity in order to provide various services within and around the cultivated area, encouraging technical and organizational breaks with standard systems, and favouring the taking of supra-plot scales into account will all lead to the development of more complex systems. They will also imply a new and stronger involvement not only of producers, technicians and advisers but also of territorial and agri-chain actors in developing modes of agroecological production. The different chapters of this book's first part show that this requires local knowledge to be taken into consideration and a participatory approach in which the producers are accorded a central role in undertaking diagnoses, prototyping of new solutions, and the assessment and adaptation of these prototypes.

Table 18.2. Technical levers of the agroecological transition for natural regulation.

Biophysical technical levers	**Expected functions**					
	Mobilizing functional biodiversity			Promoting crop-livestock interactions	Organizing landscape mosaics	Redifining the goals of genetic improvement
	Service plants	Crop associations	Rotations			
Fighting pests and weeds with biotic regulations	+++	+++	+++		++	++
Improving plant nutrition and nutrient utilization efficiency	+++	++	+++	+++	+	++
Recycling resources and managing water and nutrient cycles	++	+	+++	+++	++	+
Limiting erosion	+++	++	+++		+	

The number of crosses denotes the potential of each lever on each function.

Cognitive and organizational levers

This book highlights how much the progress of the agroecological transition depends on changes both at the individual level (what the actor knows and how he acts) as well as at the collective level (how collective action is organized). Cognitive and organizational levers are therefore essential for the deployment of agroecological alternatives to conventional intensification-based production models. Changes in ways of thinking and in working practices have to take place at the different levels of organization of agricultural activity: territories, agri-chains, producer organizations, etc. These changes can be triggered in various ways, in a more or less supervised manner (Chapter 14), through the implementation of intervention mechanisms or the provision of services to support those undertaking the transition and to address their specific needs.

Over the course of this book's chapters, three types of support systems for cognitive and organizational changes have been analysed and appear complementary and essential to the agroecological transition:
– collaborative innovation mechanisms such as 'innovation platforms', which support collective action for change, and coordination between and alignment of interests of the various categories of actors involved in the deployment of agroecological alternatives (Chapter 14);

– ‘territorial mechanisms’ that support the reorganization of activities in territories (Chapter 16);
– novel institutional frameworks that support the development of new agri-chains – especially of those linked to organic farming – and the evolution of traditional ones, and which encourage the formulation of pro-agroecology public policies (Chapters 14, 15 and 17).

Each of these mechanisms is based on a vision of the changes to be made, on methods of supporting individual and collective learning, and on new skills specific to the agroecological transition. For example, they encompass activities aimed at:
– identifying and leveraging the diversity of strategies and capacities of producers, and encouraging their active participation in and voluntary commitment to the agroecological transition of their systems (Chapters 5, 10, 14, 15 and 16);
– promoting the capitalization and transmission of knowledge (scientific or originating from producers' practices), the use of feedback, the learning of producers and rural populations (peer-to-peer, demonstrations, tests, training) (Chapters 5 and 16);
– improving the engagement and capacity of producer support services (Chapters 14 and 16);
– encouraging the involvement of downstream and upstream operators of the agri-chains concerned (Chapter 9), e.g. for the supply of seeds, inputs, and adapted mechanized equipment;
– taking consumer needs and expectations into account in a short- and long-term prospective vision, promoting the marketing of productions based on agroecological practices, proposing standards to recognize products from systems that espouse environmental and social values (Chapter 15);
– encouraging policymakers to increase their political and institutional commitment to ensure support for local and territorial initiatives through appropriate political and legal frameworks (laws; regulations; economic, financial and fiscal instruments) (Chapters 10, 16 and 17).

These activities call for new profiles for development agents, facilitators and those providing support to these change-inducing multi-stakeholder innovation partnerships or development networks. As a result, training and education mechanisms must also evolve in parallel to be able to provide training in the new jobs related to transition (Chapters 2, 5, 6, 7, 10, 14 and 16).

Innovation platforms: ensuring local support

The authors of many of the book's chapters not only confirm the importance of local support but also highlight its difficulties and limitations (Chapters 1, 2, 10, 14, 15 and 17). At present, the most successful mechanisms pertain mainly to agricultural production at the farm scale and the regional agri-chain scale, and primarily involve farmers and their direct upstream and downstream contacts. The purpose of these support mechanisms is usually to contribute to the construction and exchange of knowledge between local actors and to the sharing of practices between them; facilitate collective action and the evolution of collaborative practices; catalyse the formation of relationships between multiple organizations; and facilitate action planning, monitoring and evaluation, and capitalization.

Some of these platforms are part of the 21 platforms in partnership for research and training co-managed by CIRAD with its partners in the various countries of the Global South.

Strong contrasts are inherent to the agroecological transition and influence the operationality of these innovation platforms:
– the long time required for learning new technical approaches based on agroecological concepts, for the construction of social and human capital and for the tangible expression of results are in stark contrast to the actors' expectations of quick results so that they can satisfy development donors (Chapter 14);
– the actors have different and even divergent interests, which make it difficult to build a shared vision of the problems and their solutions.

