Innovation and development in agricultural and food systems

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Chapter 16

Simulation tools to understand, evaluate and strengthen innovations on farms

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Summary. The evaluation of agricultural production systems with computerized tools makes it possible to analyse, design and support innovation at the farm level. We present here two experiences of using computerized tools in Africa: Olympe, in Madagascar, and Cikeda, in Burkina Faso. Olympe helped assess *ex post* the relative impact of adopting an innovation such as conservation agriculture on farm income. It also demonstrated its medium- and long-term benefit, through an *ex ante* analysis, by suggesting ways of stabilizing incomes. Cikeda allowed an *ex post* analysis of the performance of existing farms and an *ex ante* determination of new modalities of crop-livestock integration in an approach to support these innovations amongst farmers. Since these tools are only intended to address a specific issue, they are likely to be eventually discarded; they may, however, be of value to advisory organizations if they are incorporated in these organizations' workflows.

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The evaluation of agricultural production systems allows the study of the trade-offs and synergies between their different functions (production, income, food security, employment, preservation of landscapes, biodiversity, etc.) and the comparison of current systems in terms of the complex dimensions of sustainability (van Ittersum *et al.*, 2008). This evaluation can also help identify the determinants of change in technical or organizational practices (Cialdella *et al.*, 2009) or to determine the consequences of these changes in the short, medium or long term (Andrieu *et al.*, 2015). The results of the evaluation can then be used to guide the decision making of farmers, agricultural advisers and policymakers wishing to analyse *ex post* or *ex ante* the effects of different options for change in the management of production systems or in the farming environment. Evaluations, whether *ex post* or *ex ante*, are at the heart of approaches for co-designing new production systems, which include shared diagnoses, the testing of new systems and the measurement of their performances (Duru *et al.*, 2012; Le Gal *et al.*, 2011). An *ex ante* evaluation essentially involves comparing virtual scenarios and identifying promising patterns, whereas an *ex post* evaluation involves drawing lessons from the performance of existing practices. The evaluation is a tool and an approach at the same time, and can be used to analyse, design and support farm-level innovation.

This evaluation can be based on qualitative or quantitative approaches using mathematical and/or computerized models. The line of research that has now developed around the use of computerized models of the functioning of farms was inspired by the analytical frameworks of the management sciences, initially focused on accounting and fiscal analysis, and by the analytical frameworks of the economic sciences, by combining the management of farms with the analysis of income formation (Penot, 2012). These computerized tools, and especially the simulation tools, help undertake an analysis that takes time into account (cropping season, a

single year, or several years). They also allow a prospective analysis through the creation of scenarios to either estimate expected results or test the usefulness of certain changes.[55]

By focusing on specific technical or organizational changes at the farm scale, these approaches can be distinguished from other approaches to simulate accompaniment, such as Companion Modelling (Barreteau *et al.*, 2003), whose primary goal is the coordination of actors around the management of a collective or common resource, or Mesmis (*Manejo de recursos naturales incorporando Indicadores de Sustentabilidad*) (Lopez-Ridaura *et al*., 2002), whose goal is to define, in a shared manner, the relevant criteria for evaluating the sustainability of agricultural activities of a given family or community.

In this chapter, we want to discuss the utility of computerized tools for both *ex post* and *ex ante* evaluations of innovations and changes in farms, and to support actors in innovation processes, by referring to two experiences of using computerized tools in Africa. The Olympe software package, which permits a step-by-step budgetary simulation, was used with farmers in the Lake Alaotra region of Madagascar (Penot, 2012), and Cikeda, a simulation tool to evaluate crop-livestock integration, was used in Burkina Faso (Andrieu *et al.*, 2015; Sempore *et al.*, 2015). The evaluations based on these tools, carried out in Madagascar and Burkina Faso respectively, are part of the dynamics of the participatory accompaniment of innovating actors.

In both cases, the farmers were involved in the construction of models and in discussion of computer outputs, through presentation sessions in focus groups (in Madagascar) or through exchanges amongst individuals (in Burkina Faso).

We will present and compare these two examples to show the utility and limitations of these types of quantitative simulation tools for evaluating technical and organizational innovations at the farm level. We will then propose methodological avenues to broaden their area of application.

