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Agroecology

Research for the transition of agri-food systems and territories

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Foreword

Over the past decade, many national and international entities have become enthusiastic proponents of agroecology. In 2012, the French Ministry of Agriculture launched the "Agroecological project for France". This mobilizing project for all of French agriculture is aimed to produce differently by rethinking agricultural production systems and by making them part of collective dynamics, especially through Economic and Environmental Interest Groups, i.e. groups of farmers sharing the same agroecological perspectives (GIEE)[1]. The French Economic, Social and Environmental Council (CESE) took up the issue of agroecology and weighed in with an opinion in 2016. The Food and Agriculture Organization of the United Nations (FAO) organized the first "International Symposium on Agroecology for Food Security and Nutrition" in 2014. It subsequently organized meetings by world region and shared conclusions of these meetings at a second symposium in April 2018, where it launched the "Scaling up Agroecology Initiative". At the same time, the French Agricultural Research Centre for International Development (CIRAD) and the French National Research Institute for Agriculture, Food and Environment (INRAE) highlighted their convergence of views on agroecology in a joint note[2]. All of this activity not only stimulated national and international research efforts, but also led to better articulation between societal initiatives and the research systems of the countries of the Global North and the Global South.

Launched in 2011, INRAE's "agroecology" project is providing a new impetus to research. Agroecology is thus considered as a scientific discipline in its own right, located at the interface between ecology and agronomy. This first project makes it possible to amplify a systemic and ecological vision of research on agroecosystems, considering them as ecosystems managed no longer for the sole purpose of agricultural production, but, more broadly, for the provision of ecosystem services. The objectives of preserving natural resources (water, soil, biodiversity) and cultural heritage (landscape), and mitigating climate change are added to that of producing biomass.

Five research priorities have been identified: knowledge and use of biological interactions in agroecosystems; agroecology of the landscape; multi-criteria assessment of agroecosystems that includes biodiversity and the provision of ecosystem services; sustainable management of soil and water resources as a mechanism for agroecology; and the design of new agricultural systems through the mobilization of human and social sciences.

In 2012, this work led to the production of an overview[3] as well as the drafting of recommendations for INRAE. In 2013, a conference was organized by INRAE, under the

1 See https://agriculture.gouv.fr/pres-de-10-000-agriculteurs-engages-dans-les-groupements-dinteret-economique-et-environnemental-giee.

2 Soussana J.-F., Côte F., 2016. *Agro-écologie : le positionnement des recherches de l'Inra et du Cirad*, 8 p. See https://www.cirad.fr/content/download/11293/132717/version/3/file/Agro-ecologie-Inra-CIRAD-note-longue.pdf.

3 See https://www6.inrae.fr/ciag/content/download/5608/42552/file/RevueIAvolume43.pdf.

aegis of the Ministry of Agriculture, bringing together researchers, decision makers and actors from the agricultural world. It was an occasion for exchanges and the insertion of agroecology into the agenda of the research community, of the agricultural world and, more generally, of civil society as a whole. The conference's deliberations were reported in the free online journal *Innovations agronomiques*[4].

The term "agroecology" soon started being increasingly used across INRAE – and in society in general – as a new paradigm for rethinking agroecosystems and agricultural activities. In 2014, the "New modelling challenges: agroecology"[5] seminar stimulated progress in the field of representation, prediction and management of agroecosystems. Since 2014, the EcoServ ("Services provided by ecosystems") metaprogramme has proposed an ecosystem approach to agroecosystems: agriculture is a provider of ecosystem services (and disservices) among which one seeks to leverage synergies and identify antagonisms. This holistic approach also improves agriculture by embracing a systemic vision. The AgriBio programme ("For and on organic farming"), launched in 2000, was supported by a specific research project in 2015. In 2019, it was adopted as an INRAE metaprogramme, Métabio "Scaling up organic farming". Organic farming is seen as a label based on agroecological principles. The study of the mechanisms that can amplify biological and ecological regulations in agroecosystems is now the basis of a new engineering discipline whose performance deserves to be assessed.

In 2016, with its "Inra2025"[6] orientation document, INRAE decided to intensify research in agroecology by choosing certain themes to study in depth and by widening the field of investigation, considering larger transformations, at the scales of agri-food chains and territories. Agroecology is not a simple or new way of seeing agronomy, but a redesign of agricultural production as part of a social process, with economic, sociological, food and environmental dimensions. This decision led to the launch by INRAE in 2017 of a forward-looking interdisciplinary discussion on the research necessary for agroecology, involving around 80 researchers and teacher-researchers.