While innovation platforms are able to stimulate local dynamics, they often struggle to take them to their conclusion in a short period. One solution can be to extend the life of these platforms beyond the completion of the projects concerned, so that the targeted objectives can be attained (Chapter 14). The studies have additionally shown that the objectives assigned to these mechanisms need to be clarified and defined more precisely. This would make it possible to identify and deploy the type of coordination mechanism between actors that is most suited to each situation (platform, network, innovation partnership). And doing it at different scales (local, regional, national) would make it possible to address the issues relevant at each territorial level with the appropriate actors. The results also underscore the need to renew forms of support for and funding of platforms, so that they are made more flexible, focused on strengthening collaborative and cognitive processes, and not just on obtaining technical and economic results (Chapters 10 and 14). Finally, all the experiments carried out show the importance of building up the capacities of the individuals in charge of undertaking innovation: the producers themselves, of course, but also the other agents of change (technicians, agricultural advisers, trainers and even rural leaders). These (re)orientations and adaptations will make these mechanisms more effective and facilitate the agroecological transition.

Territorial mechanisms: invoking the territory and policymaking

One of the key elements of development is the best possible use of resources available in a territory through the implementation of renewed approaches (Caron *et al.*, 2017). Territorial mechanisms try to respond to this need for accompanying the agroecological transition (Chapter 16). They complement the functions provided by innovation platforms because they are focused on the territory, its specificities and its political context. Their organizational and institutional processes and frameworks (governance) pertain to political spheres and markets, and are little concerned with biotechnical processes. The territorial mechanism constitutes in itself an institutional arrangement formalized between territorial actors, and an intentional assembly of heterogeneous elements (norms, discourses, practices, instruments, tools, organizational structures, knowledge, etc.). The whole is designed to address a shared purpose in the territory: encouraging, supporting, and consolidating the agroecological transition by leveraging local knowledge and the territory's resources, by fostering collaborations between stakeholders keen to promote agroecology, and by proposing new values, standards and rules compatible with agroecology or conducive to its adoption.

Several principles govern the construction and the mobilizing deployment of a territorial mechanism (Chapter 16):
– the effective involvement of actors as a fundamental principle, across all stages. Participatory and support tools for collective action are thus emphasized, aimed at the matching and hybridization of knowledge, negotiation, the search for synergies and points of convergence, the formalization of agreements, dispute resolution support, etc.;
– the initial diagnosis, as an essential step to take the diversity of the actors into account (production models, agri-chains, markets, etc.);
– the shared acknowledgement of this diversity and of temporalities in the change for each of the actors and their forms of organization;
– an accurate and shared knowledge of external standards (regulatory frameworks, policies and measures to support the agroecological transition) and dynamics endogenous to the territory (strategies and objectives of the various actors);
– the definition of a suitable territorial perimeter, which can range from the very local (municipality) to the regional, validated by the actors, and in which they recognize themselves and feel able to act together.

As a common good, shared and governed by a set of local actors, a territorial mechanism is sustainable if the conditions specified by Ostrom (1993) are met. Nevertheless, it is necessary to involve representatives of public action (local elected officials, for example), whose role is often crucial to initiate action, convince higher levels of governance, and influence the drafting of corresponding public policies. To ensure its appropriation by local stakeholders, as well as their participation and sustained interest, the territorial mechanism must also remain focused on the objectives assigned by these actors and on finding answers to their concerns through suitable products: new local standards, charters, certification schemes, capacities, and properly governed common goods (nurseries, supply mechanisms, transport). The management and the quality of information are crucial elements of a territorial mechanism's functioning, which must produce relevant, usable and actually used information (for example, a technical reference base on agroecology experiments in the territory). It is essential to produce summary documents that are easily understandable, for example in the form of maps. Information should not, however, replace the necessary guidance and facilitation. These actors must be supported, often trained, in acquiring new technical as well as organizational capabilities. Innovative facilitation and participation methods have shown their potential (role playing, participatory modelling, farmer-to-farmer exchange methods, etc.).

Innovative institutional mechanisms to support the marketing and development of new agri-chains

Even though the issues concerning the marketing of agroecology products appeared later than those pertaining to production systems in the timeline of research and development work on the agroecological transition, they are not any less important. The adoption of agroecological practices often leads to lower yields and additional costs for the producer in terms of labour, sometimes inputs (of biological origin). In the absence of incentives to produce differently in the form of financial compensation offered by aid mechanisms, these additional costs have to be offset, via new agri-chains, by new and more remunerative outlets and by a targeting of more quality- and environment-conscious customers. The articulation between agroecological production practices and specific commercial practices is crucial. The transition can be based on new market dynamics with a relocation of productive systems, a proximity between producer and consumer (direct sales and short circuits), and the establishment of new standards and guarantee mechanisms (certification of systems or products) (Chapter 15).

Because it concerns the food system, the agroecological transition marks a break with the socio-technical system resulting from the Green Revolution, characterized by the standardization of products, long supply chains, and the involvement of numerous intermediaries such as processors and large, even global, distributors. Indeed, the processing and marketing systems for products from agroecology are much more diversified. Consumers, producers and processors often weave intertwined, networked, quasi-partnership relationships (Thérond *et al.*, 2017). These new food systems challenge existing ones, coexist with them or hybridize. The concept of the localized agrifood system (LAFS) and its concrete applications – although not covered in this book, but which has been extensively documented in the literature – is a good example of these new systems that will have to be designed, bringing together small businesses and territorializing these systems' different functions (production, processing, marketing).