66. Olympe: a tool for budgetary simulation in a network of reference farms in Madagascar

66.1. Context and issues in the Lake Alaotra region

Madagascar's Lake Alaotra region is a densely populated area, struggling to maintain long-term land fertility in hilly and rainfed areas. The main problems faced by farms here are heavy erosion and high soil fragility, significant variability in the amount of rainfall and the length of the rainy season, a lack of capital resulting in reduced use of agricultural inputs, inadequate mechanization for unirrigated rainfed agriculture, and difficulties in marketing. In order to understand the strategies of agricultural households, and then to be able to accompany them better in a transition towards a more sustainable agriculture, an annual monitoring of a network of reference farms (set of agricultural farms representative of the various agricultural situations and selected from a typology) was instituted to gauge the impact on farms of a

[55] There are several tools for prospective analysis. They include linear programming, to define the technical optimums, methods centred on decisional rules, such as MATA (Multi-level Analysis Tool for Agriculture), DEXi (Decision EXpert for Education) and MASC (Multi-attribute Assessment of the Sustainability of Cropping systems), and simulation, with or without a decision-making process.

development project (the BV-Lac or 'Basin-Watershed-Alaotra Lake'[56] project) whose goal was, among others, to promote conservation agriculture.

This annual monitoring had a twofold objective:

- estimate the impact on the results of the farms of the adoption of new farming techniques and practices proposed by the project;
- compare the results obtained with those of other potential scenarios.

The Olympe modelling tool was used for this purpose.

66.2. Features and goals of the Olympe tool

Olympe, developed by researchers from the French National Institute for Agricultural Research (INRA), the Mediterranean Agronomic Institute of Montpellier (IAMM) and the French Agricultural Research Centre for International Development (CIRAD), is a tool for farm budgetary modelling and simulation of the economic functioning of farms that takes their diverse activities and resources into account. It is capable of creating models of farming systems that are sufficiently detailed to allow an economic analysis of performances based on technical choices, types of production and labour management methods. Olympe simulates economic performance at the scale of a cropping or livestock system, or a product-processing sector, at the scale of the farm or of groups of farms. In addition to undertaking automated calculations (farm accounts, balance sheet, monthly cash flow, hours worked, labour calendar, records of animal entries and exits), Olympe can be used to create customized data output tables by selecting a set of calculated variables and by creating indicators that appear relevant. The tool includes a module for graphic presentations. It is capable of analysing ten-year data series and can compare farms according to different scenarios. Basic structural farm data are obtained through farm characterization surveys. Information is collected on production systems and technical itineraries adopted, on sources of agricultural and non-agricultural incomes, and on hours worked. Data is also collected on constraints on farms, strategies of farmers and the opportunities available to them. The modelling of farms, on the basis of the reference farm network, also relies on the availability of a plot-level database that was created from the monitoring of 3000 plots over the ten years of the BV-Lac project.

66.3. Using the Olympe tool

The network of reference farms, consisting initially of 55 farms, was set up in 2008. In 2011, it was reduced to 15 farms that were considered representative in order to carry out a prospective analysis focused on the likely effects of the adoption of conservation agriculture through an exploration of different possible scenarios. This network made it possible to measure the potential impact of the adoption of new practices proposed by the project (cropping systems in conservation agriculture), first at the level of the cropping systems and then at the farm level (Penot *et al.*, 2015). The actors concerned by this mechanism included the surveyed farmers – regularly invited to sessions for the presentation of results –, the 60 technicians and engineers involved in the project (from the project team, consultancy firms and non-governmental organizations) – responsible for experimentation and extension

[56] In French: *Bassin-Versant-Lac*.

activities –, and researchers from CIRAD and FOFIFA (National Centre for Applied Research on Rural Development, Madagascar). The presentations of the results, sometimes organized in the villages, made it possible not only to discuss the results but also to improve the modelling by taking the participants' observations into account and defining new simulations based on their proposals.

66.4. Results of the Olympe tool

The results showed that aside from a limited core of about 600 farmers who had fully adopted conservation agriculture techniques, a large number of farmers had partially adopted agroecological techniques and had thus achieved varying results that are yet to be really assessed. Although the techniques promoted in conservation agriculture ensure production over the long term and appear to maintain soil fertility, it is still the standard agricultural intensification (which uses significant amount of mineral and organic fertilizers for soil fertility) that provides the best yields, and thus the highest incomes. The quantification obtained by modelling with Olympe helped detail the farmers' costs and margins, and thus put into perspective the real impact of the adoption of conservation agriculture on the income of a farm using low levels of inputs. The impact is greater on production stability in the medium term. The prospective analysis also made it possible, by testing various possible technical innovations and theirs impact on the farms' economic results and by taking into account the variability existing between farms, to change the perception of the technicians of the development project on the technical choices they were proposing. Thus, new actions have been proposed by the project in terms of agricultural experimentation, technical proposals made to farmers, and training them. In a certain way, farmers were the first beneficiaries of these modelling activities since it was their realities and constraints that were taken into account, thus leading to modifications in the extension services on offer. Figure 16.1 illustrates this approach.

