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Insight on France-CGIAR research

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AGROPOLIS INTERNATIONAL

Based in Occitanie (France), Agropolis International is a nonprofit organization that brings together an exceptional array of institutes and organizations involved in agriculture, food, environment and biodiversity. This crossroads of knowledge and expertise was founded in 1986 by research institutes and higher education establishments with support from national, regional and local authorities. Agropolis International has always been a dedicated collective workspace, providing links between different collaborators in target areas:

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- International research agencies
- Regional and local authorities
- Civil society organizations.

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For further information: www.cirad.fr/en

CGIAR

CGIAR is a global research partnership for a food-secure future. CGIAR science is dedicated to transforming food, land, and water systems in a climate crisis. Its research is carried out by 14 CGIAR Research Centers in close collaboration with hundreds of partners, including national and regional research institutes, civil society organizations, academia, development organizations and the private sector.

The 14 CGIAR Research Centers are AfricaRice, Alliance of Bioversity International-CIAT, CIFOR, CIMMYT, CIP, ICARDA, ICRAF, ICRISAT, IFPRI, IITA, ILRI, IRRI, IWMI, and WorldFish.

For further information: www.cgiar.org

CGIAR's new 2030 Research and Innovation Strategy:
https://cgspace.cgiar.org/bitstream/handle/10568/110918/OneCGIAR-Strategy.pdf

INRAE

Created on January 1, 2020, the French National Research Institute for Agriculture, Food, and Environment is a major player in research and innovation. INRAE—the result of the merger of INRA and IRSTEA—carries out targeted research. It is a community of 12,000 people with 268 research, experimental research, and support units located in 18 regional centers throughout France. Internationally, INRAE is among the top research organizations in the agricultural and food sciences, plant and animal sciences, as well as in ecology and environmental science. It is the world's leading research organization specializing in agriculture, food and the environment. INRAE's goal is to be a key player in the transitions necessary to address major global challenges. Faced with a growing world population, climate change, resource scarcity, and declining biodiversity, the institute is developing solutions that involve multiperformance agriculture, high-quality food, and the sustainable management of resources and ecosystems.

For further information: www.inrae.fr/en

IRD

French National Research Institute for Sustainable Development, a major player in sustainability science

IRD is a French public research establishment that supports an original approach to research, expertise, training and knowledge-sharing for the benefit of southern countries and regions, making science and innovation key drivers in their development. IRD sets its priorities in line with the Sustainable Development Goals (SDGs) adopted by the United Nations in September 2015, to steer development policies. Combining critical analysis for the implementation of these goals, IRD seeks to tackle the challenges facing us today: global, environmental, economic, social and cultural changes that affect the whole planet.

For further information: https://en.ird.fr

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Editorial

It is usual for the President of Agropolis International to write the editorial introducing each Dossier. In this particular case, given the theme, I have the pleasure and honor to also sign this one as a Member of the One CGIAR Board. In the year when the United Nations is organizing a Food System Summit and on the eve of a major reform of CGIAR to become One CGIAR, which aims to strengthen the capacity of this leading global organization to more effectively address the challenges in meeting the Sustainable Development Goals, I am delighted to unveil this *Dossier* devoted entirely to research and partnerships in agroecology. What a superb initiative—I congratulate all those who spearheaded it! This I believe offers a key pathway to enhance the sustainability of our food systems. We had already recognized this when, at the High Level Panel of Experts on Food Security and Nutrition (HLPE) of the UN Committee on World Food Security, which I had the honor of chairing at the time, we published the 'Agroecological and other innovative approaches for sustainable agriculture and food systems that enhance food security and nutrition' report in 2019. These approaches are essential for the future of the planet, and agroecology is one of the three priorities—along with climate change and sustainable food systems—of the Action Plan signed by the French government and One CGIAR, represented by Marco Ferroni, President of its Board, on February 4, 2021.

I am impressed by the quality and number of contributions from researchers affiliated with both French and CGIAR institutions, often in collaboration, that shape the three parts of this pivotal document. I also applaud many contributions of authors from some 70 partner institutions and organizations, thereby illustrating the high commitment of all actors from the scientific community and beyond to agroecology research. This confirms the extent to which agroecology is now a key focus for hundreds of researchers, government representatives, development service agents, professional agricultural organizations and the associative community on all continents worldwide. This also demonstrates the potential for bringing together farmers' practices and scientific outcome to generate unique and relevant knowledge and design relevant solutions to address challenges at different scales.

The pages that follow showcase the broad and diverse scope of research carried out in the field, territories and policy sphere, while also underlining how much remains to be done—together I hope!

Patrick Caron
President of Agropolis International
Member of the One CGIAR Board

Foreword

We are pleased to preface this *Dossier* - a wide-ranging and comprehensive compendium of knowledge on agroecology. We trust that it will represent a milestone in this research field, which has to actively contribute to the transition towards sustainable food systems that we are striving to achieve.

The insight showcased in this Dossier illustrates agroecology principles from a scientific standpoint. It highlights the dynamics sparked by this concept internationally, and particularly in France where agricultural research and higher education institutions have invested in this line of research. These dynamics are underpinned by ministries for which agroecology is viewed as a vital lever for action to meet the food security and resource conservation challenges emerging in the wake of climate change.

Agroecology is fostered in France via the 2014 *Loi d'avenir*, and in Europe in discussions focused on the Common Agricultural Policy (CAP) and the Green Deal. At the international level, through its policy and cooperation instruments, France is supporting this trend, alongside its partners, particularly within the three Rome-based agencies (FAO, WFP, IFAD) and the Committee on World Food Security (CFS), as well as in the framework of development projects such as the Great Green Wall Accelerator for the Sahel. Yet the dialogue under way at these different levels reveals that our partners are not always aware of the scientific scope of agroecology.

The collaboration between our research organizations and CGIAR was therefore particularly welcomed in view of clarifying the scientific foundations and issues underlying the agroecology concept. We would like to thank all scientists who contributed to this project and we are pleased that their collective research contributions can now be readily shared through the present *Dossier*.

This publication is an outcome of the Action Plan between CGIAR and France, which is honored to host the headquarters of this international organization in Montpellier, at the epicenter of one of the most significant concentrations of agricultural research and educational institutions, including CIRAD, IRD, and INRAE, which have long been associated with CGIAR. We hope that this anchorage will strengthen partnerships between CGIAR and French agricultural research bodies to help meet sustainable development challenges together. In this light, France commends the far-reaching reform of One CGIAR and the emphasis placed on systems approaches such as agroecology, while looking forward to pursuing a rich and stimulating dialogue that will in turn benefit the international community.

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Today, it is more important than ever that our food, land, and water systems are equipped to cope effectively with environmental threats such as climate change, land degradation, loss of biodiversity, and depletion and contamination of water and soil resources. This requires a transformation of those systems. But we must take care that system transformation—yet another intervention by humans—does not cause irreversible damage to our planet, drive unhealthy diets, or exacerbate social and economic inequalities. Agricultural research for development and innovation must be reoriented to account for the myriad of linkages between agriculture, the food system, and our water and land systems. The complex, interlinked nature of the challenges demands that agricultural research responds with equally interlinked, whole-of-system solutions, such food system interventions that target all pieces of the puzzle from agricultural production to consumer behaviour. Food systems that sustain the planet, land and water systems that sustain food production, a food system environment that feeds and nourishes people, and people benefiting *equitably* from resilient food, land, and water systems—these are universal goals. We believe that we have a unique opportunity now to unite efforts across multiple food, land, and water systems and sectors to get us closer to meeting those goals.

The CGIAR 2030 Research and Innovation Strategy responds to this demand for a systems transformation approach to food, land, and water systems with an ambitious research agenda that uses science-based innovation to drive advances across multiple scales, from genetic innovation in the laboratory to production in the fields to the complex web of policy and agreements at system level, and across five impact areas, namely (i) Nutrition, health, and food security; (ii) Poverty reduction, livelihoods, and jobs; (iii) Gender equality, youth, and social inclusion; (iv) Climate adaptation and mitigation; and (v) Environmental health and biodiversity.

A systems transformation approach for food, land, and water systems requires leaning towards embracing circularity in the use of natural resources, boosting environmental and ecosystem health in step with productivity, diversifying agricultural and food systems, and supporting healthy human diets. These improvements must go hand in hand with more equitable benefits sharing for men, women, and young people, respect for the plurality of cultures and values served by these systems, and a greater degree of co-creation of knowledge with our partners. These principles, which will be fully integrated into the various solutions investigated by our agricultural research systems, align with the principles of agroecology, which call for a redesign of our food, land, and water systems from farm to table to simultaneously achieve ecological, economic, and social sustainability.

This publication highlights the multidisciplinary expertise and global partnerships network of the CGIAR and French research organizations used to conduct research into the process of transforming agricultural and food systems with the aim of equipping them to embrace critical agroecological principles in different contexts. The publication also reflects the enormous opportunity ahead to integrate more of these different disciplines when conducting the transdisciplinary research needed to respond to the challenges facing our food, land, and water systems now, in the 21st century.

Claudia Sadoff
Executive Management Team Convener
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summary

Overview

This Agropolis International *Dossier* N° 26 is part of a series of special partnership issues, like N° 15, which reviews 10 years of activities of the LABEX-Europe 'laboratory without walls' program of the *Empresa Brasileira de Pesquisa Agropecuária* (EMBRAPA), and N° 22 on family farming in Argentina, Brazil and France (2016). It illustrates the dynamic research and extent of expertise on agroecological transitions that abounds in French research institutions and CGIAR, in collaboration with many partners worldwide.

This initiative is under way within the framework of the Action Plan signed by CGIAR and the French government on February 4th 2021 to strengthen French collaboration with CGIAR, where agroecology is highlighted as one the three key priorities (alongside climate change, nutrition and food systems). Agroecology has been a priority in France since the 2014 *Loi d'avenir sur l'agriculture, l'alimentation et la forêt*, in Europe within the framework of the Green Deal (especially the Farm to Fork Strategy), with the building a European partnership on agroecology, and under France's international development policy geared towards the Global South. In recent decades, CGIAR has conducted research for development together with its partners in the Global South on many aspects related to agroecology, from more sustainable agricultural practices to more inclusive business models, and recently on responsible food consumption strategies.

The Editorial Board members also put forward the relevance of this initiative in the light of the current CGIAR reform process towards a unified 'One CGIAR' with a view to mainstreaming and focusing its research forces and partnerships on achieving the SDGs, while specifically targeting the five Impact Areas identified in the CGIAR 2030 Research and Innovation Strategy document published in late 2020: (i) Nutrition, health and food security; (ii) Poverty reduction, livelihoods and jobs; (iii) Gender equality, youth and social inclusion; (iv) Climate adaptation and mitigation; and (v) Environmental health and biodiversity. The aim is to link these different elements in a holistic and transformative approach to food systems, beyond the usual focus of CGIAR research teams on agricultural production.

According to the Food and Agriculture Organization of the United Nations (FAO), "**agroecology** is an integrated approach which simultaneously applies ecological and social concepts and principles to the design and management of food and agricultural systems. Agroecology aims to optimize the interactions between plants, animals, humans and the environment while taking into account the social aspects that must be addressed for a sustainable and equitable food system."[1] The agroecological transition aims to harness nature's goods and services whilst minimizing adverse environmental impacts, and to improve farmer-consumer connectivity, knowledge co-creation and inclusive relationships among food system actors.

The urgency of the agroecological transformation of agricultural and food systems linked to SDGs is one of the game changing solutions to be discussed at the **UN Food Systems Summit** this year. Moreover, addressing agricultural and food systems will also contribute to the **2030 Agendas** being prepared in 2021 on climate (UNFCCC COP 26*), land (UNCCD COP 15*) and biodiversity (CBD COP 15*). Clearly the diversity of agriculture and food systems on this planet heralds the way to a variety of agroecological transition pathways (different baselines, input usage levels, socioeconomic contexts and particularly different labor costs and availability in agriculture, different value chain arrangements, levels of connection between farmers and consumers, and consumer preferences in food systems), and also diversity in terms of public action needed (subsidy levels that could be reoriented to incentivize change, implementation of policies from different sectors, research and extension, etc.). However, there are also communalities in terms of understanding the biology, ecology and socioeconomics of farming agroecosystems and their functioning, and how to manage risks, including those triggered by climate change, how they contribute to food system functioning.

Lessons are to be learned from past trajectories in the Global North and other parts of the world. Such insight could help avoid the simplification levied by conventional agricultural models, while shedding light on pitfalls to elude when considering socioeconomic power asymmetries and developing inclusive cooperative systems.

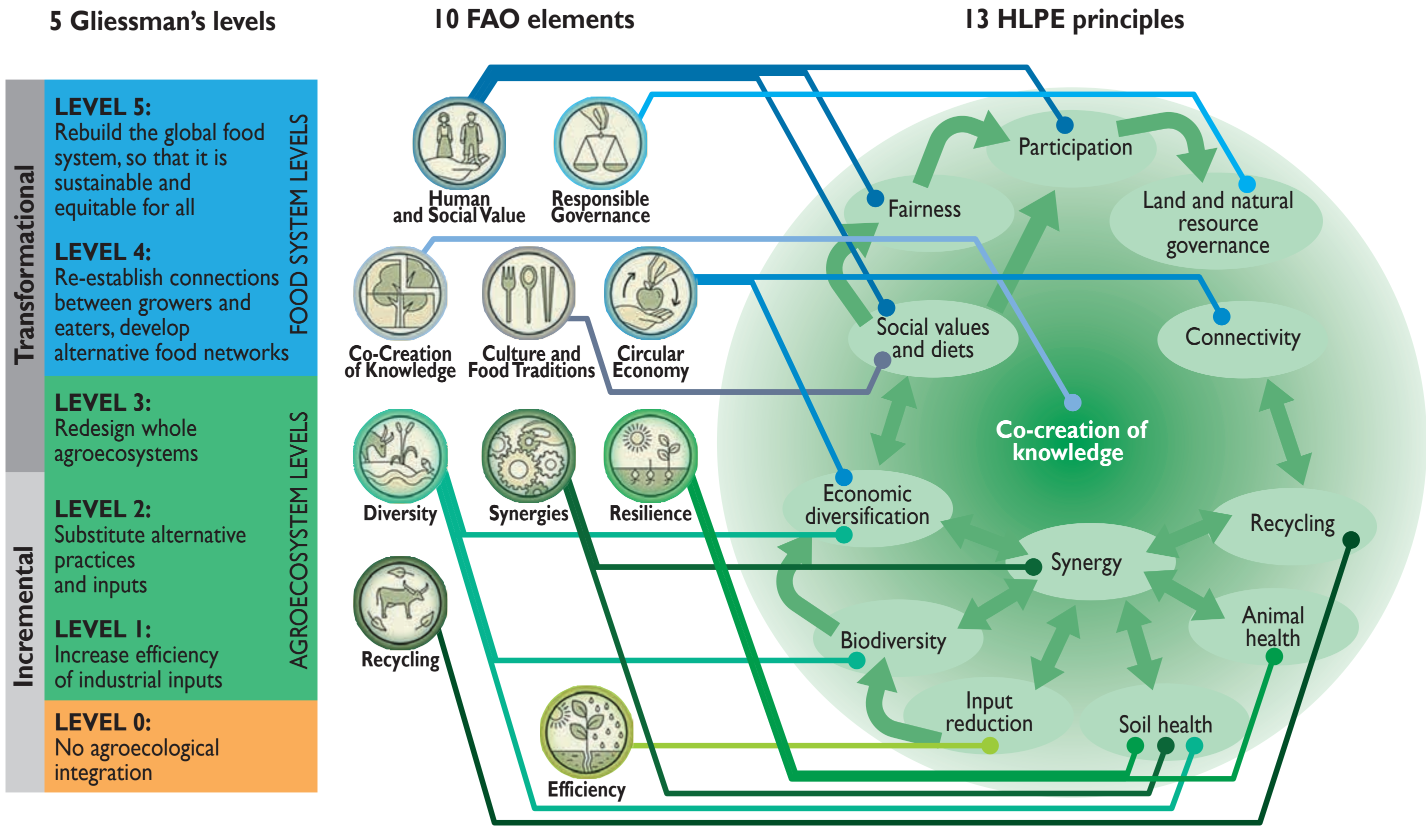
These transformations need to be **closely tuned to the initial contexts, which vary considerably between regions and countries**. Agroecological transformation cannot be a 'one size fits all' endeavor. Indeed, in some parts of the world where inorganic input and pesticide use is generally low and sometimes nonexistent, and where available water is in very short supply, the priority is often focused on increasing access and usage of these inputs to boost production and productivity. Agroecology is relevant, even under these conditions, and can provide solutions while minimizing environmental impacts. Any decisions to increase such input use must strive to strike a balance between short-term productivity gains and longer-term resilience, environmental health and sustainability gains. The linkage between sustainable intensification and agroecological transformation emerges here as a point of analysis.

These issues have led researchers from CGIAR and French research organizations to work together in compiling this *Dossier* to **showcase their expertise and research advances at the disposal of other researchers, policymakers, extension services, NGOs and farmers' associations** committed to promoting the agroecological transition. This transition process requires commitment to explore and support new ways of conducting research based on systemic and transdisciplinary approaches, implementing inclusive participatory methods, the solution-based theory of change, fostering partnerships with national agricultural research systems, while **enhancing orchestration of research, policy and investment efforts to converge towards sustainable and resilient food systems!**

We clearly highlight research conducted on the basis of these premises in this *Dossier*. The research outputs showcased have been achieved through recent research programs and projects geared towards the design and implementation of genuinely sustainable food systems, i.e. equitable for both producers and consumers in different parts of the world. To reflect this, we have drawn on the different food system transformation levels identified by Stephen Gliessman (2016). These are intersected with FAO's 10 elements for agroecology and the 13 principles outlined in the report of the High Level Panel of Experts on Food Security and Nutrition (HLPE) on agroecological and other innovative approaches for sustainable agriculture and food systems that enhance food security and nutrition (2019).

* CBD: Convention on Biological Diversity
COP: Conference of the Parties
UNCCD: United Nations Convention to Combat Desertification
UNFCC: United Nations Framework Convention on Climate Change

1. FAO. The 10 elements of agroecology guiding the transition to sustainable food and agricultural systems, http://www.fao.org/3/I9037EN/i9037en.pdf



▲ *Linking FAO's 10 elements, Gliessmann's 5 levels of food system transformation and the 13 HLPE principles*
Correspondence based on Wezel et al.*, 2020. Agroecological principles and elements and their implications for transitioning to sustainable food systems. A review.* Agronomy for Sustainable Development*, (2020) 40: 40.*

This *Dossier* is organized in two main parts, i.e. Agroecosystems and Food Systems, while adopting the organization levels proposed by Gliessman, as well as a third part that showcases the results of cross-cutting and more methodologically-oriented research.

Part 1 - Agroecosystems

1 - Increasing the efficiency of practices in order to reduce the use of costly, scarce or environmentally damaging inputs

This chapter deals with Gliessman's first transformation level which aims to increase the efficiency of inputs and natural resources. It presents results of research conducted in many countries geared towards improving resource use efficiency (soil, water), while reducing chemical input reliance and the environmental footprint of production systems and postharvest treatments. Research on complex processes (nutrient cycles, interactions between soil organisms, crop protection), as well as the added benefits of participatory research approaches in varietal selection and breeding programs are discussed. The chapter also illustrates the 'co-creation of knowledge' principle.

2 - Substituting intensive external input use by biodiversity-derived ecosystem functions

This chapter focuses on increasing crop performance by strengthening ecosystem functions driven by the agrobiodiversity. This so-called ecological intensification process enhances biomass production by improving nutrient and water cycles and combating pests and diseases, while keeping external input use to the bare minimum. It relates to Gliessman's second transformation level, and essentially concerns cropping systems.

3 - Redesigning agroecosystems on the basis of a new set of ecological processes from farm and landscape

This chapter focuses on the redesign, implementation and management of agroecosystems that differ from current systems. This redesign process may represent a real break with the past while being geared towards long-term change. Although often having a specific focus (less dependence on pesticides and water, work and wellbeing, adaptation to climate change, landscape quality and biodiversity preservation, etc.), it also strives to reconsider all agroecosystem functions and services, and their sustainability and resilience in response to the highly variable nature of external constraints (climate, prices, etc.). This redesign process may take place on the farm or in the landscape, within the scope of collective management or within a broader territorial project involving non-farmer stakeholders.

Part 2 - Food systems

4 - Identifying and overcoming constraints within food systems to achieve agroecological transitions at scale – reconnecting producers and consumers

The development, implementation and scaling of agroecological practices requires an appropriate enabling environment, while overcoming structural constraints that lock farmers into conventional agricultural improvement models, thereby necessitating fundamental shifts in the way food systems are organized and function. This chapter addresses the issue of identifying and surmounting constraints within agricultural, food and land systems to achieve agroecological transitions at scale. Five main issues are tackled: (i) the economic environment linked to value chains, markets and regulations; (ii) the innovation environment; (iii) the role of markets in re-establishing a more direct connection between producers and consumers; (iv) leveraging nutrition objectives and food traditions for agroecology; and (v) designing territorial food systems.

5 - Building a new global food system based on equity, participation, democracy and justice

This chapter focuses on far-reaching transformations in value chains, business models and funding sources, and in the socioeconomic dynamics in territories, as a result of agroecological approaches applied in a diverse range of specific situations with different food system actors. These transformations result in changes in the terms of interaction between agricultural and food system actors that are conducive to more environment-friendly and equitable systems, to the mutual benefit of producers and consumers.

Part 3 - Key processes, methods and tools for agroecology

This crosscutting part illustrates how France and CGIAR are working to provide essential agricultural and ecological knowledge, as well as research methods and tools for initiating the transformation of current schemes into agroecology-oriented systems, value chains and territories. These span different spatial scales, and cover human and social sciences as well as ecology and biotechnology. Research carried out within institutions (national or international) and research infrastructures—often in a transdisciplinary way, with the participation of stakeholders, as well as local or national social initiatives that foster the agrifood system transition process—is showcased.

Some 500 French and CGIAR agroecology scientists and experts from around 100 national and international universities and research organizations from France (among others CIRAD, INRAE and IRD) and abroad, and all CGIAR Centers, were involved in this *Dossier*.

This Dossier is not meant to be exhaustive and other outstanding publications could have been mentioned, as for example the 'Handbook for the evaluation of agroecology' published in 2019 by collective of French NGOs*; the research examples presented reflect the diversity and dynamism of scientific and technological research at national and international levels and it shows very well that research partnerships between CGIAR and French institutions are not only numerous and productive but also generate multiple and open partnerships with many other research institutions, including the national agricultural research systems (NARS).

* e.g. The 'Handbook for the evaluation of agroecology' (Working Group on Agroecological Transition, 2019): www.fao.org/agroecology/database/detail/fr/c/1197691/

New research questions and a brand new way of doing research

Agroecological approaches come with new research questions. When you change the paradigmatic vision of food systems, address the multifunctionality of agriculture, recognize the urgent and imperious necessity to respect ecosystems and marshal nature and its resources, including biodiversity and its functions, then you need to address questions that have been overlooked by conventional approaches. This includes soil biodiversity, ecosystem health, optimization of functions at plot and landscape levels, etc. Moreover, agroecology is dovetailed with principles such as fairness, social values, diets, land and local resource governance, which implies that scientific research must also focus on addressing questions linked to labor and market organization, stakeholder interactions, behavioral change mechanisms, social inclusion, public policies, added value distribution along supply chains, etc.

Agroecological approaches also imply new ways of doing research and contributing to innovation, as stated in the Call for Action for Agroecological Transition of Agri-Food Systems[2]. Agroecological transformation requires hybridization of scientific knowledge, technological and institutional innovations, local actors' capacities and knowledge, public policies, infrastructures and means. It is a context-dependent process, with multiple transformational solutions and pathways and local innovation systems have a crucial role to play. Scientific research therefore has to produce knowledge to fuel these local innovation systems through new ways of cooperation with stakeholders, including policymakers. This means accounting for the complexity of agroecosystem functioning in a diverse range of situations and settings, by connecting biological, technical and sociopolitical questions, using inclusive, systemic, interdisciplinary, participatory and transdisciplinary research. These are some of the ambitions of the Transformative Partnership Platform on Agroecology (TPP)[3] that was jointly built by French research institutions and CGIAR.

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2. Conclusions of a Joint France-CGIAR Workshop 'Stepping Up to the Challenge of Agroecological Transition Through Agricultural Research for Development', held in Montpellier, June 19-20, 2019. www.foreststreesagroforestry.org/fta-publication/call-for-action-for-agroecological-transition-of-agri-food-systems-pdf/

3. https://glfx.globallandscapesforum.org/topics/21467/page/TPP-home

PART 1

Agroecosystems

Chapter 1

Increasing the efficiency of practices in order to reduce the use of costly, scarce, or environmentally damaging inputs

The transformation of food systems towards sustainability through the implementation of agroecological principles in the field involving co-creation of knowledge with farmers who are the actors and beneficiaries of these transitions can be categorized in relation to a series of transition levels on a gradient of incremental to transformational change (Gliessman). This chapter deals with the first Gliessman's level, to "Increase the efficiency of industrial and conventional practices in order to reduce the use and consumption of costly, scarce, or environmentally damaging inputs".

We present results of research conducted in many countries geared towards improving resource use efficiency, while reducing reliance on chemical inputs and the environmental footprint of production systems and subsequent postharvest handling. This includes research on complex processes (nutrient and water cycles, action of soil organisms, crop pest and disease management), as well as the added benefits of participatory research approaches in varietal selection and breeding programs. Among the 13 HLPE agroecological principles, 'recycling', 'input reduction', 'soil health' and 'biodiversity' are highlighted, as well as the 'synergy' between them. The chapter also illustrates the 'co-creation of knowledge' principle where researchers are "...just one among several key stakeholders" (see Trouche *et al.*). It is structured in three parts that illustrate the levers for increasing the production efficiency focusing on keeping plants healthy, harnessing genetic diversity and improving post-harvest processes. The chapter ends with examples of approaches that address several of these partial processes in an integrated way.

Keeping plants healthy: Crop nitrogen and water use efficiency and pest control must be enhanced to be able to reduce chemical inputs without jeopardizing crop yields or intensify production without negative environmental impacts. The research presented concerns management of soil mycorrhizal potential (Duponnois & Prin), the importance of soil biological diversity in plant phosphate nutrition (Trap & Plassard), the manifold effects of microbial inocula (Masso *et al.*), and pea-rhizobia interactions (Bourion *et al.*). Laplaze *et al.* show that root traits are largely driven by the plant genotype and have an impact on nutrient recycling. In Vietnam, Herrmann *et al.* demonstrate that a cowpea-cassava intercropping system can improve soil health.