The topic of marketing was explored in Chapter 15. Based on case studies, the authors note the diversity of marketing experiences and draw lessons about the potential and limitations of these market mechanisms when impacts at significant scales are sought:

– the success of marketing initiatives for products of the agroecological transition depends mainly on the resistance shown by the dominant socio-technical system (standardization of products, length of supply chains, price requirements, lack of information to consumers, etc.); some initiatives manage to influence or help to modify these elements, others stay separate from them;

– the institutionalization of processing, the formalization of quality assurance modalities, and the role of States in supporting the transition are essential elements for stimulating innovation and providing opportunities for farmer organizations and territories searching for new ways of producing and marketing;

– a linkage exists between production practices and methods to derive value from the market; the case studies highlight the observation that strong certification systems (backed by territorialized groups or social movements) are more systematically associated with significant agroecological transitions.

Evaluating and producing new localized knowledge in order to innovate and cope with uncertainty

Production volumes per unit area and economic profitability are often the only metrics used to measure the performance of agricultural production methods. This book's various chapters emphasize the need to change the way agricultural systems are assessed in order to qualify and measure a set of functions carried out by agriculture and to compare the performance of agroecological systems with that of other systems (Chapter 1, 5, 6, 8, 11, 12 and 16).

The challenge of assessing the sustainability of agricultural systems

There are very many economic, social and environmental dimensions of sustainability, acting in a synergistic or antagonistic manner with each other. Each of the various development actors has his own vision of the relative importance to be accorded to each sustainability indicator. The assessment also depends on the spatial and temporal scales chosen. These few observations reveal the complexity and challenge of assessing farming and processing systems in terms of sustainable development (Chapter 12). Every assessment is conditioned by the norms, values and objectives on which it is based. In this sense, assessing the impact of these systems on sustainability can also be a political act, which must then be based on a process of consultation on objectives to focus on, actors to support, benefits to maximize, and trade-offs to accept. Assessment is therefore not just about measuring phenomena and producing knowledge to be used subsequently to inform decision-making.

The question of assessing the impact of the mode of production on sustainability requires an interdisciplinary approach. In Chapter 12, the authors examine, for example, how to quantify the benefit that would accrue to society from the conservation of a small area of fertile land by a few farmers whose individual incomes and labour productivity would, however, suffer from the adoption of these conservation measures. It remains to be decided what form of monetary or non-monetary compensation this benefit deserves. Similar questions arise for biodiversity, landscape quality, and water resources. Methodological advances in environmental economics and their applications in the forest and carbon sequestration domains can point the way to a multicriteria assessment to accompany the agroecological transition.

Evaluating a set of services and trade-offs between services

Services rendered to society as a whole by agricultural ecosystems can no longer be reduced to the sole production of commercial goods measured by economic value. In addition to the basic services of supply (food, fibre, energy, materials, etc.), agriculture and forests provide a range of services to society: regulation services (water cycle, greenhouse gases, pests and diseases), cultural services, etc. The assessment of these different services – and of their negative impacts, i.e. the disservices that can be generated – calls for a rethinking of the implications of agricultural activities for society. The citizen-consumer is becoming aware of the value of these services and is increasingly willing to pay a premium for quality and territorial products and for those produced ethically or in an ecologically responsible way. Indeed, the private sector and entire agri-chains are structuring themselves around this fast-growing demand. The assessment of these services obviously raises the question of the search for acceptable trade-offs between these services and for arbitrations that can be made through levers for change in agricultural practices, the territorial organization of activities, and incentives and penalties through public and private policy instruments. These arbitrations themselves depend on the values accorded to these services by territorial actors, markets and public policies (Chapters 5, 8 and 16).

Developing standardized and shared methods of assessment

Proposing new assessment methods and tools – or improving existing ones – that are understandable, robust and widely adoptable remains a priority. Only then can we have common references for the comparative assessment of the performance of production and processing systems (Chapters 1, 5, 6, 7, 8 and 12). For example, life cycle analysis is a standardized method that illustrates this relook at approaches for assessing systems. It is based on an assessment that encompasses all the resources mobilized by a production process. It is well-suited to the environmental assessment of production and processing systems in their overall dimension, without being limited to the local impact of a particular practice. Research is also being conducted to make it a tool for assessing social performance and at a territorial scale (Chapter 6). The research community has developed other methods that are based on mathematical tools (multi-attribute method and constrained optimization method, for example) but which are still little used by development actors (Chapter 12). It must be recognized that methodological advances in the environmental, economic and social assessment of sustainability remain uneven. Even though environmental assessment remains a complex exercise, there already exist a set of methods and tools for qualifying environmental system performance and impacts. But few methods and tools are available to evaluate economic and, in particular, social performance (Chapter 12). For example, quantifications of the notions of equity, distribution of added value, and employability in rural areas remain major challenges.

Combining different scales of assessment of performance

The need to develop the ability to undertake multi-scale assessments of the economic, social and environmental performance of systems was noted in the feedback from several sources involved in the case studies presented in this book. Defining integrated indicators of system performance at different organizational levels is a priority for researchers and development agents; it will allow choices and trade-offs to be made that incorporate the views of as many actors as possible. In this respect, the territorial level clearly stands out as does the conception of new forms of organization that contribute to the sustainable management of resources (Chapters 5 and 7). It is at this level that the use of resources and the trade-offs in their uses are negotiated. Indeed, the territory is defined by a community of life and action that leads to and underpins such decisions (Chapter 16).