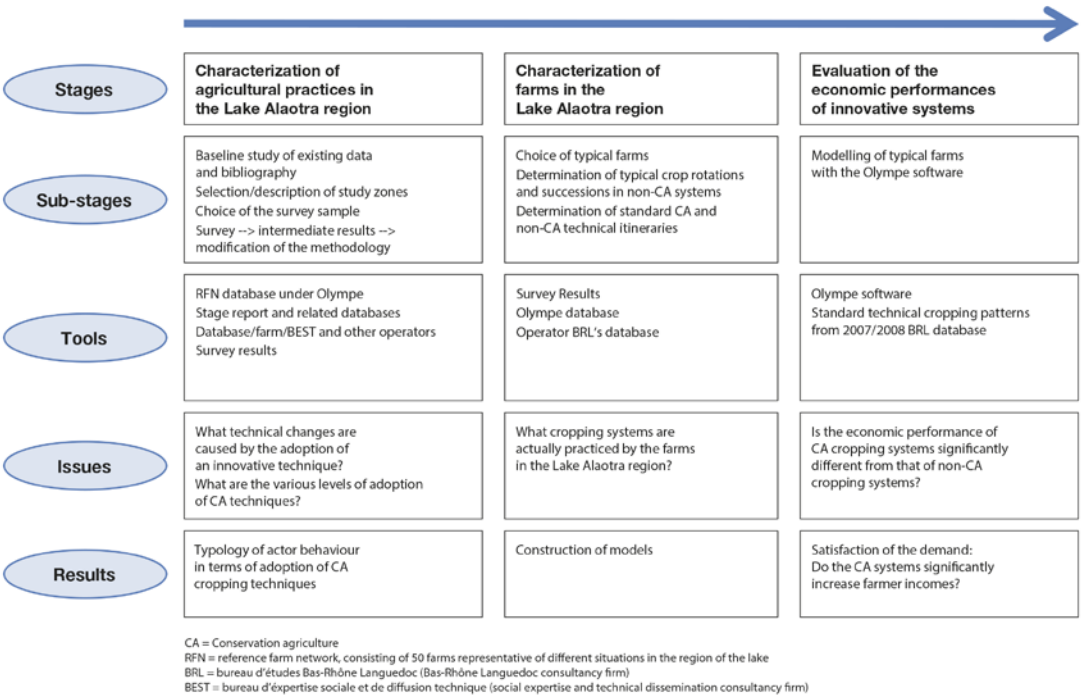

Figure 16.1. Methodological approach using Olympe in the Lake Alaotra region (Madagascar).

67. Cikeda: a computerized tool for the co-design of mixed farming

systems in Burkina Faso

67.1. Context and issues in western Burkina Faso

Like other areas in sub-Saharan Africa, western Burkina Faso has experienced demographic growth and the settlement of its populations over the last 30 years. The upsurge in the clearing of rangeland to increase arable land and an increase in the same period of the size of cattle herds of both livestock herders and farmers, has led to friction between these two producer groups. One of the challenges faced by our research and development efforts within the framework of the collaboration between CIRAD and its research partners in Burkina Faso was to develop and implement new production systems with producers to find and strengthen complementarities between crop and livestock systems. These new systems include, for example, innovations based on the inclusion of fodder crops in cropping systems and on the use of crop residues. It was also a matter of updating the approaches for the co-design of production systems and for the accompaniment of producers. Tools to simulate farm operations were used to do so. We present here one of these tools, Cikeda (meaning 'farm' in Dioula), the manner in which it helped farmers who used it to make *ex ante* evaluations of the different scenarios of change they themselves had defined, and the effect the approach had on their knowledge and practices.

67.2. Features and objectives of Cikeda

Cikeda aims to strengthen approaches for co-designing production systems within the framework of a participatory approach involving the researcher, the farmer and a technician (deputed from the agriculture or animal resources ministries). This tool helps calculate the effect of different technical and organizational alternatives on resource flows (residues, organic manure, cereals) at the farm level, in terms of balances of fodder, mineral and cereals, as well as of income (Andrieu *et al.*, 2012). Cikeda was developed on the basis of surveys on the functioning of farms, as well as several focus groups with farmers between 2008 and 2013, so that its inputs and outputs could be defined and farm specificities better taken into account. It has been used to help producers compare the performance of different strategic and tactical choices and, in particular, those of different scenarios for crop-livestock integration (Sempore *et al.*, 2016).