This book presents the fruit of this collective reflection. The aim is to share this work and open it up to discussion internally, with our partners in the research community and the agricultural world, and with society at large.

The creation of INRAE as the result of the merger of INRA and IRSTEA in 2020, the expansion of skills, and the implementation of new interdisciplinary metaprogrammes and of "Territories of innovation" projects will help amplify research in agroecology, advance necessary knowledge frontiers, and put knowledge and co-construction at the heart of developments in agri-food chains and territories with the involvement of all actors.

Philippe Mauguin*, president and CEO, INRAE*

4 See https://www6.inrae.fr/ciag/Revue/Volumes-publies-en-2015/Volume-43-Mars-2015.
5 Garcia F., Gascuel-Odoux C., Soussana J.-F. (eds), 2014. *Colloque sur les nouveaux défis de la modélisation : l'agroécologie*, Synthèse, INRA, 49 p.
6 https://hal.archives-ouvertes.fr/hal-01607768/document

Introduction

Given the increasing world population, environmental and climatic challenges, and the growing scarcity of water and fossil fuel resources, an adaptation of, or even a complete break from, current agricultural production methods has become unavoidable. Agricultural systems will henceforth have to be designed not only to produce agricultural goods, but also to provide other ecosystem services. To this end, agricultural actors will need support from the research community and appropriate training.

In industrialized temperate-zone countries, improvements in productivity of agriculture and its economic competitiveness since the 1950s have been made possible by a modernization process which has resulted in specialization of production systems, expansion of farms and increased reliance on synthetic inputs, agricultural machinery, and plant varieties and animal breeds with high productive potential. The specialization of systems and the alteration and homogenization of environments have made economies of scale possible, both in terms of production and agri-food processing to more standardized food products that better meet the needs of processing sectors and agri-food industries.

During this period, the agricultural sector organized itself by creating frames of reference and advisory structures. Natural environments were considered to be largely abiotic and homogenized through land consolidation and drainage, while agriculture-friendly biotic interactions in the soil and ecosystems were ignored. Advice provided to farms was aimed to optimize production. Agriculture became industrialized. This industrialization generated externalities considered to be positive ("sanitized" environments, without pests and with high productivity), but also negative externalities (soil, water, and air pollution; greenhouse gas emissions; biodiversity loss), whose consequences have led to crucial questions being asked in recent decades. The conclusions by IPBES[7] in its global assessment of biodiversity and ecosystem services are clear: through changes in land use and the use of inputs, agriculture, including animal production, is one of the main drivers of biodiversity loss (IPBES, 2019).

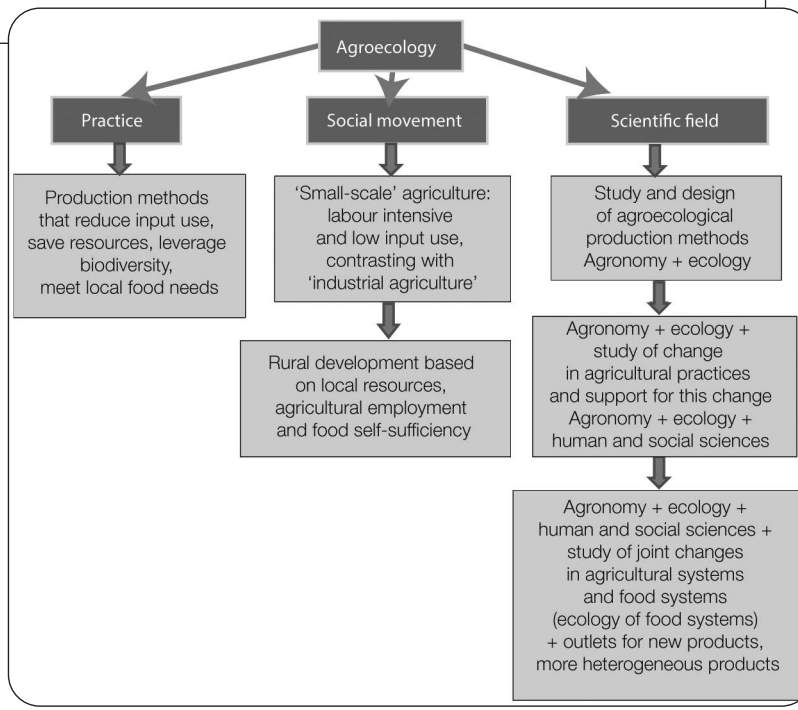
A better compromise between agriculture and the environment has been sought by improving the efficiency of inputs, decreasing discharges of waste into the environment, and even completely redesigning agricultural systems. Several movements (organic farming, conservation agriculture, and eco-farming at the international level; "reasoned" agriculture, high environmental performance agriculture in France, etc.) have proposed terms and advocated concepts to better combine and reconcile the economic, social, environmental and health performances of agriculture. Agroecology appears, including in this context of industrialized countries, as the essential, inclusive and principled way to contribute to the development of sustainable and resilient agriculture.