▼ *Participatory variety selection with pilot farmers.* © M. Major

Harnessing genetic diversity: Derero and co-authors present the results of a participatory approach to enhance the natural diversity of trees adapted to different agroecological regions in Ethiopia. Genetic improvement and varietal selection are effective long-standing levers for boosting crop yields, while also enhancing adaptation to local conditions. Several contributions showcase the results of participatory approaches to cattle breeding in India (Ducrocq & Swaminathan), the promotion of seldom-studied tree species for agroforestry system diversification (Hendre *et al.*), the articulation of participatory breeding and community-based seed enterprises (Bassi *et al.*) and the rollout of farmer-selected varieties (sorghum, barley, rice, maize, wheat) in Ethiopia, West Africa, Central America and Nepal (Hendre *et al.*; Sanchez-Garcia; Tiwari & Sinclair; Kidane *et al.*). This research demonstrates the relevance of a multi-stakeholder approach based on the development of state-of-the-art techniques, while also taking the field conditions and farmers' needs into account. There are particularly interesting impacts where this research has been conducted in partnership with the private sector.

Improving post-harvest processes: The research presented in this section concerns the implementation of agroecological practices for postharvest handling of banana (Brat) and maize using a technology that avoids pesticide treatments (Odjo *et al.*). The aim is to safeguard product quality.

Integrated examples: Muthuri *et al.* show that agroforestry systems in Rwanda offer a sustainable and cost-effective way to boost climbing bean production through the provision of tree stakes to support them. Ameur *et al.* mapped and analysed local agroecological farming practices to increase irrigation efficiency. Corbeels & Naudin conducted a meta-analysis to assess the effects of different components of conservation agriculture practices in sub-Saharan Africa. In addition, Barnaud *et al.* have suggested that the creation of a seed exchange network in sub-Saharan Africa would help farmers adapt to climate change by providing access to seeds from other regions.

Jean-Luc Chotte (Eco&Sols, IRD)
Fergus Sinclair (ICRAF, CGIAR)

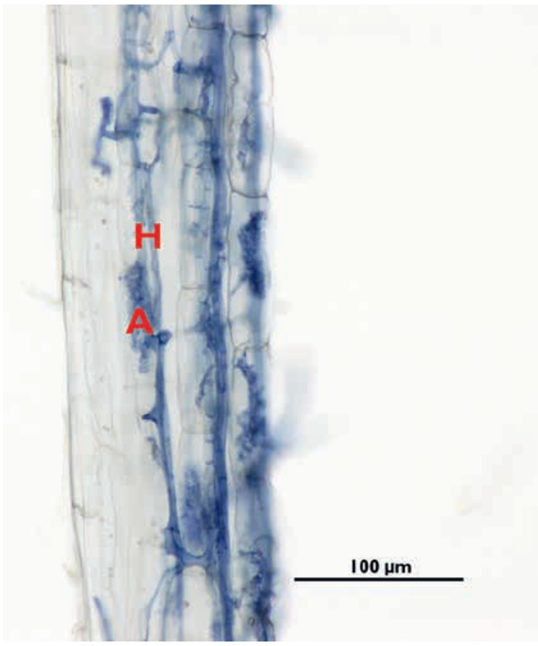
Keeping plants healthy

Optimizing agroecosystem productivity through effective mycorrhizal performance management

Mycorrhizal symbiosis is a reciprocally beneficial relationship between certain types of fungi and plant roots (Photo). It is a major microbial constituent of biological mechanisms governing soil fertility and the spatiotemporal dynamics of terrestrial plant communities (diversity, productivity, resilience). Many scientific studies have shown that this biological process facilitates plant growth in environments under abiotic (mineral deficiency, heavy metal pollution, water scarcity) and/or biotic (high parasitic pressure of phytopathogenic agents) stress[1]. The extent to which this symbiosis will benefit plant growth is dependent on the composition of the soil mycorrhizal fungal community (spore abundance and diversity), i.e. the mycorrhizal infection potential (MIP) of the agroecosystem. The degree of soil degradation is closely correlated with this MIP (Figure). Based on scientific findings concerning this symbiotic process, different soil MIP management strategies may be developed according to the extent of degradation of the system targeted for remediation:

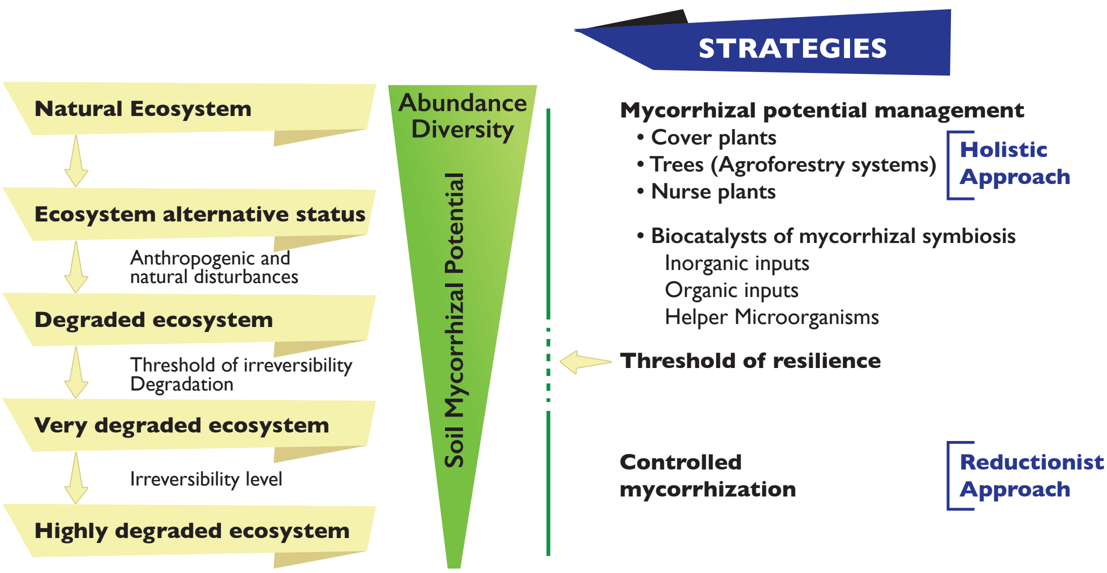
1. If the MIP value is considered high enough to be revived, a 'holistic' approach is implemented by installing plant cover that hosts a variety of highly mycotrophic plants (e.g. legumes).
2. If the MIP value is low, a 'reductionist' approach is favored via the mass reintroduction of mycorrhizal spores. Soil inoculations of one or more fungal strains preselected under controlled conditions for a given parameter (e.g. effect of the strain on growth of a target plant) are then carried out.

Many research results highlight the importance of soil mycorrhizal fungal communities in promoting sustainable agriculture. They also show **the potential advantages of mainstreaming these microorganisms in the design of innovative agroecological cropping sequences, with emphasis on beneficial plant/microorganism interactions.**



▲ ***Spores and hyphae of arbuscular mycorrhizal fungi****. A: arbuscules, H: hyphae*

THINKING THE MYCORRHIZAL SYMBIOSIS MANAGEMENT IN RELATION WITH ENVIRONMENTAL SPECIFICATIONS



▲ ***Strategies for managing the mycorrhizal infection potential (MIP) according to the extent of degradation (resilience threshold) of the environment to be remediated.***
Holistic approach: increased MIP via biological vectors (cover plants, nursery plants, etc.).
Reductionist approach: mass introduction of mycorrhizal spores into the environment to be remediated (controlled mycorrhization technique).

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(1) Ramirez-Flores M.R., Perez-Limon S., *et al.*, 2020. The genetic architecture of host response reveals the importance of arbuscular mycorrhizae to maize cultivation. *eLife*, 9: e61701. https://doi.org/10.7554/eLife.61701

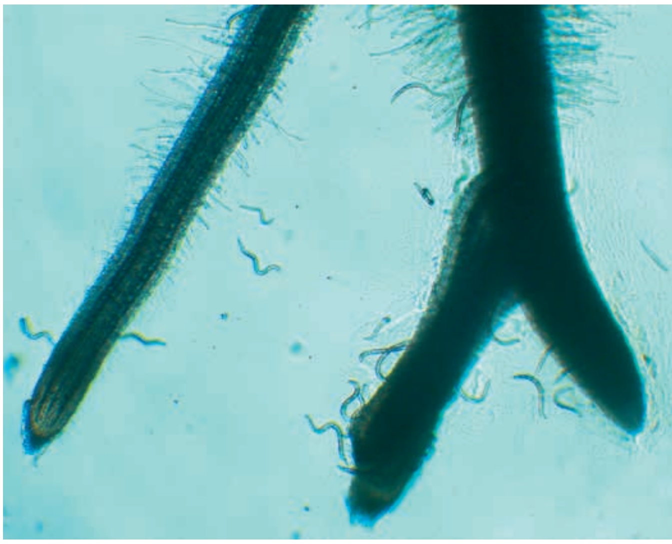
(2) Wahbi S., Sanguin H., Baudoin E., Tournier E., Maghraoui T., Prin Y., Hafidi M., Duponnois R., 2016. Managing the soil mycorrhizal infectivity to improve the agronomic efficiency of key processes from natural ecosystems integrated in agricultural management systems. *In*: Hakeem K. *et al.* (eds) *Plant, soil and microbes. Volume 1. Implications in crop science. Springer,* Cham: 17-27. http://dx.doi.org/10.1007/978-3-319-27455-3_2

Effects of soil biological diversity on plant nutrition are driven by the nutrient source and mobility

The case of phosphorus

In natural ecosystems, selection gradually shapes multiple complex interactions between plants and soil organisms to maximize nutrient mobilization. A current key challenge of ecologically intensive agriculture, including agroecology, is to gain insight into and take advantage of these ecological processes. This form of agriculture seeks to make a sustainable use of natural soil processes, particularly to optimize efficient nutrient recycling. This is the case for phosphorus (P), an often not readily available nutrient that is fundamental for plant growth. Roots cope with P deficiency by forming a mutualistic symbiotic relationship with fungi—a so-called mycorrhizal association. Roots can also interact with bacteria involved in P mineralization or solubilization to promote plant growth. Finally, roots interact with microscopic fauna (protists and nematodes) that—by consuming bacteria and fungi—release P ions that can be accessed by plants. Plants thereby have many soil partners with which they can interact.

We conducted a set of six microcosm experiments in a growth chamber and tested the hypothesis that the relationship between soil mutualistic organism diversity and plant P acquisition depends on the soil P source and mobility. **A highly significant relationship was noted between plant P acquisition and soil biological diversity in an organic P amended soil with a high P uptake capacity.** Non-significant or very weak relationships were observed in the other five situations. Appropriate management of soil fertility and biotic interactions involving plant roots and soil organisms, is essential for a successful agroecological transition. Fostering the diversity of rhizosphere interactions could be a promising way to optimize crop nutrition.



▲ *Bacterial-feeding nematode of the Cephalobidae family around* Pinus pinaster *roots.* © *Eco&Sols*

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• Hinsinger P., Herrmann L., Lesueur D., Robin A., Trap J., Waithaisong K., Plassard C., 2015. Impact of roots, microorganisms and microfauna on the fate of soil phosphorus in the rhizosphere. *In*: Plaxton W.C., Lambers H. (eds), Phosphorus metabolism in plants, *Annual Plant Reviews*: 377-407.

• Nehls U., Plassard C., 2018. Nitrogen and phosphate metabolism in ectomycorrhizas. *New Phytologist*, 220: 1047-1058.

• Trap J., Ranoarisoa P.M., Irshad U., Plassard C., 2021. Richness of rhizosphere organisms affects plant P nutrition according to P source and mobility. *Agriculture*, 11(2): 157.

• Ranoarisoa P., Trap J., Pablo AL., Dezette D., Plassard C., 2020. Micro-food web interactions involving bacteria, nematodes, and mycorrhiza enhance tree P nutrition in a high P-sorbing soil amended with phytate. *Soil Biology & Biochemistry*, 143: 107728.

Environment-friendly microbial inoculants improve resource efficiency and resilience of agricultural systems

Agricultural land degradation in sub-Saharan Africa, partly due to low-input agriculture, is steadily leading to a critical dilemma and it is essential to find ways to increase food productivity to support the growing population without jeopardizing soil ecoservices, biodiversity and quality. The immediate consequences of this are major yield gaps alongside related food and nutrition insecurity. The effective application of microbial inoculants in the context of integrated soil fertility management (ISFM) to improve nutrient availability, water and nutrient use efficiency and plant health offers one of the most viable and cost-effective options to address this challenge, particularly for resource-constrained smallholder farmers. **In legume-based cropping systems, inclusion of high-quality rhizobia inoculants in ISFM can increase legume N uptake, while doubling grain yields and benefiting rotation crops.** Arbuscular mycorrhizal fungi inoculants can enhance P availability, reduce reliance on P fertilizers (by ≈25-50%), and improve water use efficiency in crops like cassava and potato, etc., in addition to protecting crops, such as bananas, against nematode pests. Our studies revealed that co-application of rhizobia and other microbial inoculants to enhance P availability enhances soybean performance.

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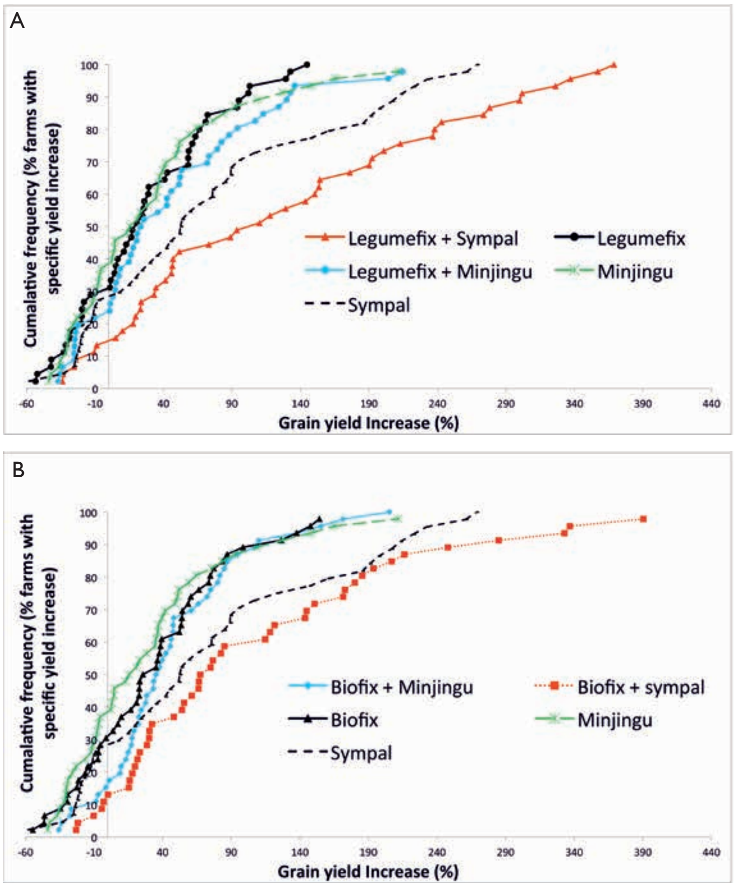

◀ *Cumulative frequency of farms reporting grain yield increases above the control treatment following application of various combinations of fertilizers and rhizobia inoculant Biofix (A) and Legumefix (B). Adapted from Thuita* et al. *(2018).* © *Eco&Sols*

Nutrient and water uptake from soil also requires a healthy root system, including the control of root pests and diseases, and can be critical for nutrient and water uptake and utilization. *Trichoderma* spp. were shown to have a significant impact in controlling a range of soilborne diseases and nematode pests on a range of crops, e.g. *Phytophthora infestans* on tomatoes, *Fusarium verticillioides* on maize and *Meloidogyne javanica* on pineapple. Root rot diseases and root infecting nematode pests can have a major detrimental impact on the root systems of most crops, including legume crops. **The joint application of those microbial inoculants under ISFM is highly promising for sustainable soil management and crop productivity, across agroecological settings, which is worth further investigation.**

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For further information

• Kiriga A.W., Haukeland S., Kariuki G.M., Coyne D., Beek N.V., 2018. Effect of *Trichoderma* spp and *Purpureocillium lilacinum* on *Meloidogyne javanica* in commercial pineapple production in Kenya. *Biological Control*. doi: 10.1016/j.biocontrol.2018.01.005

• Korir H., Mungai N.W., Thuita M., Hamba Y., Masso C., 2017. Co-inoculation effect of rhizobia and plant growth promoting rhizobacteria on common bean growth in a low phosphorus soil. *Front. Plant Sci*. 8: 141. doi: 10.3389/ fpls.2017.00141

• Pena R., Robbins C., Corella J.C., Thuita M., Masso C., Vanlauwe B., Signarbieux C., Rodriguez A., Sanders I.R., 2020. Genetically different isolates of arbuscular mycorrhizal fungus rhizophagus irregularis induce differential responses to stress in cassava. *Frontiers in Plant Science*: 1-14.

• Thuita M., Vanlauwe B., Mutegi E., Masso C., 2018. Reducing spatial variability of soybean response to rhizobia inoculants in farms of variable soil fertility in Siaya County of western Kenya. *Agriculture, Ecosystems and Environment*. doi: 10.1016/j.agee.2018.01.007

Major advances in knowledge on beneficial pea-rhizobia interactions

Pea is a crop of major interest in agroecology because of its high protein seed production, while not requiring nitrogen fertilizer inputs because of its symbiosis with rhizobia, i.e. atmospheric nitrogen fixing bacteria. Symbiotic fixation may, however, be suboptimal if the symbiotic partner associations are not very efficient, or the environmental conditions are unfavorable. Cultivated peas interact with native rhizobial strain populations. Preferential associations are established between peas —depending on genotypes—with certain rhizobial strains, which may be competitive but inefficient (Fig. A)[1,2]. **The GRaSP* project has identified the gene regions involved, thereby providing a lever for breeding productive pea varieties that will preferentially associate with competitive and efficient soilborne or inoculated rhizobial strains.**

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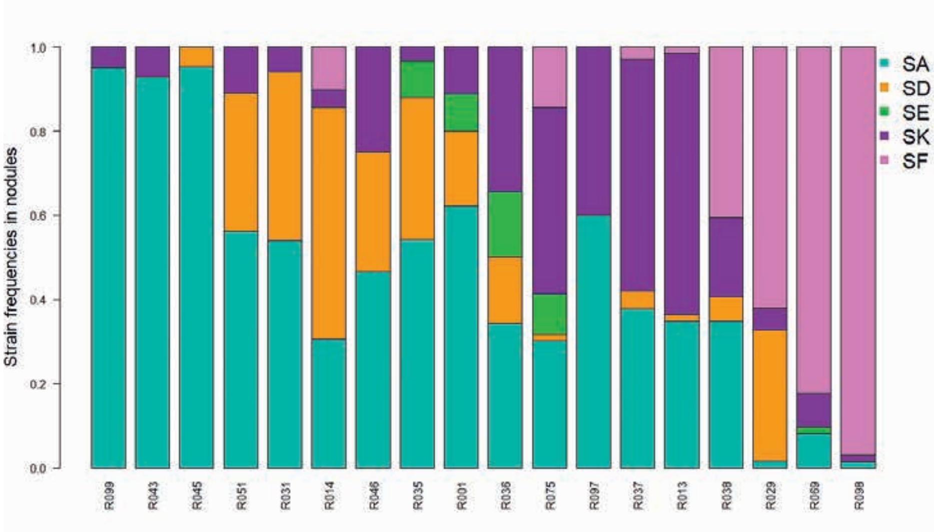
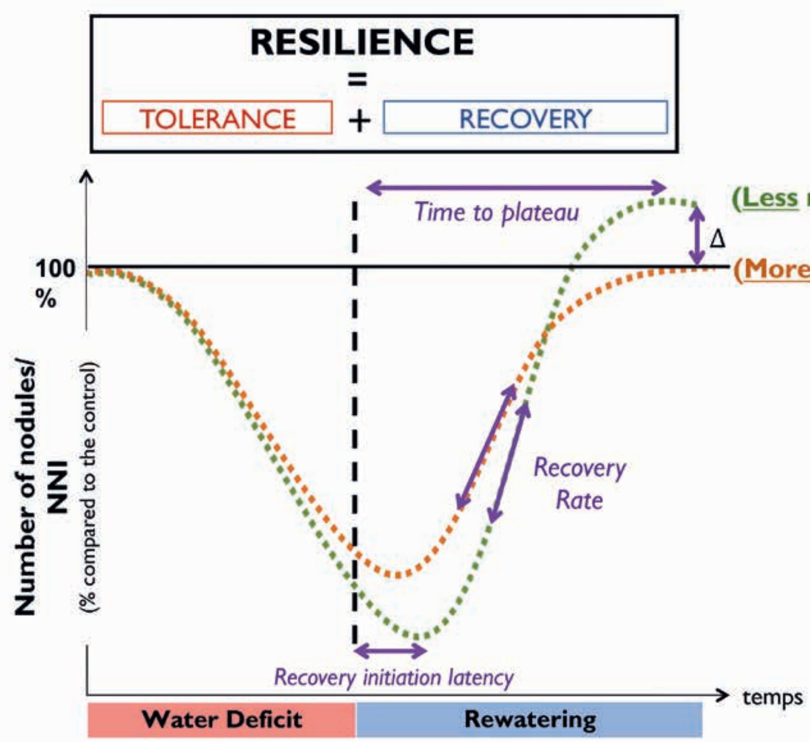


▲ ***Figure A.** Pea-rhizobia associations depend on pea genotypes and strains: variability in the proportion of nodule occupancy by five strains (SA, SD, SE, SF, SK) mixed inoculation of 18 pea genotypes.*
From Bourion et al. *(2018)*



◀ ***Figure B.** The pea crop resilience process can be divided into water deficit tolerance and post-stress recovery.*
The curves represent the nitrogen uptake dynamics of two genotypes in reference to two traits: the number of nodules and the nitrogen nutrition index (NNI).
The values of these two traits decrease during water shortages and recover during the re-watering period until plateauing. The recovery capacity is characterized by four variables (purple): recovery initiation latency, recovery rate, time to plateau, and delta (Δ), the difference in trait value at the plateau between well-watered plants and those under water deficit).
For the more resilient genotype (orange), the lag time is shorter and the recovery rate slower. The less resilient genotype (green) overcompensates. The comparison of these two genotypes suggests that rapid initiation of nitrogen uptake recovery associated with finely regulated nodule formation would be essential for better resilience.

Moreover, the reduction in greenhouse gas emissions linked to the non-use of nitrogen fertilizer could be further enhanced by field inoculations of strains capable of reducing soilborne nitrate-derived N_2O levels, as is the case with some soybean-nodulating rhizobial strains[3]. N_2O-reducing strains of pea-nodulating rhizobia have been isolated in the NatAdGES* project. **Their field inoculation will serve to increase the ecosystem services provided by pea crops.** Finally, in the current climate change setting, crops are subject to water stress which affects their productivity. The LEGATO* and ARECOVER* project results are shedding light on processes underlying the resilience of pea-rhizobia trophic relationships (Fig. B, previous page), and the findings should give rise to pea ideotypes that are more productive under water stress conditions[4]. Various levers are now available to take beneficial biotic interactions in pea breeding approaches into account, and to boost the role of pea crops in agroecological systems.

*** Projects**

- GRaSP, Genetics of rhizobia selection by pea: https://anr.fr/Projet-ANR-16-CE20-0021
- NatAdGES, Multi-scale avoidances of soil emissions of the greenhouse gas N_2O by the use of natural additives or microorganisms: www6.inrae.fr/natadges
- FP7-LEGATO, Legumes for the agriculture of tomorrow: www.legato-fp7.eu
- Plant2Pro® ARECOVER, *Architecture racinaire nodulée et tolérance au stress hydrique chez le pois*: www6.inrae.fr/arecover

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For further information

(1) Bourion V., Laguerre G., Depret G., Voisin A.S., Salon C., Duc G., 2007. Genetic variability in nodulation and root growth affects nitrogen fixation and accumulation in pea. *Ann. Bot.* 100: 589-598. doi: 10.1093/annbot/mcm147

(2) Bourion V., Heulin-Gotty K., Aubert V., Tisseyre P., Chabert-Martinello M., Pervent M., Delaitre C., Vile D., Siol M., Duc G., Brunel B., Burstin J., Lepetit M., 2018. Co-inoculation of a pea core-collection with diverse rhizobial strains shows competitiveness for nodulation and efficiency of nitrogen fixation are distinct traits in the interaction. *Frontiers in Plant Science,* 8: 2249. doi: 10.3389/fpls.2017.02249

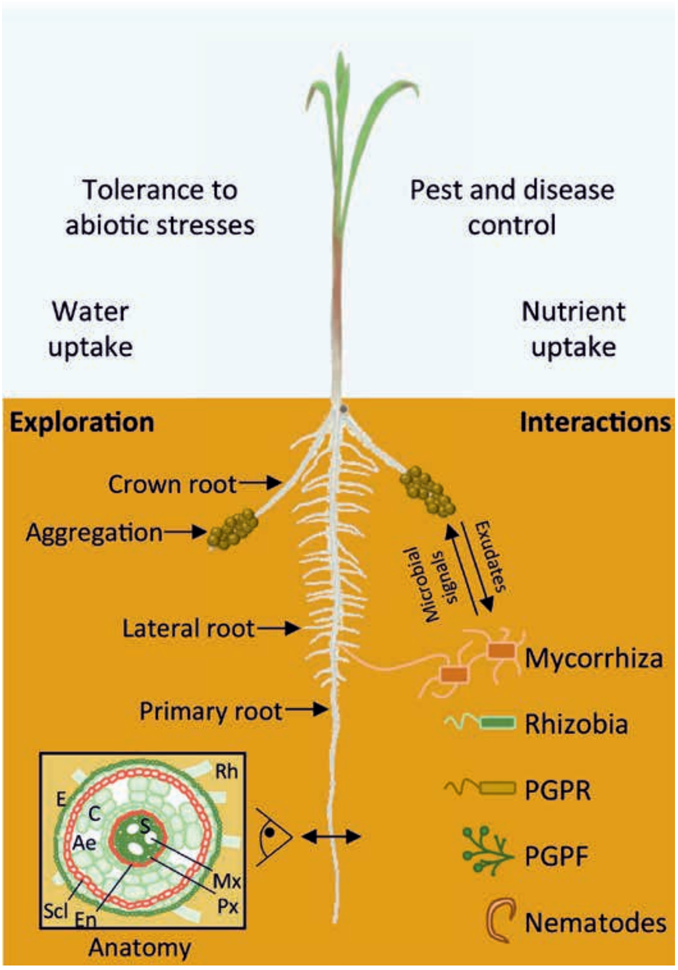
(3) Hénault C., Revellin C., 2011. Inoculants of leguminous crops for mitigating soil emissions of the greenhouse gas nitrous oxide. *Plant and Soil*, 346: 289-296. doi: 10.1007/s11104-011-0820-0-

(4) Couchoud M., Salon C., Girodet S., Jeudy C., Vernoud V., Prudent M., 2020. Pea efficiency of post-drought recovery relies on the strategy to fine-tune nitrogen nutrition. *Front. Plant Sci.,* 11: 204. doi: 10.3389/fpls.2020.00204

Root traits enhance the agroecological transition

The plant root system explores the soil to secure the plant's hydromineral nutrition. Root development and physiology are dependent on the soil physicochemical and biotic properties and, in turn, the roots actively modify these characteristics in the surrounding soil volume, i.e. the rhizosphere[1]. Despite its pivotal role in plant nutrition, the relatively inaccessible root system has received little, if any, attention in plant breeding and in the development of agricultural practices. Moreover, the first Green Revolution was based on massive use of inputs, which minimized the impact of root traits on crop yield. However, gaining insight into the genetic determinants of these traits would address two major challenges: (i) to better explore the soil to help boost crop resilience to hydromineral deficiency and enhance the complementarity between crop species in terms of nutrient access; and (ii) to better control interactions between roots and soil organisms in order to sustainably foster trophic loops governing the nutrient cycle, thereby reducing dependence on external inputs.