67.3. Using Cikeda

Cikeda was used by technicians and researchers to support the decision-making process of 13 producers representative of the three kinds of farmers (cultivators, livestock farmers, agropastoralists[57]) found in Koumbia and Kourouma villages, in western Burkina Faso. Different interactive scenarios, i.e. scenarios that were explained and discussed with the producers, were simulated: the reference scenario, or scenario 0, corresponding to the existing characteristics of each farm and its practices, and different prospective scenarios in which strategic and tactical changes were introduced by the producer, in interaction with a researcher (Sempore *et al.*, 2015; 2016) or a technician (Andrieu *et al.*, 2012), based on the results obtained in previous scenarios. The innovations evaluated were diverse and depended on the farm's strategic orientation. These included, for instance, compost production by

[57] While a cultivator may own a few draft animals, most of the animals owned by agropastoralists are for fattening.

cultivators and agropastoralists, the introduction of fodder crops and storage of crop residues by agropastoralists and livestock farmers, or the introduction of a beef fattening unit by these same producers. Surveys were then conducted with producers who had used Cikeda to assess their perception of the tool, the effect of the approach on their knowledge and practices concerning crop-livestock integration.

67.4. Results obtained using Cikeda

The use of Cikeda allowed producers to systemically and prospectively evaluate different innovations for their cropping and livestock systems, before testing them on farm, and to select options that are useful and feasible in the short term. The co-design and simulation of alternative solutions and strategies led to a rapid change in the management of soil fertility and of animal feed for the 13 producers who tested the approach between 2009 and 2013 (six producers in Koumbia, seven in Kourouma). They undertook these changes mainly because of their improved knowledge and understanding of the flows of fodder biomass and fertilizers between cropping and livestock systems on their farms.

The use of the Cikeda to evaluate different scenarios for the next cropping season, with six producers between 2011 and 2012, made them aware of the need to better manage organic manure and livestock feed using fodder. Thus, one of the agropastoralists who used the tool understood the need to prepare for the fattening process, not, as he tended to do, at the end of the harvest season, but before it even started, in order to determine the fodder plot size and the reserves of residues to maintain. Cultivators noted an improvement in their knowledge of fertilizer production and crop fertilization, as also in their ability to estimate the amount of residue to harvest to meet the needs of their draft animals and limit their dependence on cotton cake. Reflection encouraged by discussions of the scenarios resulted in changes in practices, in particular in an increase in the amount of organic fertilizer produced on the farm as compared to the initial practices.

This case study shows the value of an evaluation based on a computerized tool, used in an approach for co-designing, with the farmer, production systems using scenarios incorporating and comparing innovations that promote or optimize the crop-livestock relationship. However, one limitation of the approach lies in the time required to be devoted to each farm, which prevented the transfer of the Cikeda tool to advisory entities, even though their technicians were involved in its design and utilization phases. Reflection is needed on how this kind of tool can be used to train technicians so that they can apprehend the complexity of farms and are able to conduct the necessary dialogue with the farmers to improve production systems.

68. Lessons from these two case studies

68.1. Advantages and limitations of simulation approaches and tools

These two case studies illustrate two approaches for the quantitative evaluation of farm operations in Madagascar and Burkina Faso to support agricultural innovations (conservation agriculture, in the first case, and management of crop residues and fodder crops for animal feed and manure production in the second). These approaches use computer software to provide quantified information on the advantages and disadvantages of adopting a technical innovation (conservation agriculture) or a set of techniques and management modalities of a farm’s various production units (crop-livestock integration). This evaluation concerns the existing

situation of the farms (*ex post* evaluation) as also – and this represents the value addition of these approaches – the discussion of possibilities of change with the actors and their effects on farm performance.

In both cases, the tools used are based on a detailed knowledge of the farming environment and the ground realities of the farmers. Variables are therefore chosen, as are processes to simulate, from a shared vision with the actors involved of the situation and the agricultural problems to be addressed. These tools are complex because they incorporate a systemic representation of different farm components, and possibly of the household (notion of production systems and activities). In fact, they simulate economic flows (money, labour) and, in the case of Cikeda, material flows (biomass, nutrients) between the different compartments of the farm. They generate annual, economic (Olympe) or agroeconomic (Cikeda) reports, which can illustrate and compare the impacts of technical or organizational changes at the farm level. Passage of time is taken into account in Olympe through the looping of the simulation outputs for a given year *n* into the inputs of the model for the year *n+1*. In Cikeda, the changes are simulated at the seasonal scale (dry season and rainy season) and aggregated over the year. The structural evolutions of the farms (over a period of more than ten years) are not simulated but can, however, be input into the model by the user, if they correspond to a desired scenario. It is, however, difficult to analyse the processes of socio-economic differentiation between farms using these models.