Challenges for the agroecological transition

More involvement is necessary at the national and international levels

In addition to the organizational levers (innovation platform and territorial mechanism) and economic levers (actions concerning markets and agri-chains), political levers too appear to be essential for the implementation of the agroecological transition (Chapters 6, 8, 10, 14, 16 and 17). The widespread application of the agroecological transition depends on the implementation of dedicated national policies and their ability to derive value from new services. The importance of these national policies can be appreciated by recalling the role they played in the implementation of the Green Revolution.

The Green Revolution was promoted after the Second World War and in the early 1960s, in countries of the Global South, in a context of regional famines and risks of global food shortages. Under the auspices of major donors and international agencies, a set of investments, technological packages, credit systems, and mechanisms for institutional and financial support were put in place. These policies were also adopted, with different national trajectories but on similar principles, in countries that are today industrialized or emerging. The effort was indeed more intense in the countries of the Global North and in South and Southeast Asia, in a context of the cold war. The Green Revolution was thus initiated in a world in which States played a decisive role and in which still-nascent world governance benefited from a significant impetus (Figure 18.1).

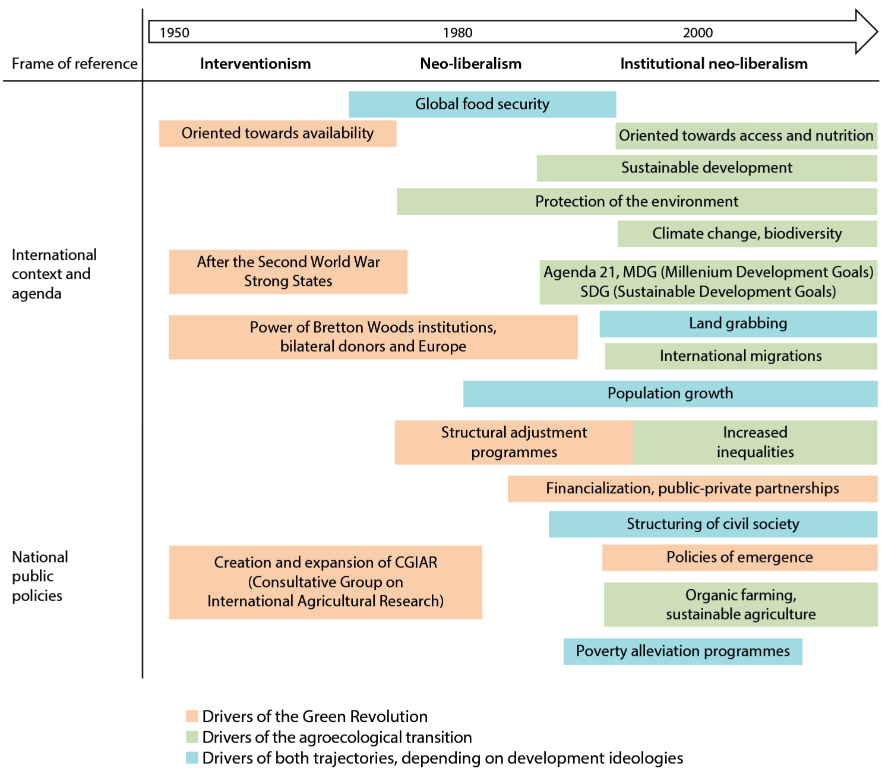

Figure 18.1. The international drivers of the Green Revolution and of agroecology from 1945 to 2018.

In Figure 18.2, we compare the main characteristics of the Green Revolution with those expected from or already known to belong to the agroecological transition. This figure shows the limitations of agroecology according to the proponents of the Green

Revolution, namely its economic risks arising from the inability of its models to produce enough, for the farmers themselves, and even beyond for society as a whole. These risks include the supposedly lower involvement of agri-chains, with potential negative consequences for the agrifood sector of today.