Based on an assessment of the genetic diversity available in pearl millet, we demonstrated that root architecture and rhizosphere interaction traits are highly variable and closely controlled by the plant genotype[2,3,4]. We showed, for instance, that control of soil particle aggregation by pearl millet roots is a trait that impacts the rhizosphere microbiota structure[2] and functions, including those affecting nutrient remobilization from soil organic matter[3]. **Root traits could therefore become new selection targets and contribute to the optimization of agroecological practices**[1].



▶ ***Root traits contributing to soil exploration and interactions with soil organisms for improved hydromineral nutrition and tolerance to biotic and abiotic stresses.***
Rh: root hairs, E: epidermis, Slc: sclerenchyma, C: cortex, Ae: aerenchyma, En: endodermis, S: Stele, Px: protoxylem vessel, Mx: metaxylem vessel, PGPR, PGPF: plant growth promoting rhizobacteria and fungi.

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For further information

(1) de la Fuente Cantó C., Simonin M., King E., Moulin L., Bennett M.J., Castrillo G., Laplaze L., 2020. An extended root phenotype: the rhizosphere, its formation and impacts on plant fitness. *The Plant Journal*, 103(3): 951-964.

(2) Ndour P.M.S., Gueye M., Barakat M., Ortet P., Bertrand-Huleux M., Pablo A.-L., Dezette D., Chapuis-Lardy L., Assigbetsé K., Kane N.A., Vigouroux Y., Achouak W., Ndoye I., Heulin T., Cournac L., 2017. Pearl millet genetic traits shape rhizobacterial diversity and modulate rhizosphere aggregation. *Front. Plant Sci.*, 8: 1288.

(3) Ndour P.M.S., Mbacké Barry C., Tine D., de la Fuente Cantó C., Gueye M., Barakat M., Ortet P., Achouak W., Ndoye I., Sine B., Laplaze L., Heulin T., Cournac L., 2021. Pearl millet genotype impacts microbial diversity and enzymatic activities in relation to root-adhering soil aggregation. *Plant and Soil*, in press.

(4) Passot S., Gnacko F., Moukouanga D., Lucas M., Guyomarc'h M., Moreno Ortega B., Atkinson J., Niang M., Bennett M., Gantet P., Wells D.M., Guédon Y., Vigouroux Y., Verdeil J.-L., Muller B., Laplaze L., 2016. Characterization of pearl millet root architecture and anatomy reveals three types of lateral roots. *Front. Plant Sci.*, 7: 829.

Positive impacts of a cowpea-cassava intercropping system on soil biodiversity in Northern Vietnam (Yen Bai Province)

Agricultural production in Southeast Asia continues to rely on massive use of pesticides and mineral fertilizers, which are readily available at low cost in the region. However, these intensive management practices have resulted in a dramatic reduction in soil biodiversity, leading to a decrease in soil health, and an increase in dependence on chemical inputs to maintain crop productivity. Soil organisms, including micro- and macrofauna as well as microbial communities, play key roles in supporting soil health and ecosystem services, such as soil porosity and aggregation, nutrient cycling and crop protection against pests and diseases. Recent initiatives are promoting agroecological practices to mitigate collateral effects of intensive agriculture on soil health. For instance, the effects of introducing legumes in intercropping systems were assessed in the framework of the Towards an Agroecological Transition in South East Asia (ACTAE) project funded by the French Development Agency (AFD). In Yen Bai province, a mountainous region in Northern Vietnam where cassava (*Manihot esculenta*) monocropping systems dominate, the introduction of cowpea (*Vigna unguiculata* L.) as an intercrop positively impacted soil biodiversity, even after a single growing season. Intercropped plots showed a higher abundance of microfauna, as compared to monocropped areas. Intercropping also resulted in an up to 100% increase in soil macrofauna richness, diversity and evenness indices. High-throughput sequencing analysis of the microbial community revealed a significant increase in bacterial community richness, while other indices were not affected (diversity, evenness). Fungal communities were not impacted by the introduction of cowpea, suggesting that changes in fungal communities may occur over a longer period. These results highlighted **the high potential of promoting agroecological practices, such as legume intercropping systems, in restoring and maintaining soil biodiversity in very fragile ecosystems such as the mountainous regions of Vietnam.**

▲ *Intercropping cassava with cowpea in Yen Bai province, Northern Vietnam.* © D. Lesueur, 2018

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Fouillet E., Herrmann L., Nguyen T,T., Nguyen H.T.T, Atieno M., Zhong S. Lesueur D., 2019. *Do legume-based intercrops improve soil fauna and soil microbial diversity? Example of the cowpea-cassava intercropping system in Northern Vietnam*. Rhizosphere 5 Conference, July 2019, Saskatoon, Canada.

Harnessing genetic diversity

Genetic and genomic improvement of cattle in India

India is the world's largest milk producer, with about 100 million cows and as many buffaloes. Yet individual production is low (two cows/farmer on average) and the breeding conditions are harsh. In this setting, it would be hard to implement conventional genetic improvement programs, while crossbreeding with bulls of Western breeds, which are ill-adapted to Indian conditions, has proven to be the only way to boost production. Artificial insemination programs have nevertheless been developed, notably through BAIF Development Research Foundation—the largest Indian agricultural NGO—resulting in the production of millions of doses of bull and buffalo semen of various genetic strains, which are disseminated through an efficient insemination service.

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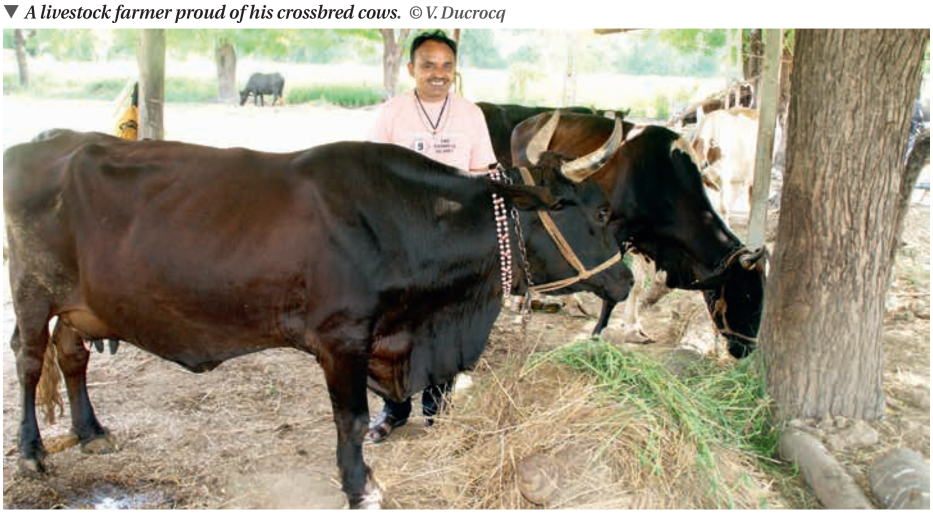
▼ *A livestock farmer proud of his crossbred cows.* © V. Ducrocq



A partnership between INRAE and BAIF was formed in 2003 to enhance local genetic diversity for sustainable genetic improvement. Since then, genomic selection based on data from the genotyping and phenotyping of reference populations has led to substantial sustainable genetic progress in Europe. A novel genomic selection program has thus been set up at BAIF using state-of-the-art technologies (genotyping, insemination) and the collection of original information to select traits associated with adaptation to harsh environmental conditions(1). **This program makes effective use of genetic diversity to enhance both performance and adaptation and is thereby in line with agroecological principles.** It benefits from a project funded by the Bill and Melinda Gates Foundation that enables BAIF to collect thousands of phenotypes and genotypes from smallholder farmers in seven Indian states. In 2018, it was extended with the launch of the Genetic IMprovement of Indian Cattle and Buffaloes (GIMIC) international associated laboratory (LIA), which also involves AgroParisTech. This LIA contributes to the implementation of technically and economically sustainable genomic selection initiatives tailored to Indian conditions in a system with very marked genotype x environment interactions. It is complemented by technical training for BAIF senior staff.

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(1) Ducrocq V., Laloe D., Swaminathan M., Rognon X., Tixier-Boichard M., Zerjal T., 2018. Genomics for ruminants in developing countries: from principles to practice. *Front. Genet.*, 9: 251. doi: 10.3389/fgene.2018.00251

Food, feed, forage and malt

Barley is the ultimate multipurpose crop for nutrition and livelihood security in the MENA drylands

Integrated crop-livestock farming is the predominant system in the drylands of the Middle East and North Africa (MENA), where small-scale farmers struggle to maximize their farm productivity under climate change. For these farmers, cereal forage, stubble and straw are the main feed source for small ruminants during summer and winter(3). With rising fodder and forage prices, it is essential to breed and grow cereals that target more than just grain yield. In this setting, barley is the perfect crop to increase food and feed security by maximizing the efficiency and resilience of the crop-livestock farming system. **Barley cropping has the dual advantage of producing substantial green forage dry matter in winter—when forage is otherwise scarce—thereby not penalizing the grain and fodder yield in summer.** This strategy is also more economically profitable than only targeting high grain yield, especially in areas with >300 mm of rainfall(2), while ensuring year-round fodder availability, hence reducing pressure on rangelands. As such, the ICARDA Global Barley Breeding Program has recently developed **new more efficient dual-purpose barley genotypes that produce up to 20% more forage in winter—as compared to the best commercial checks—that can be grazed by livestock(3).** However, maximizing sustainable farming system profitability is also essential to improve farmers' livelihoods, which means that farmers require access to new efficient varieties that could be readily integrated in the targeted agroecological system. Farmers gain higher economic and even nutritional benefit when grains target high value chains, like biofortified human food or malt production. In recent years, malt demand has increased by 83% in Ethiopia, and new contract farming schemes provide premiums of up to 20% above the market price(1), which has resulted in increased malt barley cultivation. However, some malt barley varieties fail to provide enough straw fodder to fulfill crop-livestock farming system needs. The release of new malt barley varieties that combine superior malt production and straw yield(1), such as ICARDA EIAR varieties (IBON174/3, HB1963 and HB1964), can increase farmers' revenues while generating fodder to maximize the overall efficiency and resilience of the farming system.

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(1) Ali A.B., 2018. Malt barley commercialization through contract farming scheme: a systematic review of experiences and prospects in Ethiopia. *African Journal of Agricultural Research*, 13(53): 2957-2971.

(2) Ates S., Cicek H., Gultekin I., Yigezu Y.A., Keser M., Filley S.J., 2018. Bio-economic analysis of dual-purpose management of winter cereals in high and low input production systems. *Field Crops*, 227: 56-66.

(3) Ryan J., Singh M., Pala M., 2008. Long-term cereal-based rotation trials in the Mediterranean region: implications for cropping sustainability. *Adv. Agron.*, 97: 273-319.

(4) Singh Verma R.P., 2017. *Improvement of dual purpose barley for forage and straw for livestock*. (5/2/2017). https://hdl.handle.net/20.500.11766/5807

▼ *Dual-purpose management field trial in the ICARDA-Marchouch field station (Morocco).* © *M. Sanchez-Garcia*

Development of novel field and genomics resources for diversifying food systems

The African Orphan Crops Consortium (AOCC*) and World Agroforestry (CIFOR-ICRAF) are developing modern genomic and field resources for ~50 neglected trees of African importance to help in domestication, improvement and breeding. This public-private partnership involves a group of 28 core partners and an extended network of more than 25 collaborators(1). Diversification of farming landscapes and food production systems through locally adapted and socioculturally acceptable orphan or neglected local food crops is a key to the resilience of agroecological production landscapes(2,3). These modern breeding and improvement programmes are underpinned by novel field and genomics resources as follows:

1. **Participatory domestication and genomics-driven modern breeding methods:** the consortium along with the collaborators and partners, uses CIFOR-ICRAF's participatory tree domestication approach for building locally adaptable and acceptable germplasm resources. Modern genomics-driven models of yield and trait prediction such as genomic selection, genome-wide associations, QTL mapping, etc., along with diversity breeding through different breeding populations, form a backbone of tree domestication and improvement programs.
2. **Trait prioritization and trait metrics:** apart from traits such as farm productivity, disease and pest tolerance, nutrient content, tree architecture and mixed cropping compatibility, smallholder traits like easy harvesting, processing, storage, farmer and consumer preferences are also surfacing in the era of climate change and globalization. Genomics-driven methods promise concurrent and predictable modelling of such trait improvement metrics.
3. **Genomics resources:** genome sequencing, diversity sequencing and gene/transcriptome sequencing generate data that can be routed into germplasm management plans, population improvement, prebreeding and breeding programs. The Consortium has published five tree genomes so far**.
4. **Genebank management:** in the absence of phenotypic data, tree genebanks can be guided by genomic markers to make operations more informed, efficient, economic and targeted.

Traditional methods guided by modern tools are thus expected to enhance the acceptability of these neglected trees beyond their traditional areas, thereby expanding the tree cover on farmland, boosting seed delivery systems, impacting income and providing new livelihood options to smallholder farmers.

* AOCC: http://africanorphancrops.org
** http://africanorphancrops.org/ongoing-projects

▼ ***Shea tree (*Vitellaria paradoxa *subspecies* nilotica*) in its native habitat in Gambella region of Ethiopia.***
Shea tree is a species being explored by African orphan crops consortium (AOCC) for development of genomic resources for deployment in improvement and breeding programs. © Prasad S. Hendre

▲ ***A shea tree protected within a community habitat.***

▲ ***Naturally occurring new recruitment of shea trees in the shea parkland.***

▲ ***Shea tree protected and maintained on a maize farm.***

▲ ***A shea tree protected and maintained within a community habitat.***

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(1) Hendre P.S., Muthemba S., Kariba R., Muchugi A., Fu Y., Chang Y., Song B., Liu H., Liu M., Liao X., Sahu S.K., Wang S., Li L., Lu H., Peng S., Cheng S., Xu X., Yang H., Wang J., Liu X., Simons A., Shapiro H.Y., Mumm R.H., Van Deynze A., Jamnadass R., 2019. African Orphan Crops Consortium (AOCC): status of developing genomic resources for African orphan crops. *Planta,* 250: 989-1003. https://doi.org/10.1007/s00425-019-03156-9

(2) Dawson I.K., Powell W., Hendre P., Bančič J., Hickey J.M., Kindt R., Hoad S., Hale I., Jamnadass R., 2019. The role of genetics in mainstreaming the production of new and orphan crops to diversify food systems and support human nutrition. *New Phytologist,* 224: 37-54. https://doi.org/10.1111/nph.15895

(3) Jamnadass R., Mumm R.H., Hale I., Hendre P., Muchugi A., Dawson I.K., Powell W., Graudal L., Yana-Shapiro H., Simons A.J., Deynze A.V., 2020. Enhancing African orphan crops with genomics. *Nature Genetics*, 52: 356-360. https://doi.org/10.1038/s41588-020-0601-x

When farmers and scientists collaborate

Climate smart varieties for low-input cropping systems in Africa and Central America

Improving sorghum and rice varieties to secure food for the rural and urban poor, while delivering revenue opportunities in regions vulnerable to climate change, requires joint efforts. For 20 years now, CIRAD has been collaborating with farmers' organizations, research institutes and NGOs to identify and develop new sorghum varieties adapted to low-input agroecological cropping systems in West Africa and Central America, as well as new upland rice varieties for the highlands of Madagascar—some of the regions most affected by climate change in the world. Impact analyses on these decentralized participatory breeding programs have revealed **a large adoption and dissemination of the developed varieties because of their adaptation to the prevailing soil and climate constraints, intensification objectives and local food preferences**[1,2]. Farmers appreciate the higher and more stable yields achieved in their cropping systems, not to mention the quality of the harvested grain for family consumption, as well as its high market value and enhanced fodder quality, especially for sorghum[1,3]. In Burkina Faso, collaboration between stakeholders on these varieties has prompted the set-up of new seed-production networks by farmers' organizations, generating both revenue and employment[1]. A similar breeding approach is being pursued in southern Madagascar.

The outcomes are hence of a dual nature: firstly, the development of varieties that are superior to farmers' traditional cultivars for progressive intensification and adaptation to climate change[4]; secondly, the organization of a new framework that allows farmers, extension agencies and scientists to work together toward disseminating future new varieties while developing better cropping systems. **Today, farmers demand to be involved in all stages of experiments conducted in their fields, from deciding which varieties and cultural practices are best, to accessing and exchanging the future seed.** In so doing, farmers and researchers are shifting from a researcher-led 'participatory' relationship to a partnership model whereby the researcher is subsequently just one among several key stakeholders.

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(1) Vom Brocke K., Kondombo C.P., Guillet M., Kaboré R., Sidibé A., Temple L., Trouche G., 2020. Impact of participatory sorghum breeding in Burkina Faso. *Agricultural System*, 180.

(2) Breumier P., Ramarosandratana A., Ramanantsoanirina A., Vom Brocke K., Marquié C., Dabat M.-H., Raboin L.-M., 2018. Évaluation participative des impacts de la recherche sur le riz pluvial d'altitude à Madagascar de 1980 à 2015. *Cahiers Agricultures*, 27(1): 15004. https://doi.org/10.1051/cagri/2017065

(3) Trouche G., vom Brocke K., Aguirre S., Chow Z., 2009. Giving new sorghum variety options to resource-poor farmers in Nicaragua through participatory varietal selection. *Exp. Agric.*, 45: 451-467.

(4) Vom Brocke K., Trouche G., Weltzien E., Kondombo-Barro C.P., Sidibé A., Zougmoré R.B., Gozé E., 2014. Helping farmers adapt to climate and cropping system change through increased access to sorghum genetic resources adapted to prevalent sorghum cropping systems in Burkina Faso. *Experimental Agriculture*, 50(2): 284-305. http://dx.doi.org/10.1017/S0014479713000616

▲ *Final evaluation of a set of dual-purpose sorghum varieties developed through a decentralized participatory breeding program in Nicaragua.* © G. Trouche

From gene banks to farmers' fields

The Seeds for Needs approach (durum wheat)

Smallholder farmers' needs cannot be addressed by one-size-fits-all approach in areas where the agroecological conditions are varied and farmers have different crop trait preferences. The conventional plant breeding strategy of using a narrow array of genetic stock ignores the high potential offered by genetic resources available in various gene banks. Moreover, this strategy increases the vulnerability of agriculture in the current climate change setting. The Seeds for Needs (S4N) approach, which combines genomics, conventional breeding, and farmers choices through crowdsourcing, aims at testing many varieties in farmers' fields to select best performing superior varieties for specific climatic and edaphic growing conditions. By bringing seeds to farmers' fields, women and men farmers have an opportunity to select varieties that can fulfil their needs and that are more tailored to their specific farms, with traditional knowledge taking a front seat in the management process.

...cont'd

▼ *Woman farmer carrying her durum wheat harvest.* © Y.G. Kidane

In this case, 373 farmers' durum wheat varieties from the Ethiopian Biodiversity Institute were tested under farmers' growing conditions alongside 27 varieties released by the research system. After testing the general adaptability, we selected the most adaptable varieties for distribution to farmers. Researchers collected agronomic data and farmers' preference ranking data revealed that the top 20 varieties were derived from the gene bank. By distributing these varieties to several hundred farmers using a crowdsourcing approach, we empowered farmers to manage their own seeds. **At the third season, most farmers were able to cover 1 ha of their fields with a single variety, increase their productivity by up to 100%, and on average their farm diversity was increased by fourfold.** The S4N approach of providing farmers with a portfolio of varieties and integrating farmers' decisions proved to be an effective tool for promoting agroecological transition by linking gene banks to farmers' fields.

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• Mengistu D.K., Kidane Y.G., Catellani M., Frascaroli E., Fadda C., Pè M.E., Dell'Acqua M., 2016. High-density molecular characterization and association mapping in Ethiopian durum wheat landraces reveals high diversity and potential for wheat breeding. *Plant Biotechnol. J.* doi: 10.1111/pbi.12538

• Van Etten J., Beza E., Calderer L., Van Duijvendijk K., Fadda C., Fantahun B., Kidane YG., Zimmerer K., 2016. First experiences with a novel farmer citizen science approach: crowdsourcing participatory variety selection through on-farm triadic comparisons of technologies (Tricot). *Experimental Agriculture*: 1-22. doi: 10.1017/S0014479716000739

Participatory varietal selection accelerates farmer-led agroecological transition in Nepal

Maize yields had been stagnant in the midhills of Nepal before a systems approach(1) was used to inform participatory varietal selection in a farmer-led agroecological transition context involving the incorporation of fodder trees on farmland. The first step was to understand how the maize fitted into the farmers' livelihood system by acquiring local knowledge from farmers about how they produced maize(2). Landscapes in the midhills included both individually and commonly held land. Individually used cropland was often divided into an upper slope (rainfed *bari* land where maize was grown) and lower slope (irrigated *khet* land where rice was grown) (Figure). Communal land included forest and grazing areas. A key element in maintaining cropfield fertility was through application of crop residue/livestock manure compost. Due to reduced access to tree fodder from forest areas as they came under community forest regulation, farmers fostered regeneration of fodder trees on their crop terrace risers to provide fodder in the dry winter period. Farmers did not follow agronomic recommendations for maize but instead planted at far higher densities than recommended, while thinning down to far lower densities than recommended at harvest. They used the thinnings as livestock fodder and relay cropping with millet—all on crop terraces where fodder trees on the risers were competing with the crop. Farmers did not strive to maximize maize grain yield but rather to enhance the total farm productivity, which was based on soil fertility from dung as well other livestock products, and relay cropped millet yields. **Screening maize varieties against farmers' criteria and then allowing them to test different varieties themselves, led to the identification and subsequent release of varieties that out-performed those used previously by up to 30%(3) because they had longer roots and were thus able to yield better under local farming conditions(4).**

▲ *Farmer-led agroecological transition in the midhills of Nepal where fodder trees are regenerated on crop terrace risers in response to declining fodder availability from communal forest land.*

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(1) Sinclair F.L., 2017. Systems science at the scale of impact: reconciling bottom-up participation with the production of widely applicable research outputs. *In* Oborn I. *et al.* (eds): *Sustainable intensification in smallholder agriculture: an integrated systems research approach.* Earthscan London: 43-57.

(2) Tiwari T.P., Brook R.M., Sinclair F.L., 2004. Implications of hill farmers' agronomic practices in Nepal for crop improvement in maize. *Experimental Agriculture.* 40: 1-21.

(3) Tiwari T.P, Virk D.S., Sinclair F.L., 2009. Rapid gains in yield and adoption of new maize varieties for complex hillside environments through farmer participation. I. Improving options through participatory varietal selection (PVS). *Field Crops Research*, 111: 137-143.

(4) Tiwari T.P., Brook R.M., Wagstaff P., Sinclair F.L., 2012. Effects of light environment on maize in hillside agroforestry systems of Nepal. *Food Security*, 4: 103-114.

Building resilient Mediterranean dryland rural communities

North African and West Asian countries have experienced devastating droughts in the past decade, with temperatures rising 2-8°C above the 20th century average. National crop production subsequently dropped 30-40% below average. 'Climate-smart' varieties bred with genetic tolerance to these stresses[1] represent sustainable technological solutions. However, packing a variety with genetic advantages is often not enough to ensure farmers' adoption, since subjective and objective preferences guide the decision process[2]. Hence, ICARDA has developed a participatory socioeconomic weighted (PWS) strategy to define a precise list of traits to be incorporated in an ideal variety[2]. This list of traits could then be tailored to address the needs of an agroecology or, more effectively, a set of communities with similar needs. Yet two approaches are required to be able to effectively deliver tailored varieties to individual communities: (i) participatory variety selection[3] (PVS) to promote a sense of ownership regarding the selected varieties; (ii) paired with community-based seed enterprises[4] to favor capillary seed production and adoption. Pilot farmers engaged in this system produced 20-40% more in side-by-side comparisons between new and current varieties*. **This socially weighted approach significantly enhanced the productivity and climate adaptation of the farming communities, but only marginally improved their income. For this, rural female cooperatives were engaged in the participatory process to select only varieties suitable for producing traditional Mediterranean foods. These short rural food value-chains led to a 10-fold increase in the selling price of the harvested grains on food markets**. Overall, this agroecological approach boosted farm productivity and adaptation using better varieties and generated higher income through the empowerment of rural women. These achievements ensure that local farmers will continue to grow crops as source of income, rather than shift towards a resource-degrading farming system more focused on livestock grazing.