In general, the use of these tools by the practitioners (farmers and technicians) within the framework of approaches to co-design innovation is complementary to on-farm experiments. Modelling can be used to test a wide variety of scenarios for introducing innovations in farms in order to narrow the options to the most promising innovations, whose performance can subsequently be evaluated through experimentation.

The potentially normative nature of this type of tool requires a considered and contextualized approach to their use. The results of computer-generated evaluations should not be considered in absolute terms; they should instead be used as a basis for discussions with the actors concerned to evaluate *ex post* or *ex ante* the adoption of innovations, or to evaluate changes in farm trajectories.

68.2. Appropriation of these simulation tools by the actors

The tools were mainly designed to test new production systems and to accompany farmers. However, they were also used to train technicians, project engineers and students. Thus, students of the Polytechnic University of Bobo-Dioulasso in Burkina Faso used Cikeda in their work. Olympe helped train the BV-Lac project team and students from local and French universities associated with the project.

However, these tools were not retained by the development partners (non-governmental organizations, producer organizations, etc.) when research support ended. Even though Cikeda was tested with technicians of the agriculture and animal resources ministries, the research effort was focused mainly on changes in knowledge and practices that the tool could help bring about within an approach for the co-design of innovations, and much less on the conditions of using the tool within advisory structures. Olympe was used, with the support of the research community, as part of another project (BVPI-SEHP[58]) in Madagascar between 2006 and 2013,

[58] Watersheds and irrigated perimeters in the southeast and the highlands.

based on four reference farm networks, but its use was discontinued when the projects ended, partly due to the structural weaknesses of Malagasy advisory organizations.

Indeed, advisory organizations in the countries of the Global South find it very difficult to appropriate these complex tools to support farmers within a framework of group advice (common in Africa) or of the individual monitoring of farms (common in Europe, the United States and Australia). In the case of Olympe, however, an experiment showed that its use for individual advice was easier and more relevant for large farms, even though these tools were not specially created for this type of farm. Cikeda has not been tested with farmer groups. However, in addition to this distinction between individual and group advice, the two experiments did not seek to evaluate the costs to advisory structures of using this type of tools, in terms of technician training, acquisition of computer hardware or reorganizations of the workflow of advisers.

Finally, two options are possible for the appropriation of these tools by non-research entities. We could assume and admit that the structure and use of the tools are project-specific. They depend on the context in which they are built, the nature of the innovations evaluated, as also the skills of the designers. Such an assumption implies that the tool could be discarded once the specific goals of the project have been met. This is the case in our two examples, as it appears that the tools were primarily designed to address specific research or project issues. Or we could wish for the tool to be more generally useful, beyond addressing the specific issues raised by researchers or the project, especially for advisory organizations or regional observatories – but such an intention would require the tools to be redesigned. An increased participation by development actors would be needed in the design of such a tool, so that, on the one hand, it is more adapted to the actors' need and, on the other, it may eventually be appropriated by these actors, by becoming part of the workflow of the organizations that are its intended users.

69. Conclusion: the use of simulation in the evaluation of innovation processes

Through two case studies, this chapter shows how the use of simulation tools can effectively contribute to the co-design and evaluation of innovations on farms. In Madagascar, the use of Olympe has allowed, by means of an *ex post* analysis, to put the real impact of the adoption of an innovation such as conservation agriculture into perspective, especially in terms of farm income. It has also demonstrated its medium- and long-term benefit, through an *ex ante* analysis, in terms of stabilization of farm income. The use of Cikeda in Burkina Faso allowed an *ex post* analysis of the performance of existing farms and an *ex ante* assessment of new modalities of crop-livestock integration. Its use also helped gauge its value as part of an approach to support these innovations with farmers. However, we want to emphasize that evaluations through simulation should always be combined with methods of qualitative evaluation of farm trajectories in order to better take into account the interactions between farms and their environment. It also appears important to undertake an improved analysis of the conditions conducive to the co-design of these tools with and their use by advisory organizations, in order to improve the advice they provide by incorporating the complexity of the farm.

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Spiral of innovation © Eric Vall

Afterword - What types of innovation for sustainable agriculture?