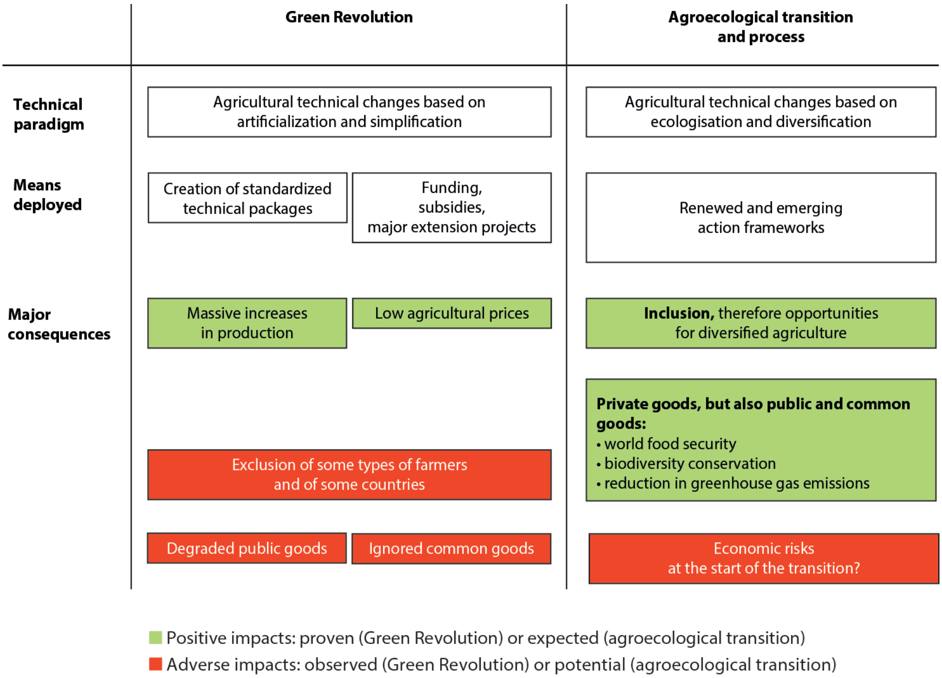

Figure 18.2. Schematic comparison of transitions leading to technical change in agriculture in the context of the Green Revolution and in the context of the agroecological transition.

This comparison, even while the various agricultural models continue to be used simultaneously, raises the question of the international and national political support for the agroecological transition. The Green Revolution attained its objectives because it benefited, at the national and international levels, from significant amounts of direct and indirect funding when it was rolled out (soft loans and investments in infrastructure, national and international research and support services, etc.) and continues to benefit from it even today in the form of a large number of direct and indirect subsidies through market policies. As always, public action is crucial to drive change. This quick comparison shows how national public policies and international agendas played a key role in the success of the Green Revolution. The agroecological transition will also have to receive similar forms and levels of support in order to develop and succeed.

Articulating the different action frameworks of the agroecological transition

In this summary of the book, we have presented the different frameworks for supporting the agroecological transition. Each framework provides a set of functions summarized in Table 18.3. In addition to the mechanisms of action described above, we also include in this table the civil society initiatives that we consider essential for the development of the agroecological transition and which we describe in greater detail in the following section.

Table 18.3. Functions of the various mechanisms to support the agroecological transition.

Expected function	**Mechanisms of action of the agroecological transition**					
	Innovation platforms	Territorial mechanisms	Support for market insertion and the development of new agri-chains	National public policies	International agendas	Civil society initiatives
Analysis of the context of production, processing and food systems	+++	++				
Analysis of the context (standards, actors, sharing rules)	+++	+++				
Multi-criteria assessment of system performances	+++	+++	++	+	+	++
Design and experimentation of technical solutions	+++	+		+		+
Design/assessment and experimentation of organizational solutions	++	+++	+			+
Formulation of standards on production methods and product quality	++	++	++	+++		++
Definition of rules and standards	+	++	+	+++	++	++
Resource management at local and regional scales	+++	+++		++		++
Resource management at global scales (essentially worldwide)		+		+++	+++	
Financing the agroecological transition	++	++	++	++	+++	
Contribution to the modification of agri-chains and markets (new service markets, other remunerated intrinsic and extrinsic quality criteria, etc.)	+	+++	+++	++	++	+++
Design and implementation of advocacy strategies for the agroecological transition	++	++			++	++

The number of crosses denotes how much a particular support mechanism (columns) contributes to functions (rows) expected for the implementation of the agroecological transition.

The agroecological transition requires an ambitious agenda and one of the major challenges in undertaking this transition is the ability to link the different frameworks of action, most notably by organizing the flow of information between them. In Figure 18.3, we attempt to depict the relationships between these different action frameworks.

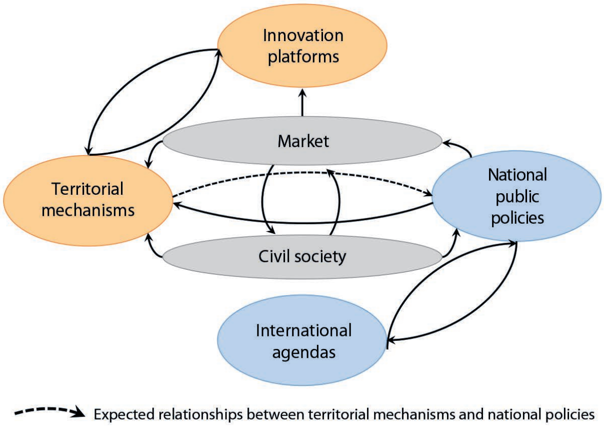

Figure 18.3. The mechanisms of action of the agroecological transition.

Orange ellipses indicate local mechanism, while blue ellipses are mostly mechanisms external to the territories. Grey ellipses indicate mechanism that can be local or external, depending on the context.

In this figure, there are three main groups. This first consists of local frameworks which include innovation platforms and territorial mechanisms, closely tied and sharing actors and locations. The second consists of more external frameworks (such as national public policies, international agendas and major international agreements). And, finally, markets and civil societies constitute a group and have their own dynamics and interact closely with each other.

The agroecological transition can take shape at the local level, irrespective of the links with other scales. This local level can also benefit from the dynamics of urban centres, some of which take charge of the organization of their food systems, or even come together with other like-minded urban centres in some cases to exchange experiences and build up their capacities for action. It seems likely that the agroecological transition has to take place first at the local and regional levels. Beyond these levels, the transition's implementation depends above all on the orientation of national policies, their capacities to accord value to the various services of production systems based on the principles of the agroecological transition, the influence of civil society, and the willingness and ability of markets to pay a premium for new ways of producing.