* DIIVA-PR Project, Dissemination of interspecific ICARDA varieties and elites through participatory research: https://mel.cgiar.org/projects/741

◀ *Engagement of rural female cooperatives in very short food value chains.* © M. Major

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For further information

(1) Sall A.T., Chiari T., Wasihun L., Kemal S.A., Ortiz R., van Ginkel M., Bassi F.M., 2019. Durum wheat (*Triticum durum* Desf.): origin, cultivation and potential expansion in Sub-Saharan Africa. *Agronomy*, 9. https://hdl.handle.net/20.500.11766/10010

(2) Alary V., Yigezu Y., Bassi F.M., 2020. Participatory farmers-weighted selection (PWS) indices to raise adoption of durum cultivars. *Crop Breeding Genetics and Genomics*, 2: 1-20. https://hdl.handle.net/20.500.11766/12044

(3) Bassi F., 2019. *Selection by stone*. https://hdl.handle.net/20.500.11766/10629

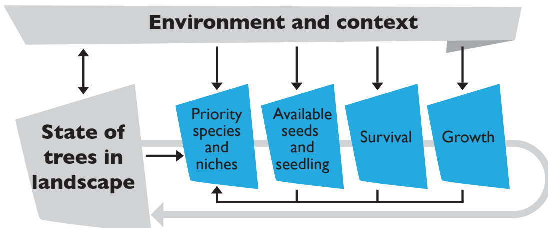
(4) Bishaw Z., Niane A.A., 2015. *Are farmer-based seed enterprises profitable and sustainable? Experiences of VBSEs from Afghanistan*. Chris Ojiewo (Curator), India. https://hdl.handle.net/20.500.11766/7097

Farmer-led increase in tree diversity across agricultural landscapes in Ethiopia

Increasing tree cover on farms in Ethiopia can contribute to environment-friendly agroecological transitions that support livelihoods. Yet most tree-planting schemes only promote a few species, thereby limiting the scope for applying agroecological principles that enhance biodiversity, recycling and synergy[1]. Recent research to gain insight into farmers' tree planting priorities in semiarid and subhumid regions of Oromia, revealed a huge potential for increasing tree diversity through farmer-led approaches[2]. Tree species and planting niches were elicited through focus group discussions. Seedling survival and growth patterns were then evaluated in participatory trials comparing 17 tree species across seven on-farm planting niches chosen by farmers.

Farmers identified a highly diverse range of tree species suitable for each niche, with fruit species mainly selected for homesteads. The diversity of desired tree species was found to be much higher than that typically available in nurseries or promoted by tree planting projects. It was hard to meet the planting demand because the existing seedling supply was not very diverse. The overall mean survival of tree seedlings planted on 1,893 farm/planting niche locations across both regions was 45.6 (±32.6) at 6 months and 33.6 (±25.5)% at 14 months, but there were striking differences among species, farms, regions and planting niches. The high variation in seedling survival amongst species, indicates the impact of local risk factors attributable to management, biotic and abiotic causes. Growth differences between the six shared species common to both agroecological regions, across different niches (*Cordia africana, Grevillea robusta, Jacaranda mimosifolia, Leucaena leucocephala, Moringa stenopetala* and *Sesbania sesban*), revealed significant effects of species and niche on growth ($p < 0.001$). **A farmer-led approach to increase tree cover, that combines an understanding of species and planting niche preferences with appropriate seedling supply and management, is proposed as a means to increase tree diversity in farmed landscapes** (Figure).

▶ *Conceptual framework for an integrated farmer-led approach to increase tree cover and diversity on farms, showing the change in tree cover (grey arrow) and filters (blue).*



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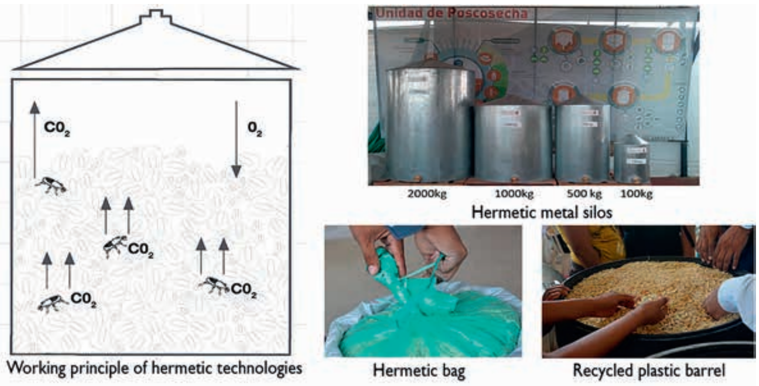
(1) Wezel A., Gemmill Herren B., Bezner Kerr R., Barrios E., Gonçalves A.L.R., Sinclair F., 2020. Agroecological principles and elements and their implications for transitioning to sustainable food systems. A review. *Agronomy for Sustainable Development*, 40: 40. https://doi.org/10.1007/s13593-020-00646-z

(2) Derero A., Coe R., Muthuri C., Hadgu K.M., Sinclair F., 2020. Farmer-led approaches to increasing tree diversity in fields and farmed landscapes in Ethiopia. *Agroforestry Systems*, (2020). https://doi.org/10.1007/s10457-020-00520-7

Minimizing insecticide use during grain storage in smallholder farming systems

Reducing food losses is important to make more nutritious food available and achieve Sustainable Development Goal 2 – Zero Hunger. In a smallholder farming system, from on-field predrying and harvest onward, grain undergoes processes during which improper handling associated with abiotic (ambient temperature, relative humidity) and biotic factors (insects, fungi, rodents) may lead to losses. To reduce losses, farmers may opt to treat their grain with insecticides during storage, frequently at inappropriate doses and without adequate practices, and little is known about the associated health risks. Insecticide use by smallholders is a public health concern as intoxication cases in Mexico and Latin America are frequently reported. Hermetic storage technologies (hermetic metal silo, hermetic bags, recycled hermetic plastic containers) represent a viable alternative for smallholders as these airtight technologies—by stopping the exchange of oxygen and moisture between the stored grain and its environment—are effective in controlling pest activity inside the storage containers, without the use of insecticides. Research has shown that, regardless of agroecological conditions, **hermetic storage technologies reduced postharvest losses from, on average, 39% (with conventional farmers' practices) to 3% in lowlands (< 500 m above sea level) in Mexico, where insect pressure is greater than in highlands. Hermetic technologies also limit fungal infestation and the associated risk of mycotoxin production[1], maintain the percentage of seed germination, and minimize quality loss during storage.** CIMMYT is promoting the use hermetic technologies with smallholders along with good handling practices, including low-cost shelling and drying solutions and moisture checking using simple methods. Building the postharvest technology market is also a key aspect as it facilitates farmers' physical and economic access to high-quality technologies that have the potential of minimizing losses and strengthening their food security.

▶ *Working principle of hermetic technologies and hermetic technologies promoted by CIMMYT in Mexico.* © CIMMYT



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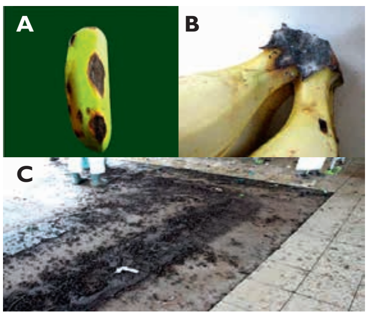
(1) Odjo S., Burgueño J., Rivers A., Verhulst N., 2020. Hermetic storage technologies reduce maize pest damage in smallholder farming systems in Mexico. *J. Stored Prod. Res.*, 88. https://doi.org/10.1016/j.jspr.2020.101664

Redesigning postharvest banana practices integrating agroecological constraints

Consumer demand has been steadily growing over the last decade for residue-free fruit and vegetables produced without chemical treatments. New marketing labels have thereby been developed to reassure consumers on the safety and high quality of such untreated produce. How can the high level of quality required by all banana stakeholders be reconciled with the barrier-breaking adoption of a field-to-fork agroecological approach? Addressing this future challenge has been a key research focus of the joint QualiSud research team (France). Indeed, banana is highly susceptible to postharvest diseases, particularly fungus attacks causing diseases like anthracnose (Photo A) and crown rot (Photo B).

It is now essential to implement an integrated approach to address this challenge while reconsidering postharvest practices through an agroecological lens[1]. This will be the best way to meet consumer demand for top quality bananas produced under environment-friendly conditions. Indeed, sanitary conditions in banana orchards as well as in packing stations (Photo C) must be optimized to curb the fungus contamination risk as early as possible. These prophylactic measures—although essential—would however not be sufficiently effective to compete the chemical fungus control. **As the harvest stage is the result of a trade-off between the banana yield, green life[2] and fungal disease susceptibility, it is a key parameter to take into account in the design of integrated solutions throughout the food chain. Moreover, the shipping stage needs to be streamlined by implementing new technologies and innovative approaches, e.g. combining controlled atmosphere conditions with the use of oxidative molecules like ozone.** Abandonment of the chemical treatment option poses many complex challenges yet it also opens new opportunities for the research community and consumers. Total elimination of chemical antifungal treatments will create a virtuous circle by restoring consumer confidence while fostering innovative research and development strategies.



▲ ***Photo A.*** *Anthracnose disease on a Cavendish banana.*
Photo B. *Crown rot on Cavendish bananas.*
Photo C. *Pistil accumulation, a source of* Colletotrichum musae *contamination at the packing station.*
© P. Brat

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(1) Lassois L., Jijakli M.H., Chillet M., De Lapeyre de Bellaire L., 2010. Crown rot of bananas: preharvest factors involved in postharvest disease development and integrated control methods. *Plant disease*, 94(6): 648-658.

(2) Brat P., Bugaud C., Guillermet C., Salmon F., 2020. Review of banana green life throughout the food chain: from auto-catalytic induction to the optimisation of shipping and storage conditions. *Scientia Horticulturae*, 262: 109054.

Fostering seed circulation for sustainable agriculture

From local to global

Farmers' seed networks have made vital contributions to crop diversity since the origin of agriculture. They provide an effective means of access to seed not only locally between farmers, but also over long distances, as illustrated by historic (e.g. spread of farming in sub-Saharan Africa with Bantu migration) and recent (e.g. African rice as a slave agricultural heritage in the Americas) introductions. This has enabled farmers to reshape—by selection, cultivation and further seed exchange—and adapt their crops. However, the role of farmers' seed networks—within which 80-90% of all seeds still circulate—with regard to biodiversity conservation and the development of sustainable agriculture in response to global climate change has only recently begun to be considered by researchers and policymakers[1]. Through several research projects under way in West Africa (Cerao, Coex, Amma2050, SeedAttach)*, we assessed the role of crop diversity and farmers' seed systems in boosting resilience to climate change. At the local scale in Senegal, our findings highlighted that family and neighborhood social networks were pivotal to the reintroduction of a long-cycle millet landraces, offering farmers a new option in their cropping strategies geared towards climate change adaptation. Farmers' seed systems must thus be preserved for the functions and services rendered within agrosociosystems. At the regional scale, mapping the projected genomic vulnerability of pearl millet by the year 2050, we showed that farmers are likely to need to source seeds beyond their traditional social ranges so as to better meet their needs for varietal adaptation to climate change[2]. The use of adapted genetic resources should be implemented at different scales while respecting the diversity with regard to value systems and access rights for multiple actors[3]. **This research has highlighted the role of farmers' seed systems in reviving crop diversity, empowering local farmers, and the need for their consideration in seed policy and genetic resource conservation.**

* Amma2050, African Monsoon Multidisciplinary Analysis 2050 (Natural Environment Research Council/UKAID): www.amma2050.org/fr/Home

Cerao, Self-adaptation of tropical agro-socio-ecosystems to global changes? A long term study for ecological intensification of cereal production in West African savannas (ANR): https://anr.fr/en/funded-projects-and-impact/funded-projects/project/funded/project/b2d9d3668f92a3b9fbbf786607250 1ef-f76a020d40/?tx_anrprojects_funded%5Bcontroller%5D=Funded&cHash=c32e0eea8f12931b19f0a101161168a3

Coex, Adaptative Governance for the Coexistence of Crop Diversity Management System (Agropolis Fondation): www.agropolis-fondation.fr/CoEX-418?lang=fr

SeedAttach (Agropolis Fondation), Community seed banks for social justice and conservation of biodiversity? Networks of actors and dynamics of seed attachment

▲ *Diversity of sorghum grains in Cameroon.* © A. Barnaud/IRD

◀ *Harvesting sorghum in Cameroon.* © A. Barnaud/IRD

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(1) Coomes O.T. *et al.*, 2015. Farmer seed networks make a limited contribution to agriculture? Four common misconceptions. *Food Policy*, 56: 41-50. https://doi.org/10.1016/j.foodpol.2015.07.008

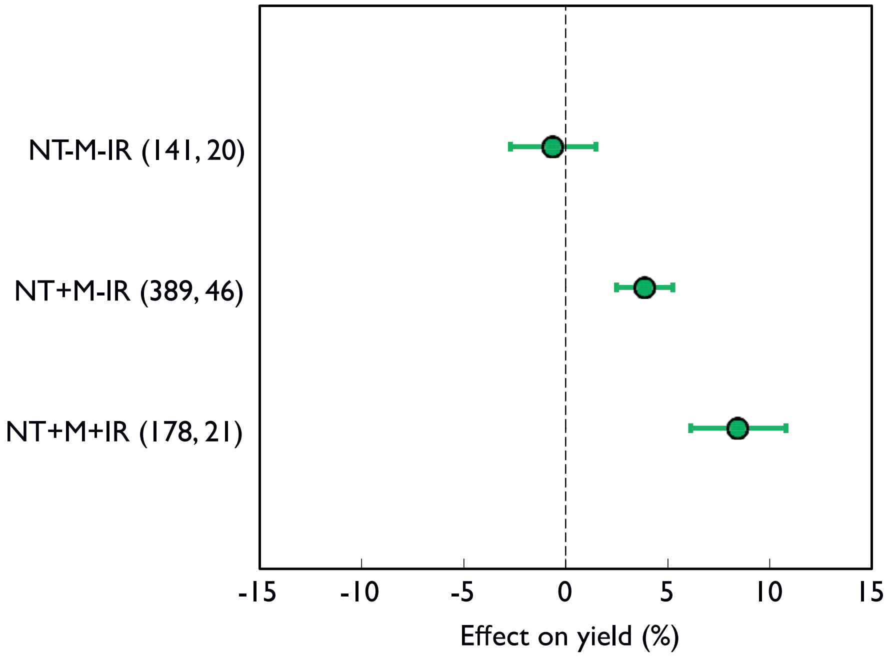
(2) Rhoné B., Defrance D., Berthouly-Salazar C., *et al.*, 2020. Pearl millet genomic vulnerability to climate change in West Africa highlights the need for regional collaboration. *Nat Commun*, 11: 5274. https://doi.org/10.1038/s41467-020-19066-4

(3) Jankowski F., Louafi S., Kane N.A., *et al.*, 2020. From texts to enacting practices: defining fair and equitable research principles for plant genetic resources in West Africa. *Agric Hum Values*, 37: 1083-1094. https://doi.org/10.1007/s10460-020-10039-3

Conservation agriculture and maize yields in sub-Saharan Africa

Conservation agriculture (CA) is promoted in sub-Saharan Africa as an agroecological practice that increases crop productivity in a sustainable way. CA is not simply a single technology but a package of management practices whose actual implementation varies among farmers. The effects on crop yields are therefore complex. We conducted a meta-analysis on the effects of the three CA principles, i.e. no-tillage, mulching and crop rotation/intercropping, and related management practices and contexts on maize productivity in sub-Saharan Africa[1]. We noted **a significant average 8.4% increase in maize yields when the three CA principles were implemented concomitantly**. Crop yield benefits resulted principally from mulching and crop rotations or intercropping (Figure next page). It was also found that yield benefits with CA were greatest under limited rainfall conditions and when herbicides were applied. Crop residue mulching provides groundcover and adds organic matter to the soil, thereby enhancing soil functioning. This can increase crop productivity, especially in low-input cropping systems with limited external nutrient inputs. Mulching also reduces soil water evaporation loss and increases soil water infiltration, so crops make more effective use of rainfall.

Crop rotations and intercropping disrupt pest and disease habitats and life cycles and the cropping system benefits from higher soil nitrogen levels when legumes are involved in the rotation. Herbicide treatments boost the CA performance, since chemical weeding is generally more effective than mechanical (hand)weeding in managing the increased weed pressure in the absence of tillage. Yet the adoption of mulching and crop rotations is not easy for many smallholder farmers in sub-Saharan Africa who manage mixed crop-livestock systems. Crop residues have several other uses on farms, especially livestock feed. Legumes are often overlooked as rotation crops or intercrops, since functional markets are generally lacking for their sale. Finally, sustainability concerns regarding herbicide use highlight the need for alternative effective weed control strategies for smallholders adopting CA.



▲ ***Effects of conservation agriculture (CA) relative to conventional tillage (CT) on maize grain yield under different combined CA principles.***
NT-M-IR indicates no- or reduced tillage without crop residue mulching and crop rotation or intercropping, NT+M-IR indicates no- or reduced tillage with crop residue mulching and without crop rotation or intercropping and NT+M+IR indicates no- or reduced tillage with crop residue mulching and crop rotation or intercropping). Values represent mean effect sizes with 95% confidence intervals. The number of observations and studies per category are shown in parentheses. Source: Corbeels et al. *(2020).*

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(1) Corbeels M., Naudin K., Whitbread A.M. *et al.*, 2020. Limits of conservation agriculture to overcome low crop yields in sub-Saharan Africa. *Nat Food*, 1: 447-454. https://doi.org/10.1038/s43016-020-0114-x

Tree stakes for climbing beans in Rwanda

Population growth and land fragmentation (farm sizes 0.3–0.6 ha) in Rwanda has resulted in reduced agricultural productivity and increased hunger and malnutrition, with 38% of children under 5 years being stunted. Rwanda has the highest bean consumption (29 kg person^{-1} yr^{-1}) in the world. Climbing and bush beans are affordable and highly nutritious. However, vertical production of climbing beans enhances land use efficiency over bush beans, with 0.5–2-fold higher yields. Despite this, climbing bean cropping is hampered by the lack or inadequate supply of stakes, other competing needs for stakes (e.g. firewood), and the high demand for fodder through the 'One-cow-per-poor-family' program.

To sustainably address this situation, the Trees4FoodSecurity project*, through a participatory approach, introduced a range of agroforestry interventions in semi-arid Bugesera and humid Gishwati districts to provide staking options for different contexts. A total of 540 participatory trials involving 387 farmers were set up. In Gishwati, bean yields using *Alnus acuminata* stakes produced **1.7-2.2 t/ha compared to 1.4-1.9 t/ha** with the commonly used *Pennisetum purpureum* stakes. At various sites in Bugesera district (Musenyi, Juru, Rweru and Nyamata sectors), **the use of stakes increased bean yields from the baseline 0.7 t/ha under bush beans to a maximum of 2.5 t/ha under climbing beans**, depending on stake type and field location. Staking options included *Senna spectabilis*, *Gliricidia sepium Calliandra calothyrsus*, *Grevillea robusta, Vernonia amygdalina* and *Lantana camara* stakes, with the latter two generally producing lower yields, probably due to weaker and shorter stakes. Irrespective of the staking treatment, yields were highest in the wetter Rweru sector and lowest in the drier Musenyi sector. The study clearly demonstrated that agroforestry offers a cost-effective and sustainable way of boosting bean production, thereby enhancing food, nutritional and environmental security in Rwanda. The identification of climbing bean varieties well-adapted to the semiarid environmental conditions in Bugesera is recommended.

* Trees4FoodSecurity project: https://bit.ly/2xOwwzV

▶ ***Photo showing climbing beans and bush beans in Juru Bugesera, Rwanda.*** *© J. Nyaga, Rwanda*

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For further information

• www.worldagroforestry.org/blog/2020/04/03/more-stakes-more-climbing-beans-less-malnutrition-rwanda-finds-solution

• Musoni A., Kayumba J., Butare L., Mukamuhirwa F., Murwanashyaka D., Kelly J.D., Ininda J., Gahakwa D., 2014. Innovations to overcome staking challenges to growing climbing beans by smallholders in Rwanda. *In* Vanlauwe B. *et al.* (eds.): *Challenges and opportunities for agricultural intensification of the humid highland systems of Sub-Saharan Africa*. Springer International Publishing, Heidelberg.

Agroecology in North African irrigated plains?

Mapping promising practices and characterizing farmers' rationales

In the irrigated plains of North Africa, productive resource sustainability is subject to multiple threats linked to the prevailing productivist irrigated agriculture model. These threats—such as soil degradation and unequal access to resources, markets and information—prompt farmers to mobilize depleting natural resources, including soil and water, often in an environmentally unsustainable way. Farmers sometimes update their strategies by implementing alternative farming practices to sustain their farming systems and derived incomes. A group of researchers, led by the G-EAU joint research unit in Montpellier, conducted a study to map and analyze these existing local farming practices with agroecological potential. The approach involved direct observations combined with 150 interviews of farmers in three major irrigated plain regions in North Africa, i.e. Merguellil, Upper Cheliff and Saiss plains in Tunisia, Algeria, and Morocco, respectively. The findings showed that **a wide range of alternative practices with agroecological potential exist or are emerging, in contrast to the predominant intensive farming-oriented model**. The most common practices are geared towards improving soil fertility management (manure tea production, integration of legumes in crop successions), increasing per-ha agricultural production (relay intercropping, intercropping, agroforestry), or providing multiple ecosystem services (diversification, livestock integration). These practices are jointly used, mostly to: (i) increase land-use efficiency, and hence address land fragmentation; (ii) diversify cropping strategies, and decrease market-related risks; and (iii) reduce expensive production costs related to irrigation and chemical fertilization. The large differences observed in the adoption of these practices in the three case study sites suggests a strong influence of contrasting sociopolitical and historical factors at regional and national levels. An analysis of farmers' rationales with regard to implementing such practices revealed that economic imperatives take precedence over environmental concerns. As such, these practices can be seen as: (i) a means of access to low-cost strategies for smallholder farmers; or (ii) a pathway to international markets for agribusiness farmers. Awareness of the extensive local knowledge related to ecological intensification strategies, as identified here, could help pave the way to more sustainable agriculture in this intensively cultivated region of the world.

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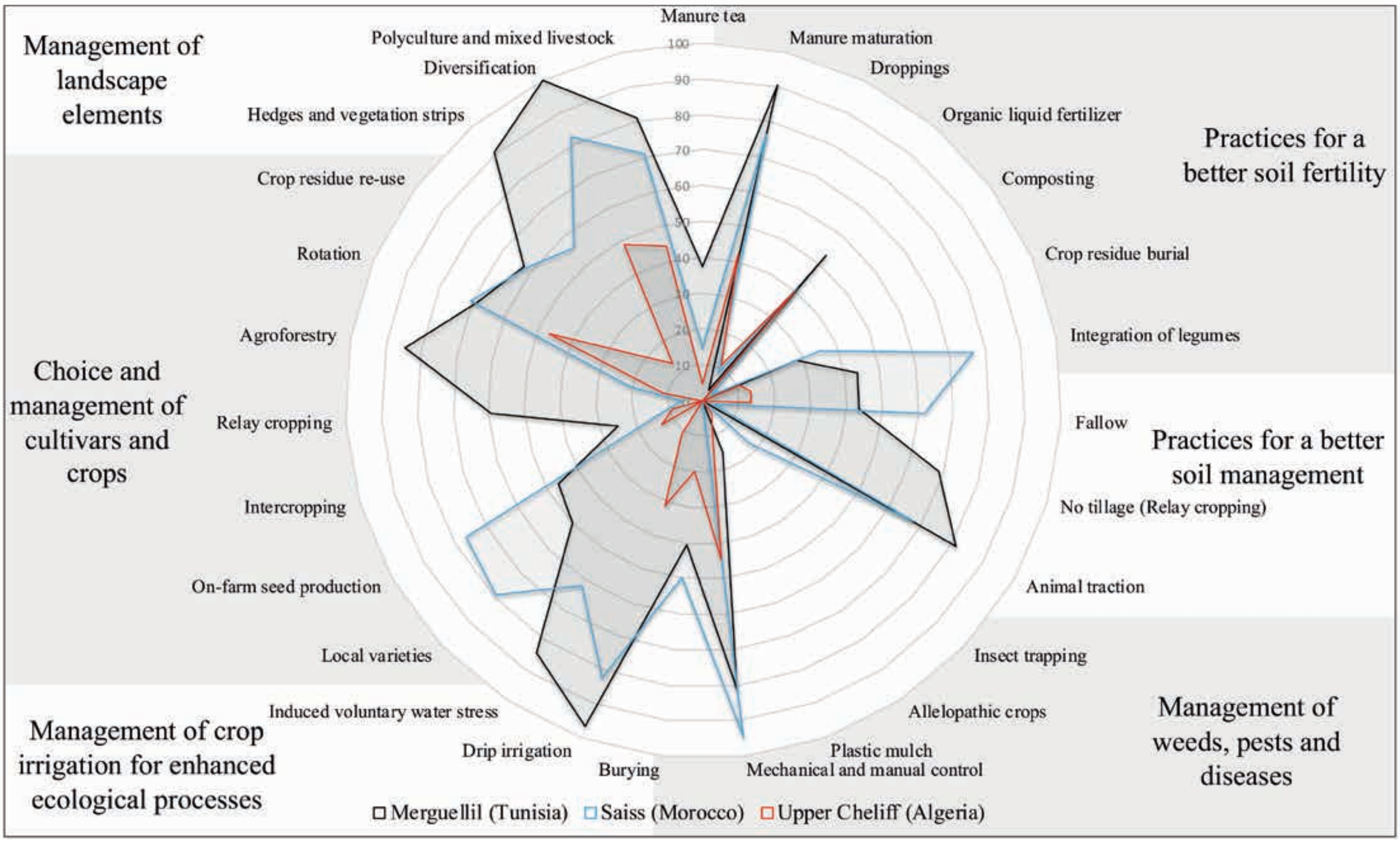
For further information

• Akakpo K., Bouarfa,S., Benoît M., Leauthaud C., 2021. Challenging agroecology through the characterization of farming practices' diversity in Mediterranean irrigated areas. *European Journal of Agronomy,* 128: 26284.

• Ameur F., Amichi H., Leauthaud C., 2020. Agroecology in North African irrigated plains? Mapping promising practices and characterizing farmers' underlying logics. *Regional Environmental Change,* 20(4): 1-17.

• Leauthaud C., Akakpo K., Ameur F., 2020. Des pratiques agroécologiques invisibles en milieu irrigué en Tunisie : exemple de la plaine du Merguellil. *In:* Bouarfa S. *et al.* (coord.) : *Quelles agricultures irriguées demain ? Répondre aux enjeux de la sécurité alimentaire et du développement durable.* Éditions Quæ, France. 212 p.

• Project website: http://viana.cirad.fr/



▲ *Presence (%) of each identified practice with agroecological potentials at the three case study sites, differentiated by practice type.*
From Ameur et al. *(2020)*

Chapter 2

Substituting intensive external input use by biodiversity-derived ecosystem functions

One of the fundamental principles of agroecology is to increase crop performance by strengthening ecosystem functions driven by available agrobiodiversity. This so-called ecological intensification process enhances biomass production by improving nutrient and water cycles and combating pests and diseases, while keeping external input use to the bare minimum. This chapter presents research summaries regarding **Gliessman's second transition** level, which aims: "to replace external input-intensive and environmentally degrading products and practices with those that are more renewable, based on natural products, and more environmentally sound [….] They employ alternative practices that include the use of nitrogen-fixing cover crops and rotations to replace synthetic nitrogen fertilizers, the use of natural controls of pests and diseases, and the use of organic composts for fertility and soil organic matter management."