The food we eat and the way we produce it are signs of our relationship to the world, to spaces and to others. Any reflection on innovations in the agriculture and food sectors thus compels us to look at the links between these innovations and our relationship to the world. And herein lies the main strength of this book: agricultural and food innovations are apprehended through the societal debates of which they are part, be it debates on animal welfare, biodiversity preservation, or the access to a balanced diet for all.

There is no easy solution to the problem of feeding a growing population given our limited natural resources – some of which, such as copper and phosphate, are already relatively depleted. How can we feed an extra two billion people by 2050 without breaching the physical limits of our planet? As it is, 815 million people in the world are today suffering from hunger, according to the Food and Agriculture Organization. The availability of a healthy balanced diet for all is nowhere near ensured, especially given the brutal disruptions that climate change is bound to inflict on agriculture, starting with its impact on soil fertility. According to the latest IPCC (Intergovernmental Panel on Climate Change) report, wheat yields declined globally by just over 5% between 1980 and 2010 due to the first observable climate-driven disruptions. If unchecked, climate change is expected to reduce median agricultural yields by 2% every decade. And yet, to meet the world's growing demand for food, production needs to increase by 14% per decade. The news is no better on the biodiversity front: we are witnessing a vast migration of species, from the equator to the poles, from the plains to the mountaintops, with their move towards more favourable climes now averaging 6 km a year across the surface of the planet. A stroll for bipeds such as ourselves, but a momentous challenge for plant cover!

Agriculture is not only a source of income for 2.5 billion people and major consumer of natural resources such as water and phosphate, but also a victim of climate change and contributor to global warming (24% of greenhouse gas emissions are of agricultural origin, if we include land-use change). As such, the sector plays a decisive role in all the major transitions: ecological, of course, but also social and demographic, political, energy, and even digital. What is worse, agriculture mainly relies on the small peasantry that often survives close to the threshold of extreme poverty. The paradox now pervading our contemporary societies is that the social value given to work seems inversely proportional to the latter's contribution to the common good. In large cities, in the event of a global disaster, one of the jobs that needs to be ensured at all costs is not that of a footballer or business lawyer, but the work of the operators of sewage treatment plants. Without them, no city can survive beyond a few weeks. *Mutatis mutandis*, the same thing applies at a global scale: without the small farmers in the Mekong Delta or the Gulf of Guinea, the overwhelming majority of humanity would run out of food within a matter of months.

Agricultural and food innovation is therefore decisive for the transformation of our food systems and the transition of our economies towards societies that are carbon-neutral, fair, and resilient to the seemingly unavoidable collapse of natural ecosystems.

70. What technological avenues?

As the book notes, the choice of technological avenues to follow in order to ensure that agricultural and food innovations contribute to the ecological transition is a source of lively debate. Contentious arguments flow back and forth between the proponents of the technical intensification of agriculture, the promoters of ecological intensification, and the followers of agroecological practices, organic farming and peasant agriculture, among others. These debates reflect the different possible avenues towards sustainable agriculture that are open to us. They clearly represent real societal choices, as important as the choice of the energy mix that will characterize our economies in the 2030s.

Until the 1990s, the agricultural models advocated by the international donor community for the countries of the Global South were predominantly those of the Green Revolution. The trend was to standardize farming practices to increase yields, with farmers rarely being seen as vectors of innovation. However, the potential of the often-frugal peasant inventiveness is today gaining more recognition. On African cocoa farms, for example, chicken droppings are beginning to be used to maintain soil fertility and avoid the expense of synthetic fertilizers, which are greenhouse gas emitters. Farmer innovations can also be a source of inspiration for researchers working on the agroecological transition of African cocoa farming. In Cameroon and Côte d'Ivoire, we are witnessing the rediscovery or continued use of complex agroforestry systems in which the cocoa tree is associated with other perennial, forest and fruit species offering multiple uses. In Ghana, a simpler form of agroforestry is being used. Planted around the cocoa tree are orange trees, teak, or other species that combine three properties: income or income expectancy, a potential ecological service such as providing windbreaks, and better land demarcation.

Agricultural and food innovations take many forms and affect the entire value chain, from production to consumption. They can help bypass the productivist model of the Green Revolution and encourage an agriculture adapted to climate change and the biodiversity collapse already underway. The survival of agriculture in areas especially vulnerable to ecological disruptions depends on the implementation of technical innovations. This is the case, for example, in the Sahel, where increased rainfall variability can endanger the food security of populations whose demographic transition is not yet complete. The use of *zaï* (half-moon planting pits for microcatchment) could be extended to help maintain soil fertility, use rainwater runoff, and combat drought. Similarly, in a warmer future climate, some traditional varieties of cereal would actually be less vulnerable than 'improved' varieties thanks to their photoperiodic characteristics.