Building and sharing transition advocacy strategies with producers, policymakers and consumers

An observation reported in this book – shared by a multitude of actors engaged in supporting the agroecological transition – is that even though we have accumulated knowledge and experiences that should make it possible to initiate this transition, it is still not widely recognized or implemented. With very few exceptions, the drivers of transition are not yet sufficiently active, visible, or effective. Even though society and public authorities are becoming increasingly conscious of the fact that the challenges facing us are urgent and need to be addressed immediately and even though we know that we are compromising our future through inaction, the complexity of international governance, the rigidities of national public funding mechanisms, the inertia of public decision-making at all levels, the low incomes of producers, and the corporate world's desire for short-term profits and quick returns on capital are leading to delays in decision-making and actions. It is clear that this transition, which seems unavoidable, will not be easy: it hurts powerful interests and calls into question our established modes of consumption. Very probably, it is only when the majority of civil society (consumers and citizens) will be convinced of the urgency of the situation and will exert pressure through the market that transformations will start to take place. We must therefore continue to document challenges, share experiences, assess the contribution of the agroecological transition to sustainability and to various services, compare production methods and food systems on the basis of relevant indicators to differentiate between those that contribute to a desirable and entirely possible sustainable development and those that do not, and communicate effectively and widely about it. To design convincing advocacy strategies, we must continue local and territorial agroecological transition experiments and to seek to understand in greater depth the conditions conducive to and consequences of the success of initiatives, especially those that encompass coherent action at different organizational levels and result in a transition on a significant scale.

Furthermore, citizen awareness and activism will also have to rely on unambiguity and important orientations in public action. It will be necessary to build coalitions bringing together the agricultural sector and consumers (especially urban ones) to apply political weight, including internationally, on decision-making in favour of agroecology and to correct the imbalance of power relationships between the proponents of conventional socio-technical models and those of agroecological models. For this reason, the conditions of access to land, investments, technical advice, markets and financing must be called into question and revamped.

Non-governmental organizations and their groupings such as the Working Group on Agroecological Transitions (French abbreviation: GTAE) have played and continue to play a determining role in promoting the agroecological transition at local, regional and international levels through training, research and development activities.

The agroecological transition must also be part of a context in which other transformations are taking place and profoundly changing the world: the energy transition and the irreversible decline of fossil energy sources, the continued depletion of non-renewable resources, and the ongoing deterioration of ecosystems and loss of biodiversity. The ability of the agroecological transition to provide some solutions to the problems posed by these other global changes must be a major component of any advocacy strategy.

Analysing and documenting the factors that can trigger the agroecological transition at a significant scale

Several key points emerge from this book's various chapters on the conditions that have to be satisfied so that local experimental initiatives can contribute to a generalization of agroecology-based practices and food systems.

We avoid here the expression 'scaling up' since it represents a concept that is not suited to agroecology. Indeed, it is based on the assumption that a solution should be tested locally and then replicated more widely. And yet, we have seen that the contexts of the agroecological transition vary from situation to situation every single time, so that replication often proves difficult or impossible to achieve without adaptation. In fact, a multiplicity of actions at different levels of organization, undertaken in a coherent way, is necessary for the transition to take place. While a technical change can be tried out at the scale of a cropping or livestock system, the agroecological transition takes shape only if there is a change in the organization of the farm, organizational changes in the territories and agri-chains, changes in public policies, consumer initiatives, etc.

The value the market ascribes to products is, as we have seen, one of the important factors for achieving the agroecological transition on a significant scale and for it to have any meaningful impact. To this end, it is necessary to build alliances with the private sector, especially companies, global or local, willing to assume some of the risks of this transition. It is a broadening that is proposed here: even though agroecology was born in the production domain, in particular to take its ecological and environmental dimensions into account, its deployment calls the entirety of the food systems – beyond the sole stages of production and processing – into question.

The need to take long timelines in the process of the agroecological transition into account was also emphasized in this book, especially those of learning: results often fall short of promises due to the incompatibility of the 'project' approach with the pace of individual and collective learning (Chapter 14). Any implementation of the agroecological transition at a significant scale must take this aspect into account.

Generating new knowledge and renewing research approaches

Although very significant progress has been made over the past ten years in understanding the biophysical and organizational mechanisms that have to be implemented for an agroecological transition, there is still need to generate knowledge. We note, in particular, the following research activities that have to be undertaken as a priority in order to help develop this transition.

Better explaining of the role of diversity

Different chapters of this book show that there is need for a specific research effort on understanding biodiversity-related biological regulation mechanisms. Examples include the functioning of soils, the management of biodiversity at the combined scales of the plot and the landscape, and the study of the links between biodiversity, climate risk and resilience (Chapter 13).

Proposing new performance indicators

In general, there is a need to better measure the contribution of agricultural and food systems to ecosystem services and to attaining the sustainable development goals. This involves not only the documentation of domains still not well known in farming systems, such as labour productivity and ergonomics, but also, at other temporal scales, the adaptation of systems to climate change and the depletion of water resources in many regions. It is also necessary to be able to measure the capacity of systems to generate employment, reduce inequalities, and promote social development at the territorial and other spatial scales.

Conducting social science research on supporting innovation for the agroecological transition

Social science research is required to understand and strengthen individual and collective learning processes and mechanisms for coordination between actors to help them innovate (networks, platforms, etc.). It is also important to better characterize and reinforce the capacity of innovation support services, especially as regards innovation's different phases.