At this level, the focus is essentially on the cropping system (more rarely on the production system) and the practice changes mainly concern specific production aspects: nutrient dynamics, pest protection, water efficiency, etc. Essentially six HLPE principles are applied in innovations, i.e. recycling, input reduction, soil health, animal health, biodiversity and synergy and in some cases co-creation of knowledge (when there is participatory innovation). The most important principle applied here is diversification and the overall idea is to mobilize or amplify ecosystemic functions while minimizing the use of external inputs that are widely used in intensive production systems. At this level of transformation, farmers are the main actors involved.

The external input substitution process depends greatly on the cropping system considered and the local context. The transformation pathways to apply transition step 2 could differ markedly because there are several starting points and different changes of pace. For example, in a low-input production system, the focus would be more on finding ways to intensify and increase yields, without recourse to excessive use of external inputs. However, in an intensive, high external input system, the focus would be on determining how to reduce the use of these inputs and substituting with organic and agroecological functions, without significant yield loss or reduction.

Research addressing this substitution stage could fall in three categories:

Biological pest and disease regulation: Controlling crop pests and diseases is a key factor determining the final yield. Pesticide-use is claimed to be 'convenient', i.e. a single product may be designed to kill a range of pests, pathogens, weeds, etc. In-depth knowledge on the functionalities at play in living communities is needed to be able to replace pesticides or minimize their use, e.g. through regulation provided by biodiversity uses. A few examples are outlined here. In general, increasing varietal diversity, and optimizing its pattern in the field is a low-cost strategy to reduce the impact of pests and diseases (de Santis *et al.*), as illustrated in Ethiopian Highlands, where temporal and varietal diversification were found to minimize the impact of rust epidemics in wheat crops, and of *Orobanche crenata* in temperate food legume crops (Kemal *et al.*). The use of auxiliary species to control pests and diseases can be a second step: in Réunion, increasing biodiversity—animal, plant and microbial—in the vicinity of the crop fields, and both above- and below-ground, can markedly reduce, and sometimes eliminate, pesticide use in horticulture (Deguine *et al.*); in southern Europe, the careful introduction and mass rearing of *Cotesia typhae*, a new parasitoid species that preys on corn stemborers (*Sesamia nonagrioides*), is promising (Kaiser *et al.*). However, decisions with regard to using these tools may not depend only on their efficacy, the concerned farmers might be locked into their technical practices due to external constraints (Navarrete *et al.*). These agroecological techniques are sometimes complex and require in-depth research in plant and animal physiology. In Madagascar, a combination of silica inputs and enhanced earthworm activity was found to enhance rice crop tolerance to leaf blast (*Pyricularia* sp.), which disappeared when nitrogen fertilizers were applied (Blanchart). Soil biodiversity is essential for crop health and rhizosphere microbiomes, when enhanced with growth-promoting microbes, produce multiple benefits of induced plant growth, defense against diseases and survival under stress (Gopalakrishnan *et al.*). Biocontrol through the use of plant extracts in crop fields is also an interesting avenue to be explored (Sylvie & Martin).

▼ ***Agroecology in Senegal.*** *© T. Chevallier/IRD*

Reducing dependency on external costly inputs: Soil fertility is one of the most important elements in production systems, which explains the massive use of external fertilizer inputs in conventional cropping systems. Alternative approaches, based on the agroecological principles of recycling, diversification and soil health management, allow substantial input reduction. This is illustrated here: by the fine-tuned management of manure applications on Sahelian soils (Lardy *et al.*; Masse); the so-called priming effect to enhance the mineralization of organic matter which is essential for soil health and nutrient supplies (Bernard & Maron); the optimized use of crop residues associated with legume cover crops in industrial palm plantations, where fertilizer inputs could represent up to 80% of the total cost of the crop (Bessou); or crop residue composting with manure in intensive rice cropping systems in the Mekong region (Nguyen *et al.*). Soil fertility and crop yields were shown to be markedly improved in agroforestry systems: associations with *Ziziphus mauritiana* trees in Sahelian regions improved the rainwater use efficiency, soil fertility and millet yields, while maintaining the soil organic carbon content (Bado *et al.* and chapter 3, see page 50). Although requiring innovative tenure arrangements with regard to both land and trees (Chomba *et al.*), as well as long-term investment and financial support, the introduction of trees was found to substantially boost farmers' income within a few years, thereby enhancing their family's livelihood (La *et al.*). Associations with legume crops were found to improve soil fertility, and the use of bioinoculants could boost crop yields provided that their quality is controlled (Herrmann *et al*). Diversification in climate change stricken regions could also provide gains in terms of water management (Devkota & Nangia)

Substituting environmentally disruptive inputs: Pest and disease control with pesticides is a major source of pollution and health hazards in the tropics, and replacing these dangerous chemicals is crucial goal of agroecology. This is illustrated here in the agroecological approaches implemented to control devastating fall army worms (*Spodoptera frugiperda*): in Africa, through integrated strategies (improving plant health through better soil fertility, diversifying farms and landscapes to favor natural enemies and increase their efficacy (Harrison); in India, combining different tools to control fall army worms without insecticide use seems very promising (Jaba *et al.*); as well as in Mexico with the use of pheromone traps (Fonteyne *et al.*). The current vegetable production boom in sub-Saharan Africa relies on intensive chemical control, and agroecological methods are now employed to reduce this chemical input reliance. One example concerns the use of affordable low-tech net houses that protect plants against pests and extreme climatic conditions (Deletre *et al.*). The next generation of crop pest and weed management in countries of the Global South will be scalable and based on a combination of nature-based solutions and affordable digital mobile phone-based tools tailored for use by low-literacy farmers (Tamò & Chikoye; Malézieux).

In livestock production, the sometimes massive use of chemicals to control crop pests and parasites has major impacts on health and the environment, particularly regarding the issue of antibiotic resistance development. Drastic changes in production systems are thus needed alongside the adoption of One Health approaches (Ducrot *et al.*). Two examples of alternatives are presented here: the promising use of color baited toxic screens and baits to control hematophagous flies that can transmit numerous diseases to humans and livestock (Desquesnes *et al.*); and the diversification of pasture plant species that was found to reduce outbreaks of sheep, goat, equine and bovine parasites, in turn significantly reducing prophylactic helminthicide treatments (Dumont *et al.*). Aquaculture also involves high usage of dangerous inputs, yet solutions for ecological intensification in aquaculture exist based on optimized diversification of trophic links and integration with other types of production (Caruso *et al.*).

The sections below provide some details on examples of agroecology interventions relating to the three categories of research that addresses the substitution stage and principle.

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Biological pest and disease regulation

Agroecology and crop varietal mixtures for pathogen damage reduction

Large-scale monocultures—triggered by the Green Revolution and the availability of new technologies—are a major feature of the agricultural intensification process. This phenomenon has led to a remarkable increase in food production over the last century. Despite increases in agricultural productivity, this move to uniformity and increased use of agricultural inputs, particularly for pest and disease management, has had profound, damaging side-effects to ecosystem functioning, such as the reduction of beneficial organisms. Despite technological advances such as the breeding of highly resistant varieties, the reduced diversity is negatively affecting farming system performance and resilience, particularly for smallholders farming in marginal rainfed agroecological areas. A burgeoning body of literature has highlighted the superior efficacy of multilines, varietal mixtures and varieties with non-uniform resistance compared to pure cultures with regard to disease control and enhanced crop yields in small- and medium-scale systems. This efficacy is particularly clearcut against airborne pathogens (e.g. rust and powdery mildew affecting small grain crops).

Varietal diversity represents a low-cost strategy to reduce the impact of pests and diseases, whose attacks are curbed by the heterogeneous responses of varieties deployed in the field. **Several factors contribute to the efficacy of intraspecific diversity in reducing pest and disease damage, including the number and type of varieties, which need to differ in their susceptibility, amount, distribution and arrangement in the field**. Varietal mixtures help reduce the pest incidence and disease severity by limiting the capacity of the infecting agents to attack the host, while also reducing the infestation severity and restraining the pathogen population and its capacity to evolve and overcome the host's resistance. A study carried out on common bean in Uganda demonstrated that **a systematic random varietal mixture (50% of a resistant variety) significantly reduced bean fly damage on the susceptible variety. Furthermore, damage reduction was often correlated with higher yields.** Varietal diversity reduces the need for pesticide use and helps maintain a healthy environment, in turn leading to an increase in natural enemies, while reducing the development of insecticide resistance in pests and pathogens.

▼ *Farmers in the field assessing different common bean varieties in Nakaseke, Uganda.* © D.I. Jarvis

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• Jarvis D.I., Padoch C., Cooper H.D. (eds.), 2007. *Managing biodiversity in agricultural ecosystems*. Columbia University Press.

• Mulumba J.W., Nankya R., Adokorach J., Kiwuka C., Fadda C., De Santis P., Jarvis D.I., 2012. A risk-minimizing argument for traditional crop varietal diversity use to reduce pest and disease damage in agricultural ecosystems of Uganda. *Agriculture, ecosystems & environment*, 157: 70-86.

• Ssekandi W., Mulumba J.W., Colangelo P., Nankya R., Fadda C., Karungi J., Otim M., De Santis P., Jarvis D.I., 2015. The use of common bean (*Phaseolus vulgaris*) traditional varieties and their mixtures with commercial varieties to manage bean fly (*Ophiomyia* spp.) infestations in Uganda. *Journal of Pest Science*: 1-13.

Management of emerging pests through crop diversification in wheat-based cropping systems in the Horn of Africa and MENA region

Traditionally smallholder farmers in the Middle East and North Africa (MENA) grow different field crops for food, income, soil fertility and animal feed. However, due to increased government incentives and high market demands, farmers tend to grow wheat year after year on vast expanses of arable land, while the demand for food legumes is filled through huge imports. In many parts of MENA, wheat monocropping is a chronic production challenge, leading to poor soil health and rust epidemics that cause crop losses and incur high production costs. The reduction in crop and variety diversification also forces farmers to buy more expensive pulse crops to fulfil household food needs in East African highland areas. Crop diversification approaches are thus required to avoid a shortage of important crops for nutritional security and to mitigate climate change and farming system transitions that favor new diseases, parasitic weeds and insect pests.

Two interventions were conducted to diversify wheat monocropping and manage parasitic weeds of temperate food legumes in the highlands of Ethiopia. ILRI-ICARDA implemented validated crop technologies and scaling to reduce wheat monocropping while promoting temporal crop and variety diversification in this region. Farmers preferred high-yielding and disease-resistant durum wheat cultivars, while barley and food legumes were scaled out using informal seed systems. **The approach increased productivity, minimized cereal rust epidemics and improved sustainable wheat-based production systems.** The second intervention focused on managing weeds (*Orobanche* spp.) affecting food legumes through crop diversification. The intervention involved selection and promotion of non-host alternative crops (fenugreek, linseed, and common bean) in farmers' fields in the northeastern highlands of Ethiopia. In conclusion, spatiotemporal crop diversification should be further investigated and promoted as an effective crop production approach to minimize the impact of new and emerging pests on the livelihoods of farming communities and on the erosion of cereal and food legume genetic resources in MENA and East African highland areas.

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For further information

• Bishaw Z., Yigezu Y.A., Niane A., Telleria R.J., Najjar D. (eds), 2019. *Political economy of the wheat sector in Morocco: seed systems, varietal adoption, and impacts.* ICARDA, Beirut, 300 p. https://repo.mel.cgiar.org/handle/20.500.11766/8505

• Michler J.D., Josephson A.L., 2017. To specialize or diversify: agricultural diversity and poverty dynamics in Ethiopia. *World Development*, 89: 214-226. https://doi.org/10.1016/j.worlddev.2016.08.011

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1. Diversification of the wheat-based cropping system in the highlands of Ethiopia was funded by AFRICA RISING/USIAD project through ILRI. https://africa-rising.net/category/ilri/

2. Management of parasitic weeds on food legumes in Ethiopia was funded by Agricultural Innovation MKTPlace, Embrapa-Brazil. www.embrapa.br/en/marketplace

▲ *Selection of non-host species for crop diversification to manage parasitic weeds in northeastern Ethiopia.* © *ICARDA*

Agroecological protection of fruit and vegetable crops in Réunion

Horticultural crops are—alongside sugarcane—the main agricultural outputs in Réunion. The use of pesticides to control animal pests, plant pathogens and weeds, as widely practiced since the 1980s, has shown its limits: low efficiency and profitability, negative environmental and health impacts, ecological imbalances, etc. Since the late 2000s, collective approaches based on agroecological crop protection (ACP) principles have been developed and implemented as a sustainable alternative to pesticide use for horticultural production. Vegetable crops (Cucurbitaceae: chayote, zucchini, pumpkin; Solanaceae: tomato) and fruit crops (mango) were considered. ACP is an agroecologically-oriented approach based on two main principles: the promotion of plant and animal biodiversity in agroecosystems; and maintenance and improvement of soil health in cultivated plots.

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◀ *Maize trap plants placed around a zucchini crop plot, as one of the agroecological levers used to control fruit flies.* © *J.-P. Deguine/CIRAD*

These initiatives involved many partners from the agricultural sector, with farmers being at the core of the system. They were conducted in several stages before, during and after partnership R&D projects. The performance of agrochemically-controlled horticultural cropping systems was compared with that of agroecological cropping systems in commercial fields (Table). **The results were very encouraging[1,2,3]: drastic reduction or even elimination of pesticides (especially herbicides and insecticides), restoration of biodiversity (e.g. arthropods) and ecological functioning of agroecosystems (fruit and vegetable production), reduction of production costs without loss of production, reduction of labor time and increased farmer satisfaction**. For example, two-thirds of the chayote (*Sechium edule*) cropping area is now under organic farming with agroecological practices. This research has given rise to new projects focused on diversified cropping systems, while generic drivers of the adoption of innovative agroecological cropping systems have also been proposed.

* http://gamour.cirad.fr/site
** https://ecophytopic.fr/recherche-innovation/concevoir-son-systeme/rescam-reseau-dexperimentations-de-systemes-cultures
*** www.agriculture-biodiversite-oi.org/Biophyto
**** https://ecophytopic.fr/dephy/conception-de-systeme-de-culture/projet-st0p

Recommended agroecological practice	Vegetable crops (Cucurbitaceae)		Fruit crops (mango)
	Chayote	Courgette	Mango
Discontinuation of conventional insecticide treatments	Yes	Yes	Yes
Discontinuation of herbicide treatments	Yes	Yes	Yes
Sanitation (augmentorium)	Yes	Yes	Yes
Permanent vegetation 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 bait	No	Yes	Yes
Curative measures*	No	No	No

▲ ***An ordered and methodical strategy for agroecological crop protection, adopted for experiments on Cucurbitaceae and mango in Réunion** (in Deguine et al., 2019b).*
Chayote and courgette are considered separately (with other field crops such as pumpkin and cucumber being pooled 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.
** In these curative measures, the use of chemical pesticides is considered to be a last resort and must only be used in an optimized and targeted way, with as little impact as possible so as not to jeopardize biological control.*

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(1) Deguine J.-P., Jacquot M., Allibert A., Chiroleu F., Graindorge R., Laurent P., Albon B., Marquier M., Gloanec C., Lambert G., Vanhuffel L., Vincenot D., Aubertot J.-N., 2018. Agroecological protection of mango orchards in Réunion. *Sustainable Agriculture Reviews*, 28: 249-308. https://doi.org/10.1007/978-3-319-90309-5_8
(2) Deguine J.-P., Atiama-Nurbel T., Vanhuffel L., Cresson C., 2019a. Recent advances in organic cultivation of chayote (*Sechium edule*) in Reunion Island. *Organic agriculture*, 10: 135-143. https://doi.org/10.1007/s13165-019-00255-5
(3) Deguine J.-P., Aubertot J.-N., de Cambiaire J.-C., Cresson C., Fares M., Lambert G., Marquier M., Nurbel T., Laurent P., Vanhuffel L., Vincenot D., 2019b. Development of agroecological horticultural systems in Réunion. *In* Côte F.-X., *et al.* (eds): *The agroecological transition of agricultural systems in the Global South*. Agricultures et défis du monde collection, AFD, Cirad, Éditions Quæ, Versailles: 127-140.
• IPSIM-CHAYOTE website: a tool to help farmers predict, discuss and manage chayote fly damage in Réunion: https://pvbmt-apps.cirad.fr/apps/ipsim-chayote/?lang=en

Promoting a new *Cotesia* species as a first biological control agent against the invasive Mediterranean corn borer in France

Insect parasitoids play an important role in limiting phytophagous insect populations. Because they often have a narrow host-range, many parasitoid species are used for pest insect control. A research program on the diversity of Lepidoptera stemborers and their parasitoids in sub-Saharan Africa has led to the characterization of a new parasitoid species, *Cotesia typhae* (Hymenoptera, Braconidae), specialized on a single host species[3]. The latter, *Sesamia nonagrioides*, mainly causes damage to maize in southern Europe where damage rates often increase due to mild winters, lack of authorized insecticides and lack of a biocontrol agent. A Kenyan *C. typhae* strain was found to have high parasitic success on European *S. nonagrioides* host populations[1]. A French-Kenyan research program* is currently investigating the potential of this parasitoid to control the pest via yearly releases, while addressing the following aspects: (i) mechanisms of parasitism success and specificity; (ii) risk of establishment in the French environment; (iii) conditions of success in greenhouses; and (iv) mass-rearing techniques.

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▲ ***From left to right:***
Cotesia typhae *female antennating a* Sesamia nonagrioides *larval dejection at the tunnel entrance. © C.J. Parisot/EGCE*
C. typhae *female ovipositing dozens of eggs into* S. nonagrioides *larva. © R. Benoist, EGCE*
C. typhae *nymphal cocoons formed around the host body after completion of larval endoparasitic development. © L. Kaiser/EGCE*

The decision to authorize the use of exotic macro-organisms for crop protection in France depends on the environmental cost-benefit balance. We expect the cost to be low considering: (i) the rare presence in non-crop habitats of *Cotesia flavipes*, a sister species that was introduced in East Africa 25 years ago to control an invasive maize pest(4); and (ii) current results with *C. typhae* highlighting a low probability of long-term establishment. Knowledge obtained on the natural habitat of *C. typhae*(2) led to a listing of a dozen non-target stemborer species in France. Few cases of successful parasitism have been recorded in laboratory conditions. This risk would be mitigated by the fact that, as *C. typhae* developmental lethality begins at 10°C, it is unlikely that these parasitoids would survive the winter. Regarding the benefits, preliminary greenhouse data on parasitism rates and length of efficiency of a single release are encouraging. Mass production will be carried out in Kenya. A mathematical model will be developed to simulate data in field conditions**. Upscaling to field conditions will also benefit from experience regarding the marketing of *C. flavipes* to control sugarcane stemborers in Brazil. **If successful, biological control with *C. typhae* will illustrate the essential contribution of long-term ecological and biological studies to the setting up of effective sustainable pest control methods.**

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* CoteBio ANR-AFB project: https://bit.ly/3septaJ

** Phenofore SEMAE project: www.arvalisinstitutduvegetal.fr/phenophore-@/view-3153-arvstatiques.htm

For further information

(1) Benoist R., Paquet S., Decourcelle F., Guez J., Jeannette R., Calatayud P.-A., Le Ru B., Mougel F., Kaiser L., 2020. Role of egg-laying behavior, virulence and local adaptation in a parasitoid's chances of reproducing in a new host. *J. Insect Physiol.*, 120: 103987. doi: 10.1016/j.jinsphys.2019.103987

(2) Kaiser L., Le Ru B.P., Kaoula F., Paillusson C., Capdevielle-Dulac C., Obonyo J.O., Herniou E., Jancek S., Branca A., Calatayud P.-A., Silvain J.-F., Dupas S., 2015. Ongoing ecological speciation in *Cotesia sesamiae*, a biological control agent of cereal stem borers. *Evolutionary Applications*, 8(8): 807-20. doi: 10.1111/eva.12260

(3) Kaiser L., Fernandez-Triana J., Capdevielle-Dulac C., Chantre C., Bodet M., Kaoula F., Benoist R., Calatayud P.-A., Dupas S., Herniou E.A., Jeannette R., Obonyo J., Silvain J.F., Le Ru B., 2017. Systematics and biology of *Cotesia typhae* sp. n. (Hymenoptera, Braconidae, Microgastrinae), a potential biological control agent against the noctuid Mediterranean corn borer, *Sesamia nonagrioides*. *ZooKeys*, 682: 105-136. doi: 10.3897/zookeys 13016

(4) Mailafiya D.M., Le Ru B.P., Kairu E.W., Calatayud P. -A., Dupas S., 2010. Geographic distribution, host range and perennation of *Cotesia sesamiae* and *Cotesia flavipes* Cameron in cultivated and natural habitats in Kenya. *Biological Control,* 54: 1-8. doi: 10.1016/j.biocontrol.2009.11.008

Towards agroecological soil pest management in sheltered vegetable cropping systems in Provence

In France, despite public policies urging reductions in pesticide use, agroecological practices for soil pest management are not widely applied on vegetable crop farms. This study focused on conventional vegetable farming systems in Provence (France) that are geared towards long-distance value chains. Based on semi-structured interviews, grey literature, participatory observations and multi-actor workshops, as well as a novel framework for analyzing farming practice determinants, we showed that **an interlinked set of barriers to changing of farming practices is impeding the agroecological transition of these vegetable cropping systems**. These barriers occur at different scales (plot, farm, territory, etc.) and involve a diverse range of stakeholders (farmers, marketing firms, R&D and institutional stakeholders, etc.). The barriers lock stakeholders into drastic soil disinfection. However, this lock-in is being challenged by societal pressure and the increased agroecology-oriented structuring adopted by a part of the stakeholders. We also identified levers facilitating the transition to agroecological management of soil pests, such as easier access to key agroecological soil management inputs (organic amendments, resistant varieties) and the development of networks for knowledge exchange between vegetable crop farmers. The outputs of this socio-technical analysis were shared with and enhanced by stakeholders using a specially tailored serious game that we designed. SoilH&co is based on a simplified representation of vegetable production and the different stakeholders that influence it, while also dealing with the effects of technical choices on soil pest infestation levels. The use of the game, while reversing the roles of vegetable growers and non-growers, enabled stakeholders to understand the current lock-in and identify levers for overcoming it. These levers were subsequently investigated. This work was achieved within the framework of Yann Boulestreau's PhD thesis research (2017-2021, ADEME and INRAE-ACT funding).

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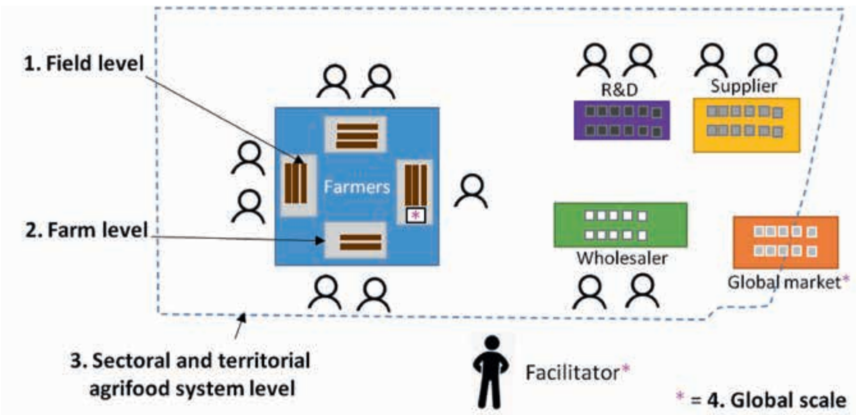
For further information

• Boulestreau Y., Casagrande M., Navarette M., 2021. Analyzing barriers and levers for practice change : a new framework applied to vegetables' soil pest management. *Agron. Sustain. Dev.*, 41, 44: 18.

• Boulestreau Y., 2021. *A co-design approach for innovating from the cropping to the agrifood system: application to the agroecological management of soil-borne pests and diseases in Provençal vegetable production systems.* PhD dissertation, University of Avignon, France, 336 p.

• Boulestreau Y., Casagrande M., Navarrete M., 2019. *Co-designing crop diversification strategies from plot to sociotechnical system to manage root-knot nematodes in Mediterranean market gardening systems.* 1. European Conference on Crop Diversification 2019, Sep 2019, Budapest, Hungary. 369 p. https://hal.inrae.fr/hal-02735611
https://zenodo.org/record/3784275#.YP6gl0A6-w4

▲ *SoilH&co workshop in 2019.* © C. Meunier



▲ *Spatial organization of the SoilH&co game in a room and representation of the different scales that impact agricultural practices.*
Colored rectangles represent the tables, with the type of actors associated with each table specified. © *Y. Boulestreau*

Nitrogen fertilization reduces the rice blast tolerance benefits of earthworms and silicon

Insight into soil-vegetation relationships is essential to pilot ecological processes and better manage plant diseases. Earthworms are involved in these relationships and silicon is a vital component in plant disease control. Understanding how earthworm-silicon interactions control aboveground plant disease is a major research challenge. We assessed the potential of earthworms and/or silicon to control rice blast severity in Madagascar in the presence or absence of NPK mineral fertilization. We used soil-dwelling earthworms (*Pontoscolex corethrurus*), with or without silicon and with or without NPK fertilization. After a few weeks of growth, rice plants were inoculated with equal amounts of *Pyricularia oryzae* fungal spores to trigger the disease. Plant biomass, rice plant nutrition and disease severity were measured after 8 weeks of growth.

It was found that **a combined treatment with earthworm inoculation and silicon input enhanced rainfed rice tolerance to *P. oryzae* compared to single earthworm or silicon treatments**, while providing the best ratio between plant biomass (and nutrition) gain and disease severity reduction. NPK nutrient input, however, induced a severe form of the disease (nitrogen-induced susceptibility phenomenon). A carbon/nitrogen ratio of 15 in aboveground plant parts is considered a threshold below which any increase in nitrogen per carbon unit will increase blast severity. **Soil organisms and functioning therefore have a key role in boosting plant resistance to aerial diseases.** With the aim of contributing to ecological intensification and enhancing the provision of ecosystem services such as disease regulation, our results indicate that **excessive use of mineral fertilizer should be reduced in favor of sustainable agricultural practices that promote earthworm populations**.