Digital advances and artificial intelligence are expanding the possibilities of innovation in sustainable agriculture across all of its three dimensions: social, environmental and economic. The collection of numerous data, whether through satellite imagery, sensors installed directly on farmers' plots, or via digital platforms, provides valuable information on the state of the soil, the weather, the availability of products, or the location of consumers. This opens countless opportunities for improved management across the sector, from production to distribution. The 2017 Digital Africa award, funded by the French Development Agency and the French Public Investment Bank, has rewarded two start-ups in the agricultural sector whose activities are firmly rooted in the new digital age. The first, e-Tumba, provides a data analysis solution for plots of land, simulating crop development, predicting yields,

and offering individual plot-level advice. The second, Farm Drive, has developed a risk analysis model of small farmers' activity using geographic, biological, and satellite imagery data. Multiple digital applications are now available for agricultural and food activities and often promote networking, as for example, the 'app' that connects retailers who have unsold products to consumers wanting to buy low-cost food.

Upstream of the agricultural sector itself, the Watex process for exploring deep aquifer sources, developed by engineer Alain Gachet, could help identify underground drinking water resources that have hitherto remained unexploited. In a world where the water cycle is already severely disrupted and will undoubtedly be more so tomorrow, the good news is that there is much more drinking water underground than on the planet's surface. But its reasoned exploitation presupposes a certain number of drastic conditions. First and most importantly, humanity must use the already available water far more judiciously. The losses, both in agriculture and in the end use of water for urban purposes, are colossal and the scope for progress is therefore huge. Second, the issue of recycling and waste-water treatment must become a priority, otherwise any additional influx of water to meet a growing demand could have disastrous health effects if the appropriate water infrastructure is lacking. Third, even if we discover the location of aquifer sources, we still need to be able to access them. Pumping water from a water table 400 metres deep requires infrastructure similar to the equipment enabling the oil industry to extract fossil hydrocarbons. The costs can be significant and must be calculated *ex ante*. Finally, we must acknowledge that this subsoil water is the last 'clean' water that humanity has. After all, we do not have another blue planet.

Yet, while technical innovation in the agriculture and food sectors is necessary to meet agricultural and food challenges, it can also pose a threat. The use of neonicotinoids in agriculture is a good example of this duality. Introduced in the 1990s to control crop pests, they have also proved destructive to pollinators. It has taken more than 20 years for the European Union to ban the use of three neonicotinoids for field crops, and this after numerous studies had shown how toxic these products are to bees. This example underscores how the quest for private short-term profit can trump the general good, since it is now clear that the corrupt campaigns of misinformation (also involving reputable scientists) that helped maintain a climate of collective doubt as to the toxicity of these insecticides were funded by industrialists with a vested interest in seeing the ban on these products delayed for as long as possible. Obviously, any evaluation of the impacts of an innovation cannot abide by the yardstick of the expected additional yield made possible by the innovation, and even less by that of the eventual additional income it may create.

71. Financial environment

Agricultural technical innovation and the possibilities opened up by digital technology are all well and good, but genuine creativity is essential for better sustainable agricultural management. In the area of financing, I can cite the example of the 'warrantage'[59] credit system, whereby a farmer is able to obtain a rural loan by

[59] *Warrantage*, a French word commonly used in West Africa, denotes the inventory credit system (normally called the warehouse receipt system, or WRS, in English).

putting up part of his production as collateral. Of course, this type of mechanism must be used with extreme caution given the risks it incurs to the said farmer if he is unable to repay the loan. The problems of moral hazard are legion in this domain, as they are in the area of microcredit in particular. The mismanagement of microcredit schemes has already led to tragedies, the numerous incidents of farmer suicides in India being one example among many.

But building a financial environment conducive to sustainable global agriculture also requires international regulation of the financial derivatives markets for agricultural commodities. As we know, the price of these basic commodities – on which not only the survival of small farmers but also the availability of food for all of humanity depends – is no longer determined in the short term by the balance between the supply and demand of agricultural products, but by capital flows into and out of derivative instruments that have these products as their underlying assets, in particular forward delivery contracts. The financial value of the derivative markets for such products is often several tens of times greater than the spot market value of the commodity itself. And the portfolio strategies that play out are mainly driven by speculative forces that are largely disconnected from the interests of farmers and consumers alike. The World Trade Organization is helpless in the face of this reality, as financial markets remain outside its ambit. It is thus crucially important to bolster the regulation of international financial derivatives markets for agricultural products. The same problem obviously applies to all derivative assets, most urgently to those whose underlying assets are energy products as vital as oil. The stark difference separating these two markets is that the oil sector has substantial lobbying power over financial regulators – the peasantry in the Global South does not.