Identifying the contribution of agroecological systems to the functioning and sustainability of food systems and territories

As we have seen earlier, the agroecological transition and transition of food systems are closely tied. Moving forward on the path of agroecological transition also means identifying in an unambiguous way the connections that link this transition to the development of new food systems. To this end, it is necessary to:
– better characterize the diversity within food systems and its effect on consumer health;
– study the organization of food systems and their sustainability, in relation to production methods and the effects of different types of public or private intervention on these systems (e.g. procurement by public canteens);
– study material flows at the scale of territories (recycling and reuse of effluents and waste, biomass management, pollution treatment) and usage trade-offs in a circular economy context;
– quantify and measure the contribution to employment (and the quality of this employment) of the different modes of production, processing and distribution.

Understanding and formulating public action adapted to the needs of the agroecological transition

Many of this book's chapters emphasize the crucial importance of public action in expanding the agroecological transition beyond the local level. The key research activities for the development of public action concern, for example:
– at the national level, the multisectoral analysis of existing policy frameworks (environment, agriculture, transport and infrastructure, water and agricultural hydraulics, trade, etc.), their ability to support the transition, and their impacts on territories;
– at the regional or territorial level, the contextual identification of the appropriate modalities of financing the transition (investments, economic and financial instruments, banking and credit systems, etc.);
– the exploration of innovative methods of remuneration, by the State or the markets, for services rendered;
– the co-construction of public action by territorializing national public policies (adaptations, taking constraints and needs into account) in line with principles of inclusion, equity and sustainability.

Taking gender specificity into account

FAO estimates that women produce 60 to 80 percent of the food in most developing countries and are responsible for half of the world's overall food production. They are also often the main actors in processing and marketing. There can therefore be no agroecological transition without taking the role of women into account. This role, although slightly better recognized in recent years, remains poorly documented and has been little covered in this book. It is up to the research community and its partners to fill this lacuna, in an active, committed and scientifically and methodologically sound manner.

The consideration of gender specificities in technical or intangible skills should make it possible to adapt agricultural support and advisory systems in order to make them more equitable. These systems have historically favoured men and their activities, and have thus exacerbated power disparities between the sexes. A gender-based approach could therefore help rebalance decision-making powers between men and women in agricultural households, while improving intra-family cooperation for an improved leveraging of collective skills and leading ultimately to better technical, social and human performance.

By building on the work of Guetat-Bernard (2014), Prévost *et al.* (2014) and Lourme-Ruiz *et al.* (2016), we have identified several areas of work that seem to us to be priorities in order to document and recognize the place of women as important actors in the agroecological transition.

First, it is important not only to characterize the place of women in the processes of production, transformation, marketing, but also the differentiated access to resources and factors of production (land for example), of which they are often deprived. It is a matter of characterizing the distribution of value in terms of the role of women and their jobs and responsibilities.

It is also a question of documenting their specific knowledge and skills in the field of agrobiodiversity, seeds, and the processing of products, especially as concerns food; their roles not only in productive and decision-making processes at the level of the household or the farm engaged in agroecology but also in decision-making processes at local, national and international levels, and in particular their vision of innovation processes; and their specific participation in knowledge networks and in the circulation of technical information within local communities in a context of transition.

Finally, we must examine the risk of women being re-relegated to domestic tasks, which often happens when there is a change in technical systems.

We believe that it is essential for the scientific communities working on gender issues and those working on the biophysical and organizational processes of agroecology to come together to document the current role of women and the one they should ideally play in the agroecological transition.

Rethinking the role of the research community

In addition to the need for producing new knowledge on these themes, there is a need to ensure that the posture of the research community continues to evolve. Indeed, the role of research stemming from the Green Revolution – top-down, normative and prescriptive – is being called into question by the contextualized and multi-actor nature of the agroecological transition. This new transition requires taking a gamble on local innovation systems and recasting scientific questions and the manner of addressing them in the light of these new relationships with local actors. Research is therefore increasingly required for studying new inter-actor and cross-sectoral collaborative processes, and even for its ability to play a facilitating role by mobilizing the various actors involved in the transition.

Conclusion

Feedback from experiments and experiences presented in this book converges to a few salient points that characterize the state of progress of the agroecological transition and which highlight its achievements as well as its difficulties. To change production methods and food systems in order to make them more sustainable, it is possible to promote a transition to technical alternatives that are based on the concepts of agroecology, in accompaniment with organizational and institutional changes. The usability and relevance of these alternatives depend on a territorial context that is always unique in terms of actors involved and availability of capital and assets (human, social, physical, natural, financial).

This dependence means we have to be very cautious about any ambition we may have for replicating an agroecological transition at a large scale simply through dissemination, duplication or the extrapolation of locally adopted solutions to much larger territories. The agroecological transition is above all the reorganization of a system in its entirety, on the basis of coordinated individual and collective changes as well as on unique or specific territorial resources.

The contextualization of the agroecological transition, however, does not invalidate the need to capitalize basic generic knowledge, which can help find solutions and undertake innovation in other territories. The analysis of the experiences reported in this book highlights the need for generic knowledge and the lines of research that have still to be pursued.

The agroecological transition is a journey, an iterative, participatory and territorial collective exploratory process based on local knowledge bases, and which mobilizes scientific knowledge. On this path, the research community must ally with other key transition actors (training services, agricultural advisory services, technical and financial services for agriculture, the private sector and agri-chains, local and regional public authorities).