7 Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services.

Founding principles

Agroecology is at the same time a scientific field, a practice and a social movement (Wezel *et al.*, 2009), as shown in Figure 1. Various definitions of agroecology have been developed, associating ecology to varying degrees with other disciplines (agronomy, genetics, sociology, etc.) or with local or traditional knowledge, in pursuit of the sustainability of production or food systems and the preservation and use of biodiversity (Wezel *et al.*, 2018). Interdisciplinarity, the interaction between disciplines, and transdisciplinarity, the interaction between the research community and society, are both key aspects of agroecology.

Figure 1. Agroecology is at the same time a practice, a social movement and a scientific field (based on Wezel *et al.*, 2009).



One objective: leveraging biological processes

Agroecology is above all a new paradigm that aims to leverage biological processes to meet expectations for agrosystems: agricultural production, of course, but also ecosystem services (protecting resources, mitigating climate change, preserving habitats and cultural heritage). A corollary is to consider agroecology as an aim so that, through agricultural systems and adopted practices, agrosystems integrate the ecological functions that

guarantee their own sustainability, especially in terms of replenishing nutrient stocks and maintaining productive potential.

From this first paradigm stems a second: leveraging biological processes means accepting and accounting for increased diversity in agroecosystems, which leads to a greater diversity of agricultural products as well as a greater heterogeneity of each product that will have to be processed and included in food products, even in new diets.

This definition makes it possible to clarify what is expected from the research community. Thus, under the terms "smart agriculture" or "sustainable agriculture", there exists a body of mainly technologically oriented studies on the best possible use of resources. This model of agriculture corresponds to "weak" agroecology, which maintains continuity with current systems, neither advocating for a qualitative leap in the efficiency of the use of inputs, nor explicitly calling to replace them with biological processes (Duru *et al.*, 2014). Weak agroecology contrasts with "strong" agroecology, defined by its pursuit of consistency and sustainability and by the mobilization of biological processes (Duru *et al.*, 2014). This strong agroecology requires in-depth transformation of agricultural production systems. It is this more comprehensive agroecology that is INRAE's goal, because getting there will require a significant commitment to research, as all agricultural production is concerned and all academic disciplines are involved. This should not be seen as a desire to oppose what currently exists, but should be perceived for what it is: an ambition to rethink the mobilization of biological processes at all levels (species, breed/variety, animal and plant physiology, feed and fertility, animal production methods and cropping practices, future of products and co-products, connections to resources, to forms of energy, to soil and water, location, etc.).

Towards the redesign of cropping systems

The desire to "leverage biological processes", the underlying principle of building agroecological systems, usually requires redesigning cropping systems, involving changes in, for example, rotations, genotypes used or agricultural practices adopted, articulations between plant and animal production, connections to distribution methods and consumption patterns, organization of landscapes, etc. The field of agroecology is not restricted to plant production alone; indeed, animal production is a major pillar of biological processes given its complementarities with plant production. The monitoring of processes and flows maintained in a dynamic balance from the field to the landscape, which allows for the exploitation and reconstitution of organic and mineral stocks and the development of soil life, lies at the heart of this redesign. Strong agroecology therefore involves going beyond the mere optimization of agricultural systems.

From a very integrative viewpoint, agroecology cannot develop without a demand from society, consistent with the needs of food consumption and their organization into agri-food chains and territories. Some authors therefore incorporate the dimension of food systems into agroecology (Francis *et al.*, 2003; Gliessman, 2006). The in-depth redesign

of agroecosystems, and that of agri-food chains and their organization into territories, in line with consumption needs, is an adaptive process that is built while moving forward along a trajectory that cannot be mapped in advance: the transition phase itself therefore becomes a subject of research.

This redesign is based on using principles of ecology. One motivation is to strengthen the resilience of agroecosystems, defined as their ability to adapt to disturbances or to return to equilibrium in a changing context. In the face of uncertainties arising from climate change, societal changes and the volatility of agricultural and food prices, the biological diversity of agroecosystems can constitute a factor of resilience that helps dampen the effects of disturbances. The vulnerability of agrosystems, at one time compensated for by short-term uses of inputs, is now assessed through their resilience and a greater stability of production types whose biological diversity is a key factor.