72. Biodiversity and the commons

The impact of innovation on biodiversity, especially on common species, is often poorly understood. So-called ‘common’ biodiversity is often overlooked in assessing the impacts of technical innovations, even though it can fulfil important functions in the ecosystem or landscape. Common species thus play a vital role in maintaining all biodiversity, be it directly (trees that provide micro-habitats for insects and cavicolous fauna, for example) or indirectly (interactions of predation or pollination). This interdependence between species has been highlighted by the recent work of the French National Museum of Natural History and the French National Centre for Scientific Research (CNRS), which report the disappearance of one-third of bird populations in the French countryside in the space of 15 years.

How can the genetic heritage of flora and fauna be preserved? The genetic diversity of peasant seed and plant varieties is the result of individual and collective innovation over the long term. It promotes the resilience of animal and plant populations to changing ecological conditions. In Senegal, for instance, some farmers in the groundnut basin have recently reintroduced long-cycle millet varieties that were abandoned during the droughts of the 1970s in order to benefit from the current rains. But genetic diversity is being undermined by monocultures. A 2011 study published by the Foundation for Research on Biodiversity on indicators used to monitor the genetic diversity of cultivated plants highlights, for example, the genetic and spatial homogenization of a species widely cultivated in France: soft wheat. The Foundation is alarmed by the growing vulnerability of wheat crops in the face of current and future environmental changes (pathogens, droughts, sustainable agricultural practices, etc.). In the intensive agriculture model, farmers no longer

maintain plant genetic diversity in their fields. Even as we await the invention of models able to safeguard agricultural biodiversity more practically than the 'refrigerators' of research centres and the world-famous seed vault in Norway – which, in any case, are unable to preserve every agricultural species –, we urgently need to reflect on ways of safeguarding biodiversity in our fields.

One possible path forward would be to treat the genetic heritage of plants as a form of 'common' property around which one or more communities could be built to preserve this heritage. We have seen, for example, the formation of commons in some countries of the Global South for the conservation of peasant varieties that are absent from, yet complement, the selection of pure seeds found in national catalogues. More generally, managing natural resources as commons can constitute a third mode of appropriation, midway between privatization and nationalization, more likely to ensure that the planet remains hospitable to our human presence. Numerous such examples exist for water resources: in Jordan, Tunisia, Bolivia, and the Democratic Republic of Congo, communities have created and implemented their own rules for managing this resource, be it groundwater withdrawal or water access services. Agriculture and the food sector would certainly benefit from being viewed and organized as commons. As would money or work, for example. But such a transition would be a societal project of some proportion!

As for institutional innovation, the creation of the Associations for the Maintenance of Peasant Agriculture (Amap) in the 1990s in Europe has proved to be an unprecedented success. In France, according to the interregional Amap movement, 2,000 associations of this type were identified in 2015. Finally, innovations in the area of labelling also deserve mention, particularly the introduction in the 1990s of eco-labels, often referred to as 'voluntary sustainability standards', which rely on the willingness of some members of society to pay more in order to encourage others to adopt more sustainable production methods. In 2012, it was estimated that 40% of the traded coffee and 22% of cocoa were eco-labelled.

As the book emphasizes, a supportive institutional and legal environment is crucial to the emergence and dissemination of innovations in civil society and small enterprises. In this respect, support services for farmers play a key role. Contrary to what a proponent of libertarian thought might suggest, the State still has a major role to play in fostering the emergence of institutional innovations that enable humans to structure their relationship to the world they share with other living things. But, as the example of neonicotinoids reminds us, it is also up to the State to regulate the use of innovations that are detrimental to the collective interest – provided, of course, that the State manages to free itself from the regulatory 'prison' in which the private financialization of Global North societies sometimes keeps it confined.

In our era of the 'capitalocene', when the activities of the top decile of the most affluent humans (responsible for 50% of greenhouse gas emissions) contribute massively to the ongoing destruction of the terrestrial ecosystem, it is our responsibility to promote innovations that will facilitate the advent of ecological and social transitions to a more just and sustainable common world.

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