Ultimately, the agroecological transition cannot be fully attained without an awareness on the part of consumers and citizens and without the rise in influence of supra-local driving forces. National and international actors must become involved and provide a political impetus and guidance, and make explicit choices which reflect the very conception they have of societies and of the planet's future.

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List of abbreviations

Institutes and organizations

AFD: French Development Agency

ARMEFLHOR: Réunion Association for the modernization of the fruit, vegetable and horticultural economy, Réunion, France

CATIE: The Tropical Agricultural Research and Higher Education Center, Costa Rica

CEDRES: Center for Studies, Documentation, and Economic and Social Research, Burkina Faso

CIRAD: Agricultural Research Centre for International Development, France

CIRDES: International Centre for Livestock Research and Development in the Subhumid Zone, Burkina Faso

CNRS: National Centre for Scientific Research, France

FDGDON: Departmental Federation of Pest Control Groups in Réunion, France

FOFIFA: National Center for Applied Research on Rural Development, Madagascar

GRET: Research and Technological Exchange Group, France

GRN-SP-Inera: Natural Resource Management Program, Production System, INERA, Burkina Faso

IICA: Inter-American Institute for Cooperation on Agriculture, Mexico

INERA: Environment and Agricultural Research Institute, Burkina Faso

INISAV: Plant Health Research Institute, Cuba

INRA: National Institute for Agricultural Research, France

INTA: National Agricultural Technology Institute, Buenos Aires, Argentina

IRD: Research Institute for Development, France

ITAB: Research Institute for Organic Farming, France

IT2: Tropical Technical Institute, Martinique, France

USPAE: Environment and Agropastoral Production Systems Unit, CIRDES, Burkina Faso

UFRGS-PGDR: Federal University of Rio Grande do Sul, Postgraduate programme in rural development, Brazil

Research units

Note: In the following, UMR is the French abbreviation for Joint Research Unit and UPR for Internal Research Unit.

UMR Agap: Genetic Improvement and Adaptation of Mediterranean and Tropical Plants

UMR Agir: Agroecologies – Innovations – Ruralities

UPR Aida: Agro-ecology and Sustainable Intensification of Annual Crops

UMR Art-dev: Actors, Resources and Territories in Development

UPR Bioagresseurs: Pests and Diseases: Risk Analysis and Control

UPR Eco&sols: Functional Ecology & Bio-geochemistry of Soils and Agrosystems

UPR Geco: Ecological Functioning and Sustainable Management of Banana and Pineapple Cropping Systems

UPR Green: Management of Renewable Resources and Environment

UPR Hortsys: Agro-ecological Functioning and Performances of Horticultural Systems

UMR IPME: Plant-Microorganism-Environment Interactions

UMR Innovation: Innovation and Development in Agriculture and the Food Sector

UMR Moisa: Markets, Organizations, Institutions and Stakeholders Strategies

UMR Prism: Perception, Representations, Image, Sound, Music

UPR PVBMT: Plant Communities and Biological Invaders in Tropical Environments

UMR Qualisud: Integrated Approach to Food Quality

UMR Selmet: Mediterranean and Tropical Livestock Systems

UMR System: Tropical and Mediterranean Cropping Systems Functioning and Management

UPR Systèmes de Pérennes: Performance of Tree Crop-Based Systems

UMR Tetis: Land, Environment, Remote Sensing and Spatial Information

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Food security, jobs, ecological transition of agricultural production models and consumption patterns… Agroecology could be one of the solutions to meet the future challenges of humanity. Part of the United Nation's 17 Sustainable Development Goals, it requires a lasting commitment from all of us. To meet the food and economic needs of growing rural and urban communities, fulfil increasingly demanding consumer requirements, conserve natural resources and adapt to climate change, we have to find new ways of agricultural production.

Over the last decade, CIRAD and AFD have conducted experiments in agroecological transitions with farmers, researchers, development agents and policymakers in many countries of the Global South. In this book, they reflect on the future of agroecology as a way for agriculture in the developing world to adapt to global changes and they examine the conditions necessary for a successful agroecological transition.

François-Xavier Côte, agrophysiologist, is director of CIRAD's PERSYST (Performance of Tropical Production and Processing Systems) department.

Emmanuelle Poirier-Magona, projects leader at AFD, is working on supporting local development, the agroecological transition, preservation of biodiversity and derivation of value from it in Asia and Africa.

Sylvain Perret, agronomist specializing in the collective management of irrigated perimeters and their multi-criteria evaluation, is director of CIRAD's ES (Environments and Societies) department.

Philippe Roudier, research officer at AFD, specializes in climate and agriculture issues in developing countries.

Bruno Rapidel, agronomist specializing in sustainable agroforestry systems based on perennial crops, is the associate director of CIRAD's PERSYST (Performance of Tropical Production and Processing Systems) department.

Marie-Cécile Thirion, project leader and deputy director in AFD's division for agricultural and biodiversity issues, has managed several projects to promote agroecology in countries of the Global South.

The ***Agricultures et défis du monde*** (Agriculture and Global Challenges) collection publishes a book every year that showcases Cirad's research into the sustainable development of tropical agricultural systems. The goal is to inform debates in scientific as well as policymaking arenas. It is co-published by Éditions Quæ, AFD and Cirad.

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