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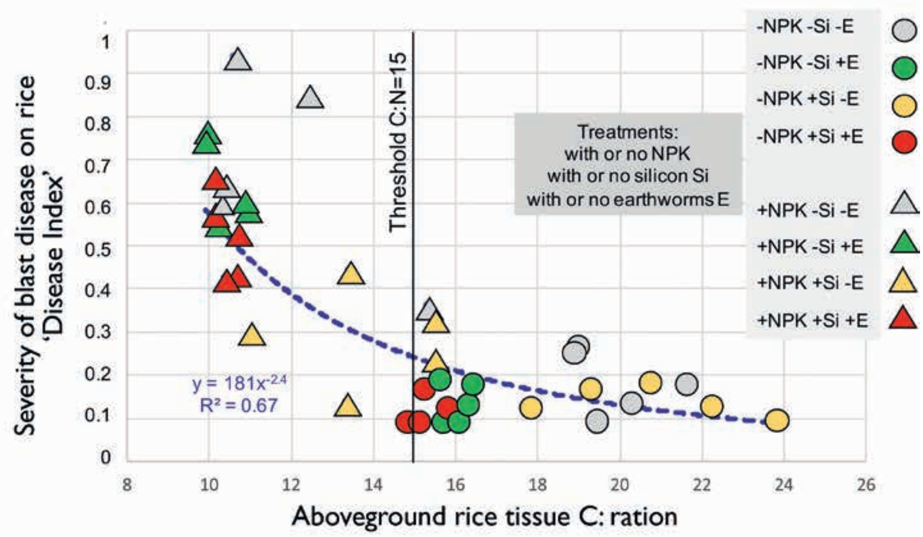
For further information

Blanchart E., Ratsiatosika O., Raveloson H., Razafimbelo T., Razafindrakoto M., Sester M., Becquer T., Bernard L., Trap J., 2020. Nitrogen supply reduces the earthworm-silicon control on rice blast disease in a Ferralsol. *Applied Soil Ecology*, 145: 103341.



▲ ***Relationship between the plant tissue carbon/nitrogen ratio and blast disease severity.*** *NPK fertilizer application (triangles) led to a drop in the C/N ratio below the threshold of 15, reflecting high disease severity. The presence of silicon (yellow triangles) tended to decrease the disease severity under fertilized conditions. In the absence of NPK (circles), earthworms (red and green circles) improved plant growth and nitrogen nutrition, while not increasing the disease severity. Earthworms and silicon offered an optimal balance between increased biomass and disease severity.*

▲ Pontoscolex corethrurus, *a tropical soil-dwelling earthworm that provides many functions useful for plant growth.* © E. Blanchart/IRD

Rhizosphere microbiomes

A new avenue for enhancing crop health, productivity, biofortification and soil fertility

Plants harbor a diverse-range of microorganisms in and around the roots, i.e. so-called rhizosphere microbiomes, which contribute to overall plant health and functions. These plant growth-promoting (PGP) microbes inhabit the rhizosphere to meet their nutritional requirements. In turn, these microbes provide multiple benefits, including enhanced plant growth, defense against diseases and survival under stress, along with many other unknown benefits. By reaction, they help by: (i) boosting plant growth through soil nutrient enrichment by nitrogen fixation, etc.; and (ii) increasing plant protection by influencing cellulase, protease, lipase and β-1,3 glucanase production, while enhancing plant defense against pests and pathogens through diverse mechanisms.

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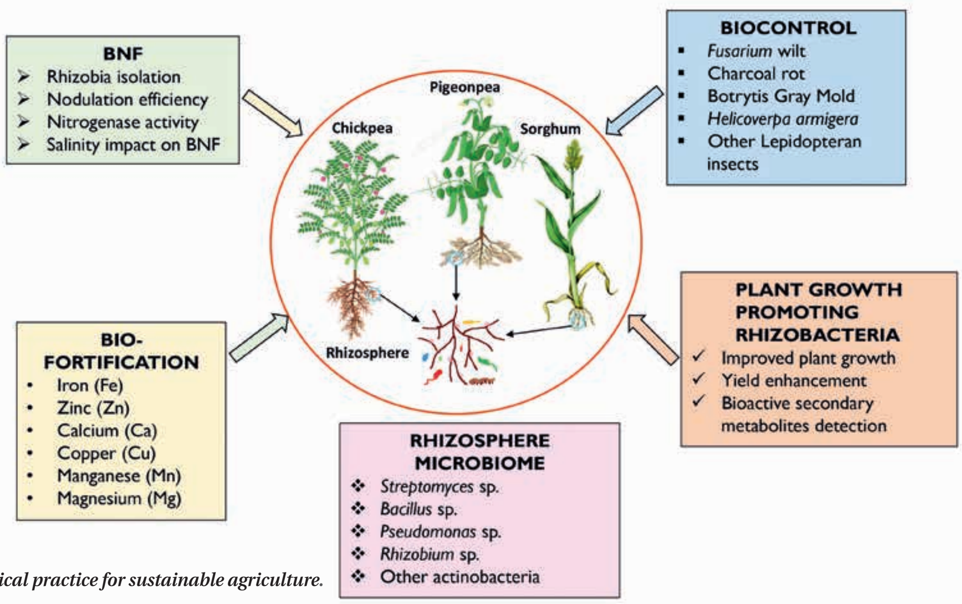

▶ *Rhizosphere Microbiomes: an agroecological practice for sustainable agriculture.*

In addition, PGP microbes have useful traits for tolerating abiotic stresses like extreme temperatures, pH, salinity and drought, as well as heavy metal and pesticide pollution. The application of PGP microbes in the field is expected to enhance crop growth and yield even when the plants are under a combination of stresses. It is therefore essential to generate comprehensive knowledge on potential strategies for screening, characterizing and formulating beneficial PGP microbes, while gaining insight into the molecular mechanisms underlying their action and evaluation at field levels. Identifying such potential rhizobial and other PGP microbes and developing a robust technology could be useful for integrated pest management (IPM) and integrated nutrition management (INM) programs, while also reducing the need for external inputs such as synthetic fertilizers and pesticides. ICRISAT research is focused on the effects of such PGP bacteria on nitrogen fixation, P-solubilization, growth promotion and against various biotic (including insect pests and diseases) stresses on our mandate crops, including chickpea, pigeonpea, groundnut and sorghum, which are staples in the semiarid tropics. ICRISAT has demonstrated **the usefulness of 16 PGP *Streptomyces* strains for their growth promotion and yield enhancement traits under rice, sorghum, chickpea and pigeonpea crop field conditions. Further, three secondary metabolites have been purified from these strains, including two against pod borers and one against charcoal rot disease in sorghum. Whole genome sequences of these strains have also documented and published.**

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• https://scholar.google.co.in/citations?hl=en&user=tINLkpAAAAAJ&view_op=list_works

• Gopalakrishnan S., Srinivas V., Vemula A., Samineni, Rathore A., 2018. Influence of diazotrophic bacteria on nodulation, nitrogen fixation, growth promotion and yield traits in five cultivars of chickpea. *Biocatal. Agric. Biotechnol.*, 15: 35-42.

• Gopalakrishnan S., Srinivas V., Naresh N., Pratyusha S., Ankati S., Madhuprakash J., Sharma R., 2021. Deciphering the antagonistic effect of *Streptomyces* spp. and host-plant resistance induction against charcoal rot of sorghum. *Planta*, 253: 57.

• Gopalakrishnan S., Thakur V., Saxena R.K., Vadlamudi S., Purohit S., Kumar V., Rathore A., Chitikineni A., Varshney R.K., 2020. Complete genome sequence of sixteen plant growth-promoting *Streptomyces* strains. *Scientific Reports*, 10: 10294.

Plant extracts as an alternative to insecticide treatments in sub-Saharan Africa

In sub-Saharan African countries, as in most countries worldwide, ethnopharmacology relates to the use of plants in traditional medicine. Some plants are also used in the form of aqueous extracts or essential oils for the protection of crops against pests and diseases both in the field and granaries. This provides a partial alternative to synthetic insecticide treatments, or even a total alternative in organic farming conditions. Ready-made formulations are seldom available and are mainly based on natural pyrethrum extracts from *Tanacetum cinerariifolium* (Asteraceae) or neem (*Azadirachta indica*, Meliaceae). The challenge is to identify new plant species based on plant diversity studies and traditional/academic knowledge, and then to disseminate this knowledge to end users, i.e. farmers, NGOs, consultants and researchers.

Plant extract uses under experimental conditions or in common practice have been inventoried in the Knomana knowledge base*. This knowledge base was built from publications compiled by members of an informal network of researchers from 13 French-speaking African countries**. Following an extension of the research to encompass other geographical areas, as well as animal and human health fields, **Knomana now includes 44,300 usage descriptions (January 2021). This includes a broad range of information, such as scientific names of plants and active ingredients of extracts used, scientific names of target organisms and protected crops. Overall, 2,543 plant species are listed as having been tested against 720 target pest species.** The focus is currently on plant usage toxicity risks to humans and other non-target organisms. Assessment of these risks—which may generate further insight to supplement Knomana—is a crucial goal with regard to the EcoHealth approach.

* Knowledge management on pesticidal plants in Africa: https://ur-aida.cirad.fr/nos-recherches/projets-et-expertises/knomana

** Benin, Burkina Faso, Cameroon, Central African Republic, Côte d'Ivoire, Democratic Republic of the Congo, Gabon, Madagascar, Mali, Mauritania, Niger, Senegal and Togo.

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For further information

• Silvie P., Martin P., Huchard M., Keip P., Gutierrez A., Sarter S., 2021. Prototyping a knowledge-based system to identify botanical extracts for plant health in sub-Saharan Africa. *Plants*, 10(5): 896. https://doi.org/10.3390/plants10050896

• Silvie P. *et al.*, 2021. Le management des connaissances liées aux usages des plantes : une initiative combinant savoirs traditionnels et publications scientifiques pour l'approche One-Health. *In* Profizi *et al.* (éd.) : *Biodiversité des écosystèmes intertropicaux. Connaissance, gestion durable et valorisation*, Marseille, IRD Éditions, coll. Synthèse.

• Silvie P., Martin P., 2017. Les plantes pesticides au secours des cultures. *The Conversation*. http://theconversation.com/les-plantes-pesticides-au-secours-des-cultures-86898

▼ ***Preparation of an aqueous plant-based extract in Senegal.*** © M. Dione

▶ ***Plant extracts used in cotton crop fields in Paraguay.*** © P. Silvie

Agroecological practices and soil carbon stocks

An example in the Senegalese peanut basin

The 4 per 1000 Soils for Food Security and Climate Initiative—launched at the 2015 Paris Climate Change Conference—encourages stakeholders worldwide to commit to agriculture based on practices that foster soil carbon storage(1) while also being compatible with agroecology precepts. In subarid West Africa, agroecological practices are primarily geared towards increasing agricultural productivity, while relying heavily on efficient management of organic inputs derived from various integrated crop and livestock farming systems. Yet the essentially coarse-textured soils in the region have a limited organic carbon storage capacity. Studies conducted by the IESOL* research group, supported by the SoCa(2) and DSCATT(2) projects, assessed carbon stocks in 1,813 crop plots located in the peanut basin of Senegal. The stocks were found to not exceed 30 Mg C ha^{-1} (average 14.6 Mg C ha^{-1}) in the 0-30 cm soil layer. The nature of organic inputs—particularly those associated with the development of cattle fattening practices—and their management in the landscape—focused especially on applications in fields located in the vicinity of dwellings (i.e. home-fields)—is conducive to increased C stocks(3). Mineralization rates are, however, extremely rapid, which affect soil organic carbon forms considered stable (Rock-Eval® approach), or even refractory in other soil-climate conditions(4). **Local organic amendment practices can hence contribute to soil fertility restoration in the short term, but they are ineffective in achieving long-term C storage necessary for climate change mitigation.** Agroecological transition innovations must focus on options that will enable optimal management of all fields, while seeking ways to enhance organic resource availability.

* An international joint laboratory on ecological intensification of cultivated soils in West Africa: https://sites.google.com/site/iesolafrica/home

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For further information

(1) Chevallier *et al.*, 2020. *Carbone des sols en Afrique. Impacts des usages des sols et pratiques agricoles.* FAO/IRD, Rome/Marseille, 268 p. www.fao.org/3/cb0403fr/CB0403FR.pdf

(2) SoCa Project: Soil Carbon for Tropical Subsistence Farming (funding: Climate Initiative, BNP Paribas Foundation): https://group.bnpparibas/actualite/soca-carbone-sols-service-agriculture-familiale-tropicale

DSCATT Project: Dynamics of Soil Carbon Sequestration in Tropical and Temperate Agricultural Systems (funding: Fondation Agropolis and Fondation Total): https://dscatt.net

(3) Malou O.P., Moulin P., Chevallier T., Masse D., Vayssières J., Badiane Ndour N.Y., Tall L., Delaunay V., Thiam A., Chapuis-Lardy L., 2021. Estimates of C stocks in sandy soils cultivated under local management practices in the Senegal's groundnut basin. Submitted to *Regional Environmental Change*, 21: 65. https://doi.org/10.1007/s10113-021-01790-2

(4) Malou O.P., Sebag D., Moulin P., Chevallier T., Badiane Ndour N.Y., Thiam A., Chapuis-Lardy L., 2020. The Rock-Eval® signature of soil organic carbon in arenosols of the Senegalese groundnut basin. How do agricultural practices matter? *Agriculture, Ecosystems and Environment*, 301: 107030. https://doi.org/10.1016/j.agee.2020.107030

◀ ***Mixture of millet straw and crop residues, uneaten livestock feed and manure.***
Used as compost in vegetable crop fields or (as here) in a watermelon field, Senegal. © T. Chevallier/IRD

Increasing the soil organic carbon content

The need for systemic and multidisciplinary approaches

Increasing the soil organic matter content is a major challenge for the sustainable intensification of agricultural production. Many interacting biophysical, social and economic factors must be taken into account at different scales—from the soil aggregate to the territory, including the farm and crop field—when assessing the condition of a soil and its organic matter content. The time-course dynamics of production systems in Senegal—in areas where Serer communities reside—were analyzed to determine the ecological and social components underlying the viability and sustainability these systems. Research conducted as part of the multidisciplinary CERAO* project (2014-2018) highlighted **the importance of crop-livestock farming integration and the trend towards more sedentary livestock farming**.

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▶ ***Cattle fattening in a concession in Niakhar region, Senegal.*** *© B. Defives*

Similarly, **the ring-shaped spatial organization of village lands and the presence of trees in the form of wooded parkland have been maintained despite the major constraints these production systems have faced over the last century** (decreased rainfall, population growth, changing socioeconomic conditions). Finally, **human societies have gradually adapted to help sustain agricultural activity** (migration, off-farm work and income, family and social ties, etc.). These systems-based multidisciplinary analyses are essential to come up with effective ways to boost the carbon content of cultivated soils. This knowledge, combined with local know-how, will pave the way for efficient, sustainable and transferable agricultural practices or social arrangements. The Fondation Agropolis DSCATT** flagship project is being implemented in this setting with the aim of developing and testing methods and tools to co-build soil carbon sequestration strategies with stakeholders.

*CERAO project (2014-2018), Auto-adaptation of tropical agro-socio-ecosystems to global climate change? ANR Agrobiosphère: www.umr-ecosols.fr/en/recherche/projects/17-projets/44-cerao

**DSCATT project (2019-2023), Agricultural Intensification and Dynamics of Soil Carbon Sequestration in Tropical and Temperate Farming Systems: www.dscatt.net

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For further information

• Masse D., Lalou R., Tine C., Ba M., Vayssières J. 2018. Les trajectoires agricoles dans le Bassin Arachidier au Sénégal : éléments de réflexion à partir de l'observatoire de Niakhar. *In* Delaunay V., *et al.*. (éd.) : *Niakhar, mémoires et perspectives. Recherches pluridisciplinaires sur le changement en Afrique*, IRD Éditions/L'Harmattan Sénégal, Marseille/Dakar: 311-332.

• Grillot M., Vayssières J., Masse D., 2018. Agent-based modelling as a time machine to assess nutrient cycling reorganization during past agrarian transitions in West Africa. *Agricultural Systems*, 164: 133-151.

• Tounkara A., Clermont-Dauphin C., Affholder F., Ndiaye S., Masse D., Cournac L., 2020. Inorganic fertilizer use efficiency of millet crop increased with organic fertilizer application in rainfed agriculture on smallholdings in central Senegal. *Agriculture, Ecosystems & Environment*, 294. doi: 10.1016/j.agee.2020.106878

• Bisson A., Boudsocq S., Casenave C., Barot S., Manlay R.J., Vayssières J., Masse D., Daufresne T., 2019. West African mixed farming systems as meta-ecosystems: an ecological source-sink modelling approach of the nitrogen cycle and crop production. *Ecological Modelling*, 412:108803. doi.org/10.1016/j.ecolmodel.2019.108803

Why should the priming effect be considered in agroecology?

Organic matter (OM) mineralization by soil microbial communities is a major nutrient source for plants and leads to a 7-fold higher global release of CO_2 into the atmosphere compared to anthropogenic emissions. It is hence essential to gain insight into the mechanisms involved to ensure the success of the agroecological transition and for climate change mitigation via soil carbon (C) sequestration. The priming effect (PE) is a key mechanism contributing to the ecosystem carbon balance. PE has long been viewed as a net soil C loss since it stimulates soil OM mineralization following fresh OM input. Yet it can serve as an efficient nutrient supply for plants if the system is in equilibrium (i.e. mineralization = C storage). PE is hard to measure *in situ* and is the outcome of several processes, each driven by its own microbial constituents and targeting a different OM pool. The balance between C gain and loss depends on: (i) the efficiency of microorganisms in facilitating biomass C uptake; and (ii) the age of the destabilized OM pool (recent dynamic rather than old stabilized OM). Although problematic from a carbon balance standpoint, a process geared towards a stabilized OM pool could enhance fertility via nutrient (N and P) remobilization. Plants naturally initiate this type of process in their rhizosphere depending on their needs. In summary, **PE can be beneficial in agroecology by controlling processes via agricultural practices, depending on the target issue —C storage and/or crop nutrition. Organic input quality management is also a highly promising thrust**.

◀ ***Rainfed rice under maize crop residue at Andranomanelatra, Madagascar.*** *© L. Bernard/Eco&Sols*

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For further information

• Razanamalala K., Fanomenzana R.A., Razafimbelo T., Trap J., Blanchart E., Bernard L., 2018. The priming effect generated by stoichiometric decomposition and nutrient mining in cultivated tropical soils: actors and drivers. *Applied Soil Ecology*, 126: 21-33.

• Razanamalala K., Razafimbelo T., Maron P.A., Ranjard L., Chemidlin-Prévost-Boure N., Lelièvre M., Dequiedt S., Ramaroson V., Marsden C., Becquer T., Trap J., Blanchart E., Bernard L., 2018. Soil microbial diversity drives the priming effect along climate gradients: a case study in Madagascar. *The ISME Journal*, 12: 451-462.

Effective recycling in oil palm plantations

Reducing economic and environmental costs

◀ ***Field application of compost from palm oil residues, Indonesia.*** *© C. Bessou/CIRAD*

Palm oil is currently the top-ranking vegetable oil consumed worldwide and production shall continue to increase. Agroecological practices should therefore be implemented to an increased extent in plantations. Oil palm plantations require fertilizer applications, which account for 46–85% of field costs while substantially contributing to environmental impacts such as acidification and climate change(1). Agroecological practices help reduce external inputs via the recycling of highly diversified and plentiful coproducts(2). Oil palm plantations can generate a total of ~16 t/ha.yr^{-1} of coproducts, besides the palm and kernel oils produced (~5 t/ha.yr^{-1}). This biomass consists of fronds, stipes, empty fruit bunches (EFB), palm oil mill effluents, shells and fibers.

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During the immature stage, the temporary legume cover brings benefits by recycling nutrients from decomposing stipes from the previous harvest, while also preventing weed development. **Then throughout the crop cycle, field application of EFB as an organic amendment proved to have substantial advantages**. Application of this coproduct can improve the soil nutrient content but it also further enhances the soil physicochemical properties and biota through various mechanisms, thereby protecting the soil and its functioning capacity[2]. Moreover, EFB may be co-composted, notably with palm oil mill effluent, thus increasing the nutrient value and stability of the amendment while reducing transport costs as well as environmental impacts from effluent treatment[3]. Harnessing the most from the co-product recycling potential implies accounting for the benefits and risks jointly at the palm agroecosystem and supply chain levels. Life cycle assessment (LCA) facilitates such a holistic analysis by considering potential substitutions and avoided impacts, as well as trade-off risks[1,4]. **LCA results have highlighted that residue compost could replace 10–25% of synthetic fertilizers while markedly reducing the climate change impact**[3]. However, despite the great quantities of coproducts generated, demand within the palm value chain or outside may exceed supply, so competition and fertility transfer issues would need to be investigated to highlight sustainable practices at the landscape level.

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(1) Bessou C., Pardon L., 2017. Environmental impacts of palm oil products: what can we learn from LCA? *Indones. J. Life Cycle Assess. Sustain.* 1: 1-7.

(2) Bessou C., Verwilghen A., Beaudoin-Ollivier L., Marichal R., Ollivier J., *et al.*, 2017. Agroecological practices in oil palm plantations: examples from the field. *OCL*, 24(3). doi: 10.1051/ocl/2017024

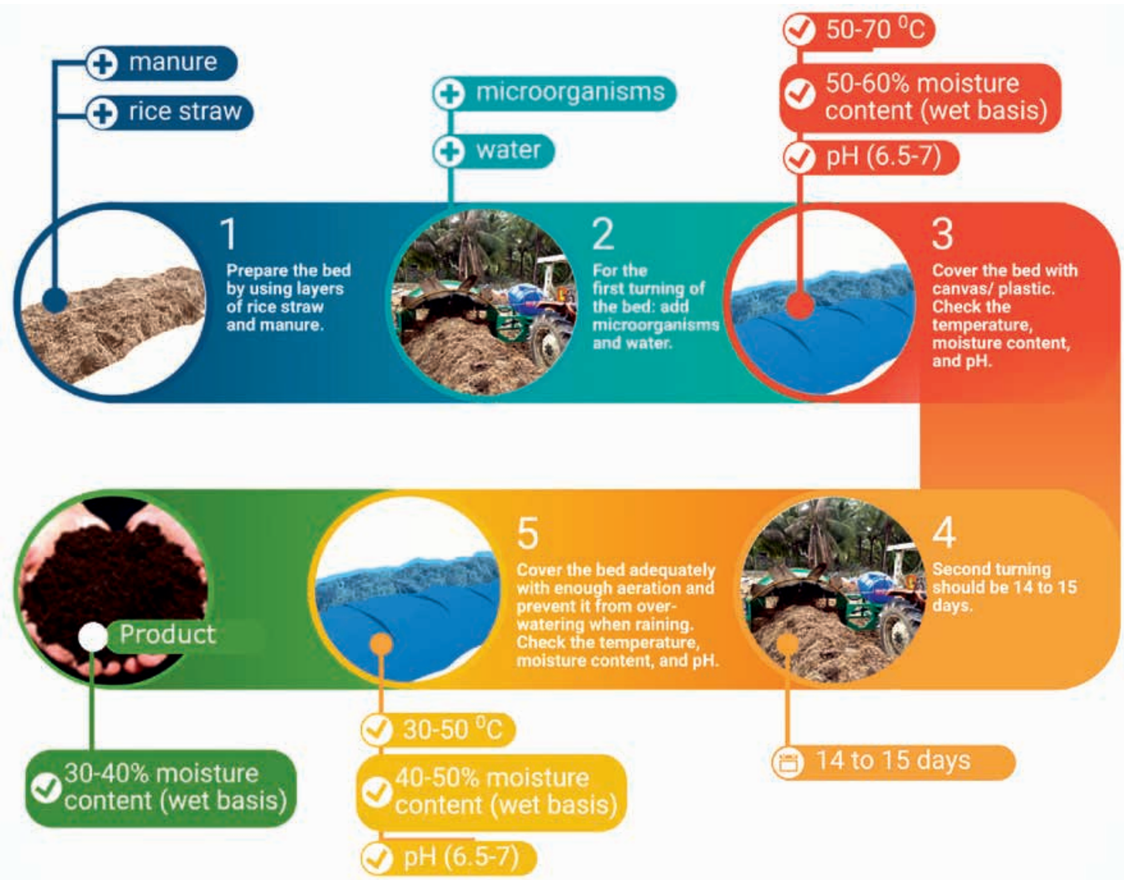
(3) Baron V., Saoud M., Jupesta J., Praptantyo I.R., Admojo H.T., Bessou C., Caliman J.P., 2019. Critical parameters in the life cycle inventory of palm oil mill residues composting. *IJoLCAS*, 3(1): 19.

(4) Wiloso E.I., Bessou C., Heijungs R., 2015. Methodological issues in comparative life cycle assessment: treatment options for empty fruit bunches in a palm oil system. *Int. J. Life Cycle Assess.*, 20: 204-216.

Mechanized composting to convert crop residues into organic fertilizer

In-field burning of crop residues is currently a serious issue, causing GHG emissions and air pollution in many Asian countries such as India or Vietnam[1]. This adverse traditional practice could be reduced by converting crop residues mixed with animal manure into organic fertilizer to enhance soil fertility and crop yield[2]. Mechanized rice straw composting developed under an IRRI-led project[1] is an innovation that combines physical and biochemical processes to optimize the rice straw decomposition efficiency and organic fertilizer quality (Figure). This technology optimizes the composting process and efficiently addresses affected parameters such as the C/N ratio, temperature, moisture content, pH, bioactiveness, anaerobic and aerobic conditions. Rice straw composting using this technology takes about 45 days, i.e. about half the time required for traditional practices such as manual composting and bulldozer mixing.

For sustainable rice production, particularly for the 'three cropping seasons per year' approach, we suggest two options to avoid rice straw burning and elevated methane emissions: (i) producing organic fertilizer from rice straw, including mechanized collection[3] and composting[1]; and (ii) composting and recycling rice straw for organic rice production. Indeed, 1 ha of rice production requires about 6-10 t of compost produced from the same amount of rice straw mixed with 20-40% of animal manure to achieve an optimized C/N ratio of 25/1. GHG emissions from rice straw composting are about 200-300 kg CO_2/t of straw[4]. In addition to the added value from rice straw, mechanized rice straw composting resulted in a significant GHG emission reduction compared to raw rice straw incorporation. Furthermore, avoiding rice straw burning is also a criterion to qualify under the global Sustainable Rice Platform Standard that enable the rice product meeting the premium markets and driving its price increased.



▲ *Rice straw composting process.*

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For further information

(1) Gummert M. *et al.*, 2019. Sustainable rice straw management, Springer Nature. https://link.springer.com/content/pdf/10.1007%2F978-3-030-32373-8.pdf

(2) Goyal S, *et al.*, 2009. Effect of rice straw compost on soil microbiological properties and yield of rice. *Indian Journal of Agricultural Research*. https://arccjournals.com/journal/indian-journal-of-agricultural-research/ARCC1540.