Figure 2. The trajectory of agricultural systems: from a specialization phase to a redesign of diversified systems based on the principles of agroecology (based on Tittonell, 2014).

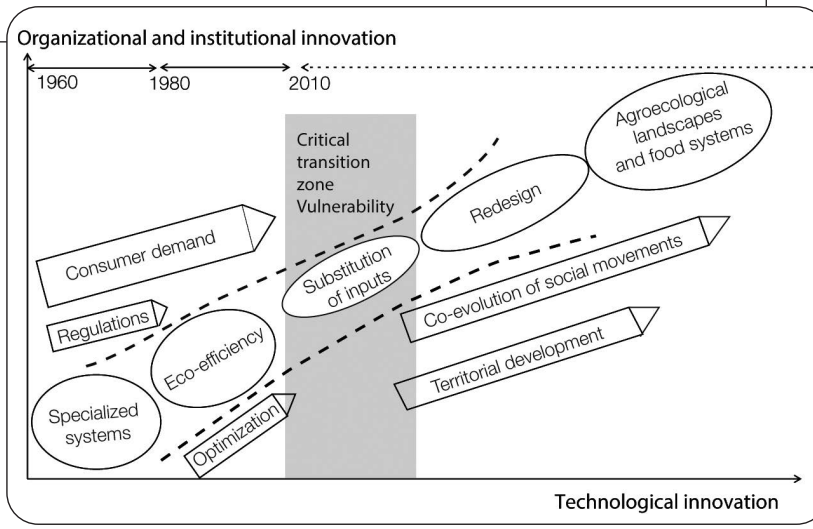


Figure 2 illustrates the fact that, in past decades, agricultural systems became specialized and were optimized according to eco-efficiency principles. The agroecological transition, which aims to replace inputs with biological processes, makes agricultural systems temporarily more vulnerable but eventually leads to more diverse systems, better adapted to environments and societal expectations, more resilient, and based on ecological principles.

Agroecology rubs shoulders with the concept of the circular economy, in the sense that both are part of the framework of sustainable development. Furthermore, they are both

inspired in particular by the concepts of the green economy, collaborative economy, and even industrial ecology, based on recycling, while closing biogeochemical cycles as much as possible and avoiding the "waste" stage, thereby decreasing the consumption of raw materials and energy. Agroecology shares with the bioeconomy the goal of replacing the use of non-renewable resources and products of fossil origin with their partial recycling and with the processing of renewable resources (photosynthesis, soil biology) into food, organic fertilisers, materials, chemical bases and various forms of bioenergy. While agroecology shares with the circular economy and bioeconomy the goal of a sustainable agriculture that uses resources frugally, it distinguishes itself by the central role it accords to deriving value from the diversity of living organisms.

National and international societal expectations

The field of agroecology has experienced significant growth since the 2000s, with the pursuit of a coexistence of several visions, whether in academic terms, research methods or practices. This is why its scope and definition remain unclear. It is not an end in itself; instead, it embodies principles to support transitions that put ecological processes at the heart of the design and management of agroecosystems. Agroecology is part of a promising national and international societal context, as illustrated by the following two examples.

The French government's Agroecology Project

The Agroecology Project of the French Ministry of Agriculture was designed to encourage production methods that have high economic and environmental performance, and to promote a joint approach to the different dimensions of farms and, even further, those of agri-food chains and territories. Its aim is to produce differently by rethinking production systems. While this implies changing agricultural practices, it also represents another way of thinking, a gradual and profound change that emphasizes the systemic dimension of agricultural activity, across large spatial scales and over long periods. It now constitutes a mobilizing framework for French agriculture to rethink agricultural training and advice. As the first article of the Rural Code has emphasized since adoption of the law on the future of agriculture, food, and forestry of 13 October 2014, "public policies aim to promote and sustain agroecological production systems, including organic production methods, which combine high economic and social performance, in particular through a high level of social, environmental and health protections. These systems focus on improving farm competitiveness while maintaining or improving economic profitability".

The French Economic, Social and Environmental Council (CESE), as a multi-actor and social expression organization, has this to say about agroecology: "A scientific discipline at the crossroads of agronomy and ecology, agroecology can, through the practices that it promotes, help meet environmental and socio-economic challenges by transforming

agriculture to move towards more sustainable food systems. Based on analysis of the obstacles to and mechanisms for its development, the CESE has formulated a set of recommendations concerning research, training, adaptation of agri-food chains, and reorientation of public policies to support farmers in the agroecological transition" (Claveirole, 2016).