(3) Nguyen-Van-Hung *et al.*, 2016. Energy efficiency, greenhouse gas emissions, and cost of rice straw collection in the Mekong River Delta of Vietnam. *Field crops research*. https://doi.org/10.1016/j.fcr.2016.08.024

(4) Zhong, J. *et al.*, 2013. Greenhouse gas emission from the total process of swine manure composting and land application of compost. *Atmos. Environ.* https://doi.org/10.1016/j.atmosenv.2013.08.048

Regreening drylands with more food and incomes for smallholder farmers

Achieving nutritional, food and income security in Sahelian regions remains one of humanity's greatest challenges. Poor soil fertility, land degradation, climate variability and large populations dependent on agriculture are often cited as major constraints. Decades of applied research and development by ICRISAT and partners in the Sahel have given rise to new farming systems, agronomic practices, crop varieties and innovative market access, etc. For example, **smallholder farmers in Niger's dry agroecological conditions can significantly increase agricultural productivity and incomes via agroforestry**[1]. A long-term experiment conducted at ICRISAT's Sadore research station with *Ziziphus mauritiana* (so-called *pomme du Sahel*) trees revealed productivity increases in pearl millet monocropping and intercropping systems under low input conditions, and a two- to threefold rise in income potential[2]. This system was also found to improve rainwater use efficiency, soil fertility and increase millet yields, while maintaining soil organic carbon levels.

Another example of regreening concerns the **bioreclamation of degraded land (BDL) approach, whereby women participate in restoring degraded lands through a combination of new and indigenous techniques**. These include water harvesting technologies, e.g. digging half-moon planting pits and trenches, application of composted plant and animal waste, and planting of hardy and high-value fruit trees (*Moringa oleifera, Ziziphus mauritiana*), as well as drought-resilient indigenous vegetables (okra, hibiscus and *Senna obtusifolia*). This is considered a gender-sensitive system that aims to restore land at minimal cost to communities and the environment, and to empower local women by securing their land rights. The examples described here pool innovations in crop improvement, agronomy, water harvesting[3] and nutrient management through microdosing[4] in best practice packages which are participatively developed with stakeholders and then mainstreamed into farming systems. These approaches have immediate effects at the household level, including higher incomes, greater food security and improved nutrition (Figures A and B). National and regional strategies for scaling such multipurpose farming systems require policymaker and donor support.

▲ *Women farmers displaying vegetables produced in set up on bioreclamation of degraded land (BDL) systems, Niger.* © *D. Fatondji/ICRISAT*

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For further information

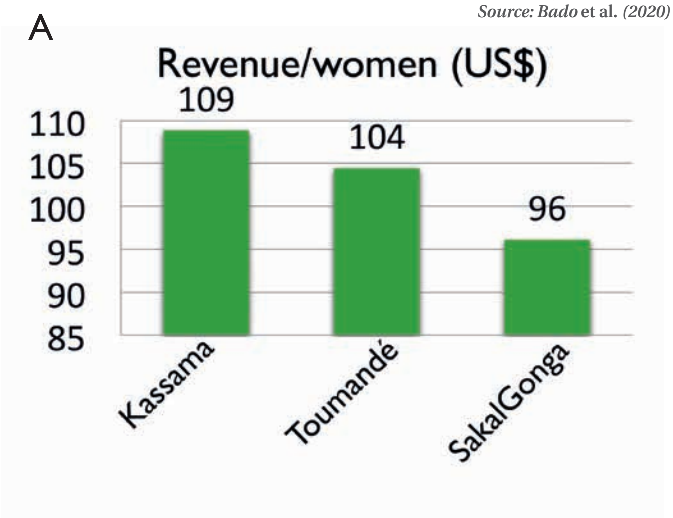
(1) Bado B.V., Whitbread A. Manzo M.L.S., 2020. Improving agricultural productivity using agroforestry systems: performance of millet, cowpea, and ziziphus-based cropping systems in West Africa Sahel. *Agriculture, Ecosystems and Environment*, 305: 107175. https://doi.org/10.1016/j.agee.2020.107175

(2) Bado V., 2020. Ziziphus agroforestry: a yield and income ladder for millet farmers in Niger. *ICRISAT Happenings Newsletter*. www.icrisat.org/ziziphus-agroforestry-a-yield-and-income-ladder-for-millet-farmers-in-niger

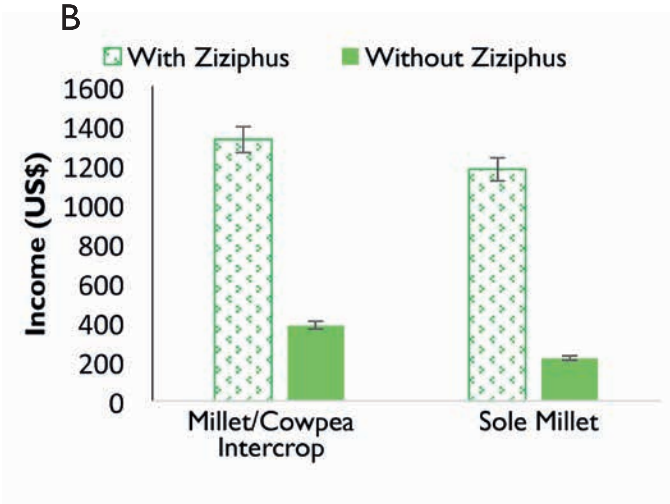
(3) Zemadim Birhanu B., Whitbread A., Fry C., 2020. *How contour bunding and other technologies can reduce soil erosion and raise productivity in African watersheds.* https://wle.cgiar.org/thrive/2020/08/28/how-contour-bunding-and-other-technologies-can-reduce-soil-erosion-and-raise?utm_source=feedburner&utm_medium=feed&utm_campaign=Feed%3A+WLEThrive+%28Thrive+Blog%29

(4) Tabo R., Bationo A., Amadou B., Hassane O., Diallo M.K., Ndjeunga J. *et al.*, 2011. Fertilizer microdosing and "Warrantage" or inventory credit system to improve food security and farmers' income in West Africa. *In: Innovations as key to the Green Revolution in Africa. Exploring the scientific facts.* Springer, Netherlands: 113-121.

▼ ***Figure A.*** *Revenues earned per woman in three villages in Niger with BDL technology.* *Source: Bado* et al. *(2020)*

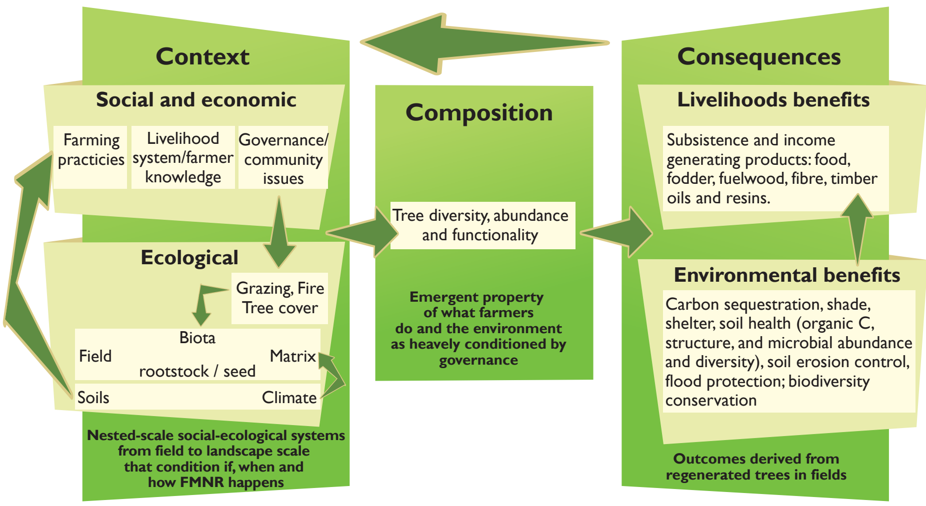


▼ ***Figure B.*** *Effect of* Ziziphus *trees on household incomes with millet monocropping and millet-cowpea intercropping compared to these two cropping systems without* Ziziphus. *Source: Bado* et al. *(2020)*



Opportunities and constraints for using farmer-managed natural regeneration for land restoration in sub-Saharan Africa

Farmer-managed natural regeneration (FMNR) comprises a set of agroecological practices used by farmers to encourage tree growth on agricultural land. It has been associated with increasing agricultural productivity through soil fertility improvement (including increased soil carbon)[1], producing feed for livestock, boosting incomes, along with other environmental benefits. It is widely promoted in Africa as a cost-effective degraded land restoration strategy that overcomes the challenge of low survival rates associated with tree planting in arid and semiarid areas. A review of scientific evidence related to the contexts in which FMNR is practiced across sub-Saharan Africa, how this influences the composition of regenerating vegetation, and the resulting environmental and socioeconomic benefits (Figure)[2] revealed that **quantitative evidence of FMNR outcomes is sparse** and mainly related to experience in the Maradi and Zinder regions of Niger. Recent advances in the mechanistic understanding about how context conditions the diversity and abundance of regenerating trees, and hence ecosystem function, suggests that: **intensity of land use (grazing and agricultural practices) and dispersal limitation inhibit regeneration, while land degradation does not[3].** The functional composition of regenerating communities shifts, with increasing intensity of land use, towards shorter statured, small-seeded plants with conservative strategies. There is little evidence, however, linking agroecosystem function to livelihood benefits, which makes it difficult to determine where and for whom FMNR is an appropriate restoration technique, and where it might be necessary to combine it with enrichment planting. Given the need for viable restoration practices for agricultural land across Africa, there is a need to combine functional ecology and socioeconomic assessments, embedded as co-learning components in scaling up initiatives. This would fill key knowledge gaps, in turn enabling the development of context-sensitive advice on where and how to promote FMNR, as well as calculation of the return on investment of doing so.



▲ ***Analytical framework used to assess scientific evidence relevant to scaling up the use of farmer-managed natural regeneration (FMNR) of trees on agricultural land.*** *Source: Chomba* et al. *(2020)*

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(1) Bayala J., Sanou J., Bazié H.R., Coe R., Kalinganire A., Sinclair F.L., 2020. Regenerated trees in farmers' fields increase soil carbon across the Sahel. *Agroforestry Systems*, 94: 401-415. https://doi.org/10.1007/s10457-019-00403-6

(2) Chomba S., Sinclair F., Savadogo P., Bourne M., Lohbeck M., 2020. Opportunities and constraints for using farmer managed natural regeneration for land restoration in Sub-Saharan Africa. *Frontiers in Forests and Global Change*, 3: 571679. https://doi.org/10.3389/ffgc.2020.571679

(3) Lohbeck M., Albers P., Boels L.E., Bongers F., Morel S., Sinclair F., Takoutsing B., Vågen T.-G., Winowiecki L.A., Smith-Dumont E., 2020. Drivers of farmer-managed natural regeneration in the Sahel. Lessons for restoration. *Nature Scientific Reports*, 10: 15038. https://doi.org/10.1038/s41598-020-70746-z

Comparative analysis of monocrops versus agroforestry contributions to the household economy of upland farmers in Northwest Vietnam

Agroforestry is a potential means for improving smallholder farmers' livelihoods and reducing land degradation. The impact of agroforestry on farmers' household income overall needs to be assessed with the aim of boosting the adoption of agroforestry in Northwest Vietnam. Different agroforestry options, including fruit trees, annual crops and forage grass, have been assessed at the field level. **The break-even point was achieved in the 2nd to 3rd year depending on the agroforestry options.** The 5-year return on investment (ROI) of the Longan+maize+forage grass, Acacia+mango+maize+forage grass, Acacia+longan+coffee+soybean+forage grass, Teak+plum+coffee+soybean+forage grass options were 7%, 25%, 39% and 59%. Meanwhile, the mono-maize option provided annual income and a 5-year ROI of 38%. Compared to annual crops, agroforestry alone required a higher investment cost and was slow in generating attractive income. However, the contribution of agroforestry to the total household income should be considered.

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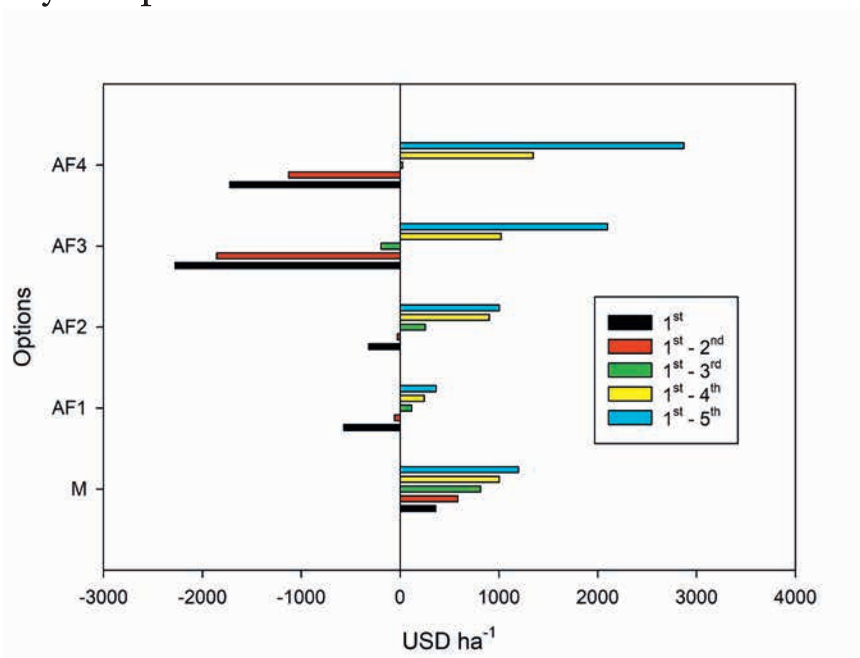

▲ ***Comparison of profits from maize monocultures and different agroforestry options over a 5-year period.*** *M: maize monoculture, AF1: Longan+maize+forage grass, AF2: Acacia+mango+maize+forage grass, AF3: Acacia+longan+coffee+soybean+forage grass, AF4: Teak+plum+coffee+soybean+forage grass.*

A survey of 30 households whose members had been practicing agroforestry since 2015 was conducted. The findings revealed that within the first 2-3 years, fodder and maize from agroforestry practices provided a major share of feedstock for livestock farming—a key local livelihood activity. **From the 3rd year, the agroforestry contribution accounted for around 5-10% of the total income. This share increased up to around 50% by the 6th year.** In return, livestock manure was applied as a crop nutrient source in fields. Incomes from other crop areas, livestock and off-farm activities were also invested in agroforestry. Further assessment of the overall role of agroforestry could shed light on the mechanisms by which farmers adapt agroforestry to meet their own specific conditions. This could in turn facilitate adoption of certain agroforestry practices. In conclusion, agroforestry was found to contribute significantly to the household economy. **The promotion of agroforestry should be in line with farmers' needs, while also supporting other rural household economic activities.**

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For further information

• Do V.H., La N., Mulia R., Bergkvist G., Dahlin A.S., Nguyen V.T., Pham H.T., Öborn I., 2020. Fruit tree-based agroforestry systems for smallholder farmers in Northwest Vietnam. A quantitative and qualitative assessment. *Land*, 9(11): 451. https://doi.org/10.3390/land9110451

• Do H., Luedeling E., Whitney C., 2020. Decision analysis of agroforestry options reveals adoption risks for resource-poor farmers. *Agron. Sustain. Dev.* 40: 20. https://doi.org/10.1007/s13593-020-00624-5

Assessment of commercial bioinoculants used for sustainable agriculture

Importance of their microbial quality and consequences for end users

The inoculation of crops with beneficial microorganisms is an applied soil microbiology 'success story'. It provides a sustainable and effective source of nutrients to plants while suppressing the soilborne pathogen population, thus decreasing the dependence on chemical fertilizers, pesticides and supplements. The increasing demand for sustainable environment-friendly alternatives has resulted in the proliferation of commercial bioinoculants worldwide, all claiming to substantially enhance crop productivity. However, many of these products are sold without robust scientific data supporting their efficacy and quality. So far little attention has been paid to the quality of these inoculants during their production, which has led to dramatically reduced effectiveness and consequently to lower adoption by farmers. There is hence growing demand for a quality control system for available commercial inoculants.

We assessed the microbial quality of diverse bioinoculants (bacterial and endomycorrhizal) available on the global market to verify whether they fulfilled the manufacturers' claims and to gain insight into the quality of products readily available to farmers. Our results showed that the majority (>60%) of bacterial bioinoculants contained one or several contaminant bacterial strains, and **only 37% of the products could be considered 'pure'. Approximately 40% of the tested products did not contain any of the claimed strains but only contaminants(1).** Similarly, **bioinoculants containing arbuscular mycorrhizal fungi (AMF) were generally of poor quality and efficacy**, with only three products resulting in a significant increase in root colonization and shoot biomass. Contaminants were found in the majority of AMF products, while spores of several claimed species were not detected in the products(2). These results highlight **the importance of an effective, regulatory quality control program to ensure that efficacious bioinoculants will reach the end users**.

▲ ***Purification of different bacterial strains found in commercial bioinoculants.*** © *L. Herrmann*

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For further information

(1) Herrmann L., Atieno M., Braü L., Lesueur D., 2015. Microbial quality of commercial inoculants to increase BNF and nutrient use efficiency (chapter 101). *In* de Bruijn F.J. (ed): *Biological nitrogen fixation, volume 2*. John Wiley & Sons: 1031-1040.

(2) Faye A., Dalpe Y., Ndung'u Magiroi K., Jefwa J., Ndoye I., Diouf M., Lesueur D. 2013. Evaluation of commercial arbuscular mycorrhizal inoculants. *Canadian Journal of Plant Sciences*, 9: 1201-1208.

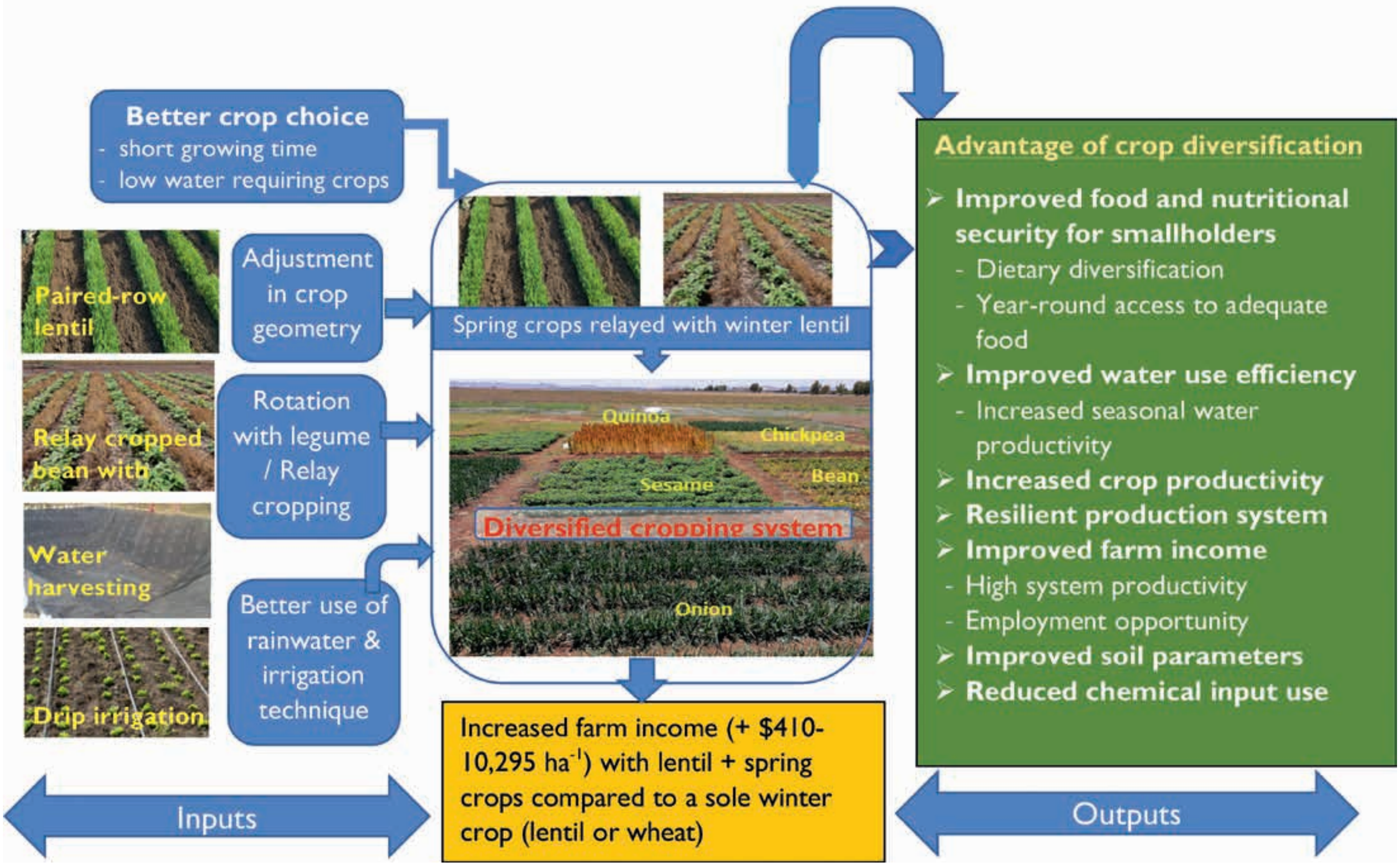
• CMBP, The Common Microbial Biotechnology Platform: www.cmbp-network.org

Diversified cropping systems enhance income, nutrition, and water-use efficiency for North African and South Asian smallholder farmers

Increasing rainfall variability and declining land and water resources are having a high impact on crop productivity in rainfed drylands, leading to acute food scarcity among rural communities in the Middle East and North Africa (MENA) and South Asia regions. As the main source of irrigation in MENA, groundwater overextraction—mainly for agriculture—is likely to increase over time, thereby calling for more efficient use of water to sustain food production. To this end, ICARDA has explored options for diversifying cropping systems through better crop choices and more efficient water use with the aim of improving crop productivity and farm profitability for smallholder farmers with limited land and water resources in these regions. Better crop choices together with rainwater harvesting provides an opportunity for supplementary irrigation and system intensification. It also reduces the risk of crop failure and helps extend the growing season via the addition of supplementary crops, e.g. a spring crop in Mediterranean climatic conditions[1] and a winter crop in semiarid areas in India[2].

Diversifying a wheat-based cropping system through relay seeding of a low water requirement high-value spring crop with early maturing lentil, combined with supplementary drip irrigation, **increased the system productivity and farm income (+ $410-10,295 ha^{-1}), while doubling the water use-efficiency compared to a cereal monocrop** in a Mediterranean rainfed environment in Morocco[1]. Similarly, in semiarid areas in central India, rainy season excess water harvesting provided farmers with **an opportunity to grow an additional crop during winter through supplementary drip irrigation using harvested rainwater**. Diversifying crop rotations with legumes is also agroecology-friendly by **curbing pest and disease infestations and reducing chemical fertilizer use**. These findings could be applicable in similar environments in sub-Saharan Africa, South Asia and MENA to enhance system productivity, farm profitability and overall food and nutrition security, while reducing production risks associated with variable rainfall, declining groundwater and changing/variable climatic conditions.

Diversified cropping systems enhance income, nutrition, and water-use efficiency for North African and South Asian smallholder farmers



▲ *Diversifying cropping systems via relay seeding of spring crops in winter seeded lentil with supplementary drip irrigation: a case study in a Mediterranean rainfed environment in Morocco.*

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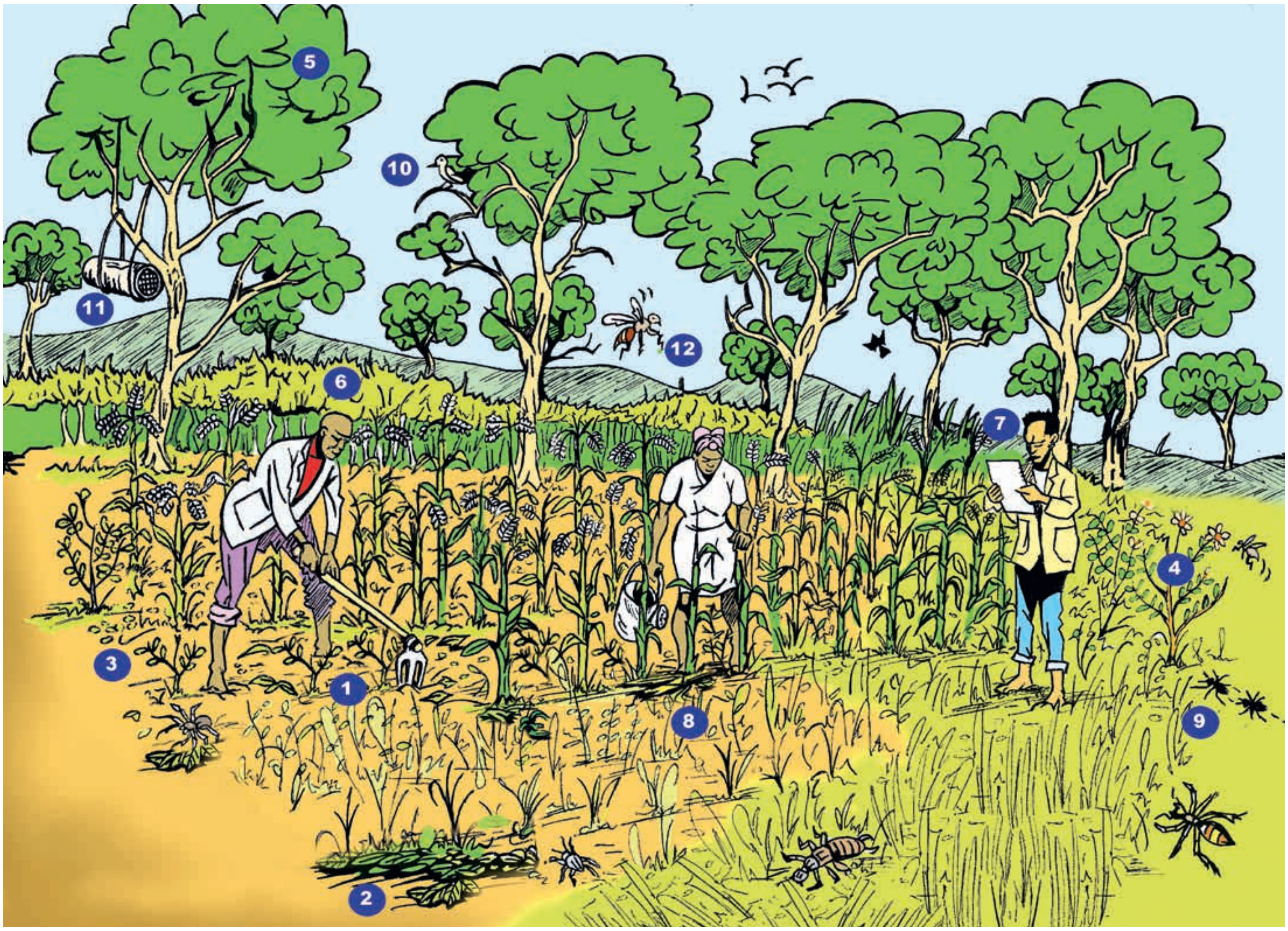
(1) Devkota M., Nangia V., Wery J., 2020. *Opportunity to diversify cropping system through relay-cropping and better use of rainwater to enhance farmer income and water use efficiency in rainfed Mediterranean agriculture.* Abstract submitted to the 7th International Symposium for farming systems design on designing climate smart agricultural systems for a sustainable transition in the agri-food systems of the dry areas, March 20-23, 2022.