FAO: priorities for agroecology

In 2014, the Food and Agriculture Organization of the United Nations (FAO) organized the first International Symposium on Agroecology for Food Security and Nutrition[8] with the intention of promoting agroecological systems at the international level. It was an opportunity to share experiences and put together an agroecology knowledge base, and it helped build a consensus on priorities for agroecology. Above all, it validated FAO's role in the implementation and promotion of agroecological approaches. The farmers of countries in the Global South had already expressed interest in such approaches for a long time, seeing them as an alternative to the dominant and intensive production systems because they led to lower dependence on inputs, higher productivity due to plant associations that used soil resources better, and lower sensitivity to pests. The 2014 symposium showed that agroecology can also be a way of rethinking agricultural systems in both developing and industrialized countries. The FAO later organized meetings by world region, including one for Europe, the conclusions of which were shared at a second symposium, in April 2018. The "Scaling Up Agroecology Initiative" was launched on this occasion[9]. This initiative has the goal of encouraging a process of transition of agricultural and food systems to a more inclusive and holistic agroecology by using knowledge-sharing tools, in particular by establishing an agroecology knowledge platform[10]. Criteria for characterizing agroecological systems were defined, and methodological work to analyse their performance is in progress.

Research based on new paradigms and new approaches

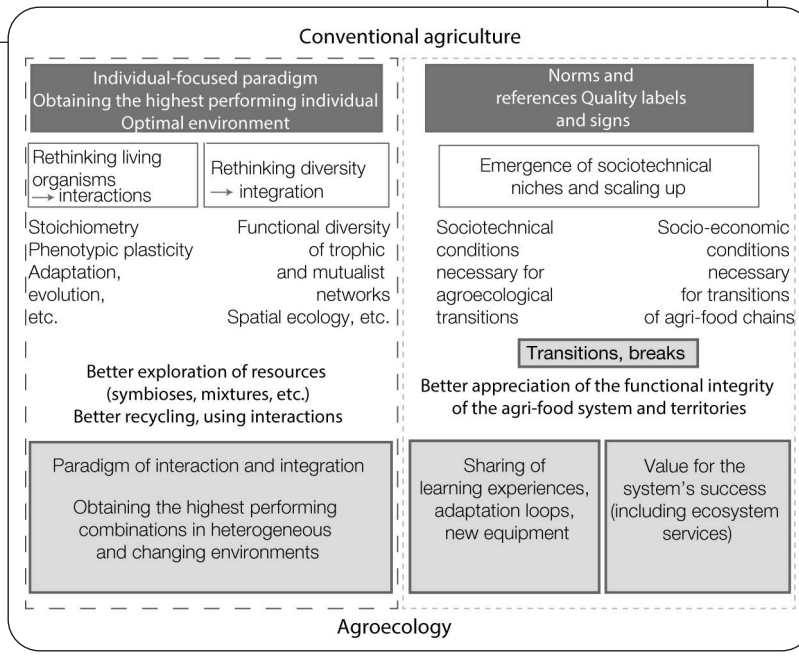
Figure 3 illustrates the research objectives and fields involved in moving from conventional systems to agroecology-based systems.

Agroecology's first ambition is a paradigm change, moving from a paradigm based on the "ideal individual", which aims to obtain the animal or plant individual with the highest performance in an environment made optimal and which underpins current agricultural systems, to a new paradigm based on "ideal interactions between individuals and their integration into ecosystems", whether at the field or landscape scale. The underlying

8 See http://www.fao.org/3/a-i4327e.pdf.
9 See http://www.fao.org/3/I9049EN/i9049en.pdf.
10 See http://www.fao.org/agroecology/home/en/.

assumption is that a diversity of individuals, varieties/breeds or species will be better adapted to heterogeneous and changing environments due to the continuous interactions between them. Their arrangements in time and space may also prove to be more efficient, because they are not only more seek out water and mineral resources better, but are also more resilient to disturbances because of their very diversity. The research community thus has reason to focus on functional properties, which provide ecosystem functions and services (supply of biomass; regulation of the water cycle, soil, and climate; landscape resources; etc.).

Figure 3. The challenges and paradigms of conventional agriculture (dark grey boxes) and of agroecology (light grey boxes).



This new paradigm draws on concepts from ecology, in particular functional ecology, which must be adapted to be useful for agroecosystems:

• stoichiometry is defined as the proportions of chemical elements, most often carbon, nitrogen and phosphorus, in organisms with trophic links. Applied to ecology, stoichiometry studies the propagation of these proportions due to a chain of reactions related to the needs of plants, the functioning of soils, and even transfers in catchments and aquatic ecosystems. Plant and animal associations can draw the most benefits from these proportions, create synergies between availability and various needs, and introduce adapted recycled resources.