(2) Nangia V., Sinha R., Kuri B.R., 2020. *Adaptive on-farm management of water resources for sustainable rainfed food production in central India.* Abstract submitted to the 7th International Symposium for farming systems design on designing climate smart agricultural systems for a sustainable transition in the agri-food systems of the dry areas, March 20-23, 2022.

Agroecological control of fall armyworm

Fall armyworm (FAW) is a major pest of cereals, particularly maize and rice. Native to North and South America, it was first detected in West Africa in 2016 and has subsequently spread throughout the continent and across Asia. It has been predicted that FAW could cause up to $US13 billion per annum in crop losses throughout sub-Saharan Africa, thereby threatening the livelihoods of millions of poor farmers[1]. Overuse and misuse of pesticides in sub-Saharan Africa is a major environmental and human health concern. We are conducting research on agroecological approaches with the aim of developing robust IPM strategies for FAW management. These offer culturally appropriate low-cost pest control strategies that can be readily mainstreamed into existing systems to improve smallholder incomes and resilience through sustainable intensification[2]. **Agroecological approaches to pest management are based on three complementary strategies: (i) improving plant health and resistance to attack through improved soil fertility management, especially via soil organic carbon enhancement; (ii) diversifying the agricultural habitat at farm and landscape scales to provide living space and resources for natural enemies; and (iii) conducting plot-scale interventions to disrupt the ability of pests to locate hosts, while increasing the efficacy of natural enemies**. Hence, through a highly replicated large-scale experiment across 12 landscapes in Malawi and Zambia, we are examining the roles of landscape-scale tree cover, farm-level habitat diversity and plot-scale management, including conservation agriculture and legume intercropping. Furthermore, we have developed protocols and data management tools that will enable this experiment to be replicated globally. Our initial first year findings in Malawi and Zambia indicated that FAW populations in smallholder fields were low and did not increase as the season progressed, suggesting that they are being held in check by natural mortality factors. We are currently monitoring experiments in a second season and examining the effects of treatments at different scales.



▲ *Some agroecological approaches for pest management.*
(1) Minimum soil disturbance enhances soil biological properties
(2) Mulching improves soils and provides habitat for insect predators
(3) Intercrops improve soil fertility and diversify the field environment
(4) Shrubs with flowers support parasitoid populations
(5) Trees provide perches and roosts for birds and bats
(6) Crop rotation improves soil fertility and diversifies the farm environment
(7) Scouting to identify pests and assess action thresholds
(8) and (9) Diverse field margins provide habitat for insect predators
(10) Insectivorous birds and bats reduce pest abundance
(11) Insect hotel for predatory wasps
(12) Predatory wasp.

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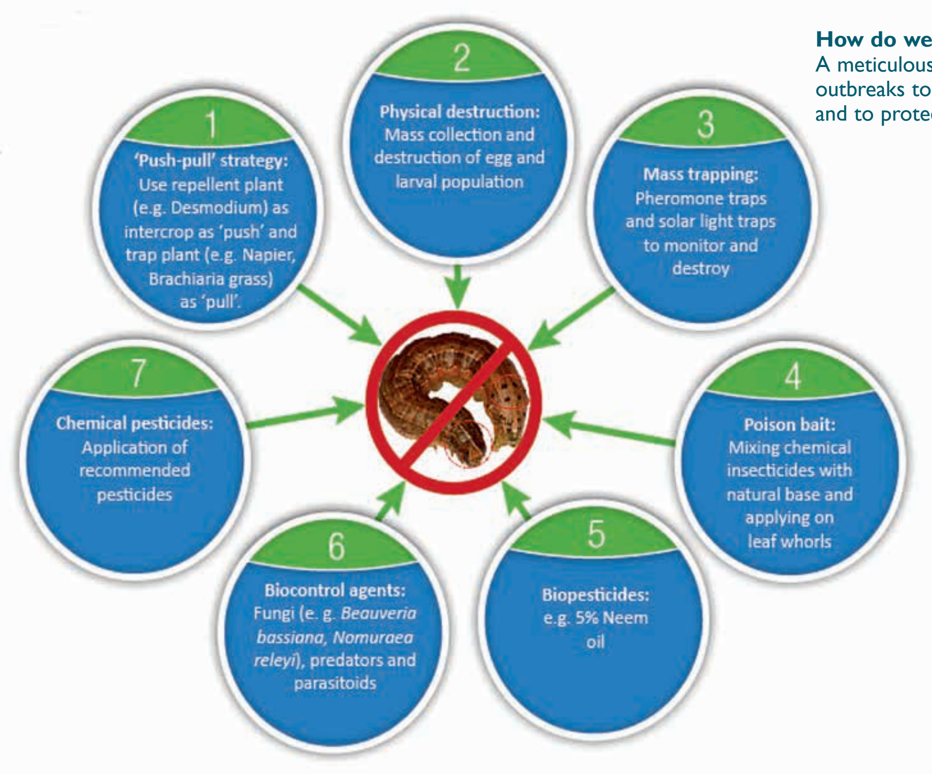
(1) Abrahams P., Bateman M., Beale T., Clottey V., Cock M., *et al.*, 2017. Fall armyworm: impacts and implications for Africa. *Outlooks on Pest Management,* 28(5): 196-201.

(2) Harrison R.D., Thierfelder C., Baudron F., Chinwada P., Midege C., Schaeffner U., van den Berg J., 2019. Agro-ecological options for fall armyworm (*Spodoptera frugiperda* JE Smith) management: providing low-cost, smallholder friendly solutions to an invasive pest. *Journal of Environmental Management,* 243: 318-330.

(3) Sinclair F., Wezel A., Mbow C., Chomba S., Robiglio V., Harrison R.D., 2019. *The contribution of agroecological approaches to realizing climate resilient agriculture*. Rotterdam and Washington DC. Available online: www.gca.org

Bioecology and sustainable management of invasive fall armyworm in sorghum crop

The fall armyworm (FAW), *Spodoptera frugiperda* (J.E. Smith) (Lepidoptera: Noctuidae), is an economically important pest native to the Americas that has recently invaded India. This polyphagous pest is reported to feed on 100 host plants from 27 plant families. However, it prefers to feed mainly on graminaceous plants, i.e. chiefly maize. It also feeds on sorghum, pearl millet and finger millet (ICRISAT Mandate Crops). Many control options were evaluated at ICRISAT (Patancheru, Hyderabad, India) with the aim of developing an effective management strategy against this pest. The results revealed that, sorghum seedlings were resistant to infestation by FAW for up to 25-30 days after planting when the seeds were treated with Fortenza Duo (5 ml/kg), which led to 15.0% leaf damage, followed by Imidacloprid (4 g/kg), 20.0% damage compared to the control, which exhibited 45.0% damage[1,2]. Other management options like pheromone traps, manual removal of eggs from host plants and poison baits were also evaluated. Insecticides, including chlorantraniliprole, spinetoram and emamectin benzoate, along with biopesticides such as *Metarhizium rileyi, Streptomyces* spp., Ecolaid Freedom, and neem oil were evaluated and found to be effective in reducing the FAW larval population in both sorghum/maize crops[1,2]. The push-pull cropping system, with napier grass (*Pennisetum purpureum*) as border trap crop (Pull) and intercrop (push), cowpea (*Vigna unguiculata*) and mungo bean (*Vigna radiata*) resulted in the least (5.0%) crop damage compared to the control plot (25% damage) in sorghum fields. **Implementing all of the aforesaid cropping system practices and other management practices resulted in a successful reduction in pest density in sorghum.**



▲ *Step-wise sustainable management of fall armyworm.* © ICRISAT

How do we fight it?
A meticulous, step-wise plan is needed to manage FAW outbreaks to prevent development of resistance to insecticides and to protect the environment.

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(1) Deshmukh S.S., Prasanna B.M., Kalleshwaraswamy C.M., Jaba J., Choudhary B., 2021. Fall armyworm (*Spodoptera frugiperda*). *In* Omkar (eds): *Polyphagous pests of crops*. Springer, Singapore. https://doi.org/10.1007/978-981-15-8075-8_8

(2) Jaba J., Suraj Mishra, Pankaj Maknwar, 2019. *Strategies for sustainable management of fall armyworm,* Spodoptera frugiperda *(J.E. Smith) in sorghum*. Paper presented in XIX International Plant protection congress IPPC2019, 10-14 November, 2019, Hyderabad, Telangana, India www.researchgate.net/publication/344768815_Strategies_for_sustainable_management_of_fall_armyworm_Spodoptera_frugiperda_JE_Smith_in_sorghum_2

Pheromone traps targeting *Spodoptera frugiperda* reduces insecticide use in maize cropping systems in Mexico

Fall armyworm (FAW), *Spodoptera frugiperda* (J.E. Smith), is a lepidopteran pest native to the Americas, which recently started spreading worldwide[1]. It is a widespread pest in most maize (*Zea mays* L.) producing areas in Mexico, where it can cause complete crop loss if not managed, especially in (sub)tropical areas. Farmers commonly lack knowledge on sustainable FAW management, and often apply large quantities of highly toxic insecticides to control this pest, causing environmental and health problems[2]. FAW sex pheromones were first used to monitor populations to determine insecticide application needs and are now used for massive capture and mating disruption. In these traps, a pheromone lure is suspended in a 20 L container with side openings (Photo A).

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▲ *Photo A. Pheromone traps in a field in Indaparapeo, Michoacán.* © CIMMYT

The bottom of the container is filled with soapy water. Males are attracted to the lure and drown in the water. The traps can capture large numbers of males, i.e. over 200 males ha^{-1} day^{-1}, depending on the local population (Photo B). Generally, **four traps per hectare can capture enough males to drastically reduce mating and thus oviposition, thereby reducing or eliminating the need for insecticides for FAW control**. The cost of pheromone traps and insecticides is similar, but pheromones have no negative effect on non-target species or farmers' health. The drawbacks include the need to change the water frequently, which is labor intensive, the fact that pheromone traps are highly specific and do not control other pest species, and the lack of pheromone availability on the local market. CIMMYT partnered with INIFAP—the Mexican national research institute that developed the practice—to implement agroecological pest management in collaborative trials. **The traps have therefore now been implemented successfully across Mexico and also tested in Zimbabwe.** This is a safe, economical and environment-friendly method for FAW control, that is suitable for smallholder farmers.

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For further information

(1) Prasanna B., Huesing J.E., Eddy R., Peschke V.M., 2018. Fall armyworm in Africa: a guide for integrated pest management. *Mex CDMX CIMMYT*, First Edit: 45-62. www.maize.org

(2) Bejarano González F. 2017. *Los plaguicidas altamente peligrosos en México*. Texcoco, Mexico: Red de Acción sobre Plaguicidas y Alternativas en México, A.C. (RAPAM).

▲ *Photo B. Massive capture of male* Spodoptera frugiperda *adults in Indaparapeo, Michoacán.* © *F. Bahena*

Insect nets to facilitate the agroecological transition in Africa

Vegetable production in sub-Saharan Africa is booming to feed the growing population, yet there is still widespread reliance on intensive chemical control. How can crop yields be increased without reliance on chemical inputs while promoting agroecology? Technology transfer and adoption of affordable low-tech techniques, such as the use of insect nets, could meet this challenge and reduce insecticide treatments. Research in Benin, Tanzania and Kenya has shown that insect nets are easy to use and protect plants against large pests and extreme climatic conditions. Growing crops such as tomato, beans, cabbage, pepper, etc., under these nets helps reduce pest attacks, especially those responsible for direct damage to fruits or leaves, including birds, snails, locusts, caterpillars and flies. Yet these nets do not completely protect crops against phloem-feeding pests such as aphids, whiteflies, thrips and mites, some of which can transmit viruses. The confined environment under nets nevertheless facilitates biological control of these pests and pollination by bees from beehives with two openings that provide access inside and outside the nethouse. **This technique thus enables farmers to drastically reduce pesticide use, while also mitigating the effects of extreme climatic conditions** such as high solar radiation, heavy rains and dry winds. Shade nets decrease heat stress during the dry season and a plastic roof can further reduce the risk of fungal diseases during the rainy season. Hence, insect nets help extend the production period, increase crop yields and improve the quality in terms of organoleptic features and lower pesticide residues. Protected cultivation techniques are often criticized because of the use of plastic. However, the insect net can be recycled and the increased efficiency in agricultural input usage would offset the negative impacts, as suggested by life-cycle assessments. Farmers' low investment capacity hampers their adoption of this insect net technology despite the fact that cost-effectiveness analyses have shown that nets help offset variations in crop yield and therefore in farmers' incomes. They help stabilize cash flows, reduce production volatility and quality variations. The use of insect nets thereby enhances farmers' long-term vision by reducing the risks, allowing them to make medium-term investments at lower risk.

▲ ***High tunnels with 0.9 mm nets on each side and plastic roof with shade nets adapted to humid and hot climatic conditions in Arusha, Tanzania.*** © *T. Nordey*

▲ ***Organic tomato production under insect nets in Nairobi area, Kenya.*** © *T. Martin*

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For further information

• Martin T., Parrot L., Belmin R., Nordey T., Basset-Mens C., Biard Y., Deletre E., Simon S., Le Bellec F., 2019. Anti-insect nets to facilitate the agroecological transition in Africa. *In* Côte F.-X. *et al.* (eds): *The agroecological transition of agricultural systems in the Global South*. Éditions Quae, Versailles: 75-87.

• Nordey T., Basset-Mens C., De Bon H., Martin, T., Déletré E., Simon S., Malézieux E., 2017. Protected cultivation of vegetable crops in sub-Saharan Africa: limits and prospects for smallholders. A review. *Agronomy for Sustainable Development*, 37(6): 1-20.

• Eco-friendly nets 2. A profitable climate smart agriculture technology (video): www.youtube.com/watch?v=Y6Ri6SuWTqk

• Eco-friendly nets to avoid the use of pesticides (video): www.youtube.com/watch?v=Vb-Ewrq42Il

Next-generation plant health management supported by science-based agroecological principles

Leveraging the use of affordable mobile digital innovations offering appropriate pest management solutions could empower low-literacy African farmers to overcome the need for inappropriate pesticide treatments. **As the first pillar of our new paradigm, mobile digital innovations** must account for the diverse literacy levels and languages of pest management actors. Therefore, sustained efforts and investments are needed to translate scientifically validated and locally appropriate pest control approaches into formats compatible for educational scaling[1]. **Research investigating the very cause of a given pest problem** —instead of just treating the symptoms— underlies **the second pillar**. This is illustrated by a case study on the legume pod borer (*Maruca vitrata*) in West Africa[3]. The 'business-as-usual' scenario tacitly considered this pest as indigenous in West Africa and hence gave priority to the development of resistant varieties combined with insecticide applications. However, the scant diversity, lack of specificity and low efficiency of locally present natural enemies in West Africa prompted us to question the indigenous status of this pod borer, as also recently supported by the findings of population genetic studies, which confirmed its tropical Asian origin. Much higher diversity of hymenopteran parasitoids was documented in Asia than in West Africa, and the two most promising Asian biocontrol candidates have now been released in West Africa. They have become established in Benin, Burkina Faso and Niger, where a substantial reduction in pod borer populations was observed at pilot sites[2]. **The third pillar is related to the efficient targeted use of external inputs** such as resistant/tolerant varieties and compatible cropping practices, supplemented by organic and inorganic fertilizers, and the application of biopesticides and synthetic pesticides as a last resort. **Our game-changing paradigm is centered around nature-based pest management, underpinned by: (i) straightforward real-time farmer access to ICT tools, thereby empowering farmers to make their own decisions; (ii) science-based ecological control first and foremost; (iii) and sustainable intensification to boost productivity in an environment-friendly way.** Our proposed next generation plant health management approach will, however, be even more knowledge-intensive than its precursor (pesticide-based IPM), so its successful implementation will necessitate significant investment in farmer capacity building and training.

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For further information

(1) Bello-Bravo J., Tamò M., Dannon E.A., Pittendrigh B.R., 2018. An assessment of learning gains from educational animated videos versus traditional extension presentations among farmers in Benin. *Information Technology for Development*, 24: 224244. doi: 10.1080/02681102.2017.1298077

(2) Srinivasan R., Tamò M., Periasamy M., 2021. Emergence of *Maruca vitrata* as a major pest of food legumes and evolution of management practices in Asia and Africa. *Annual Review of Entomology*, 66: 141-161.

(3) Tamò M., Afouda L., Bandyopadhyay R., Bottenberg H., Cortada-Gonzales L., Murithi H., Ortega-Beltran A., Pittendrigh B., Sikirou R., Togola A., Wydra K.D., 2019. Identifying and managing plant health risks for key African crops: legumes. *In* Neuenschwander P. and Tamò M. (eds): *Critical issues in plant health: 50 years of research in African agriculture*. Burleigh Dodds Scientific Publishing, Cambridge: 259-294.

▲ *The exotic parasitoid* Liragathis javana *(formerly* Therophilus javanus*) Bath and Gupta (Hymenoptera: Braconidae), stinging a* Maruca vitrata Fabricius *(Lepidoptera: Crambidae) pod borer larva feeding inside a cowpea flower in the field.* © D.A. Souna/IITA-Benin

▲ *Third instar larva of the parasitoid* Liragathis javana *egressing from a parasitized larva of the* Maruca vitrata *pod borer (red circle indicating exit hole) and continuing to feed on it as an ectoparasite.* © D.A. Souna/IITA-Benin

From natural process regulation to agroecosystem design

Agroecological solutions for the Global South – an example of service plants

Intensive agrosystems systematically eliminate some natural ecosystem characteristics, especially by drastically reducing biodiversity and species interactions through deep and frequent tillage, woody species removal, use of a narrow range of crops at the field and landscape scale, etc. The agroecological approach therefore consists mainly of (re)introducing and managing functional, cultivated and associated biodiversity within agrosystems in order to enhance ecosystem services.

The diversity of communities that prevail in agrosystems likely helps ensure provision of a number of ecosystem services[1,2]. For instance, the introduction of a service plant will modify the composition of the plant community, thereby promoting weed control. Service plants must satisfy a set of sometimes contradictory characteristics[3] (Figure). They are increasingly used in various monospecific cropping systems, such as banana plantations and fruit orchards, to control weeds (Photo), thereby curbing herbicide use. Furthermore, the inclusion of a cover crop modifies the system's overall functioning in terms of water and nutrient cycles, as well as interactions between insect and microorganism communities. Introducing a new resource in the system is an effective food web modification lever. Service plants are also used with annual crop species via numerous techniques to fulfill various objectives, i.e. plant protection through attractive and repulsive processes, or soil protection. For instance, service plants in mulch-based systems can help maintain permanent plant cover while limiting tillage. This practice reduces erosion and enhances the soil biological activity, hence contributing to sustainable soil organic matter management. Agroecological principles are based on natural ecosystem functioning analyses. For larger than plot scales, insight into several organizational levels is needed to implement these principles in agrosystems. Yet the agroecological approach must also be mainstreamed into more or less territorialized social systems, including value chains and, more generally, food systems.

▲ *Cover plants in a* Citrus *plantation, Réunion (France).*
© E. Malézieux

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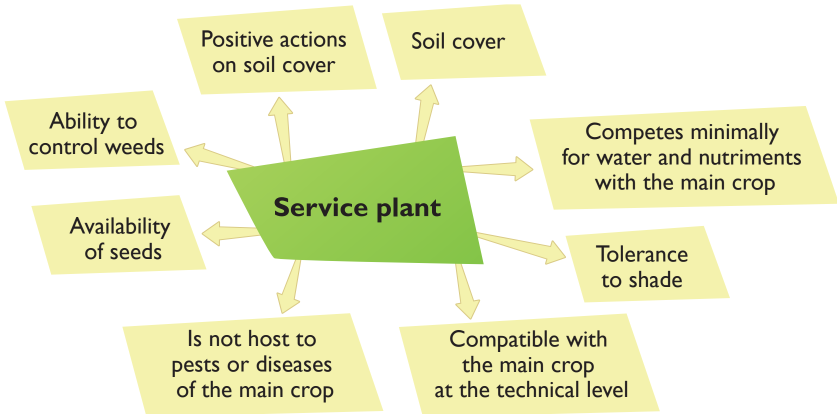
(1) Malézieux E., 2012. Designing cropping systems from nature. *Agronomy for Sustainable Development*, 32(1): 15-29. http://dx.doi.org/10.1007/s13593-011-0027-z

(2) Malézieux E., Crozat Y., Dupraz C., Laurans M., Makowski D., Ozier Lafontaine H., Rapidel B., De Tourdonnet S., Valantin-Morison M., 2009. Mixing plant species in cropping systems: concepts, tools and models. A review. *Agronomy for Sustainable Development*, 29(1): 43-62. http://dx.doi.org/10.1051/agro:2007057

(3) Malézieux E., Rapidel B., Goebel F.-R., Tixier P., 2019. From natural regulation processes to technical innovation, what agroecological solutions for the countries of the Global South? *In* Côte F.-X. *et al.* (eds): *The agroecological transition of agricultural systems in the Global South*. Ed. Quae, Versailles, France: 199-217. (Agricultures et défis du monde) www.quae-open.com/produit/114/9782759230570/the-agroecological-transition-of-agricultural-systems-in-the-global-south



Antimicrobials in livestock farming in the Global South

Minimizing their use while curbing health and socioeconomic risks

Major changes in livestock farming methods that have taken place over the last 50 years have led to the widespread use of antimicrobials in livestock and aquaculture. In some countries of the Global South—due to the growing demand for animal protein and the absence of appropriate regulations—the volume of antimicrobials used continues to rise, which has led to the emergence of bacterial resistance. These bacteria spread through natural food webs and commercial food chains (Figure), from local to global scales via human mobility and trade flows. Resistant bacteria pose a threat to human and animal health and ecosystems. International organizations and governments are calling for interventions to reduce antimicrobial use in livestock. The effectiveness of such actions depends on the implementation of One Health approaches combined with agroecological principles.

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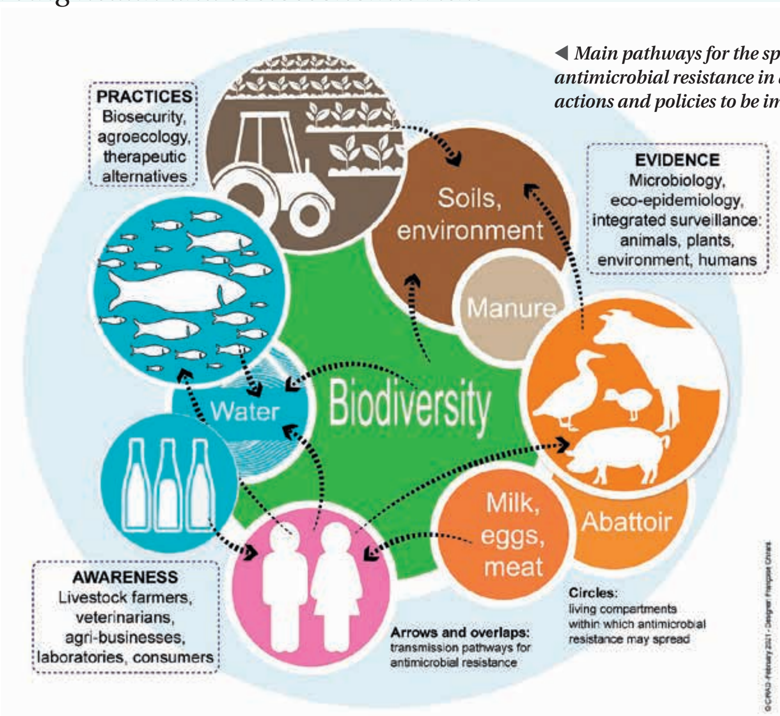

◀ *Main pathways for the spread of antimicrobial resistance in agriculture: research, actions and policies to be implemented.*

CIRAD is implementing a set of interdisciplinary approaches, drawing on qualitative and quantitative research in Asia (Vietnam, Cambodia) and Africa (Mozambique, South Africa, Senegal):

- **participatory approaches** aimed at identifying potential changes in livestock farming practices to enhance animal disease prevention and reduce the use of antimicrobials, while using them rationally and curbing the negative health and socioeconomic impacts on the livelihoods of livestock farmers, particularly in the most vulnerable regions
- **research on therapeutic and preventive alternatives**
- **design and assessment of integrated surveillance systems (One Health)** to detect the emergence of resistance and evaluate the effectiveness of implemented measures
- **research on resistance circulation between human, animal and environmental compartments**
- **research on antimicrobial supply chains and on the regulatory and institutional frameworks for their use.**

In Vietnam, for example, a stakeholder analysis and companion modeling generated a conceptual and methodological framework for implementing the One Health concept in antimicrobial resistance surveillance. Farmers and other key stakeholders are involved in research and innovation processes to support the transition to safer antimicrobial use.

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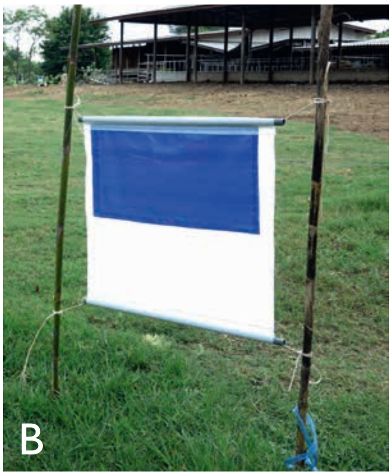
Roger F., Ducrot C., 2017. Antimicrobials in agriculture: reducing their use while limiting health and socioeconomic risks in the countries of the South. *Perspective*, 39: 1-4. https://doi.org/10.19182/agritrop/00014

Controlling hematophagous flies while curbing insecticide dissemination

Development of attractive screens and traps

Hematophagous flies (tabanids, *Stomoxys* spp., tsetse flies) are a major scourge for humans and animals because of their bites and the transmission of parasitic (trypanosomosis, besnoitiosis), bacterial (anaplasmosis, Q fever) and viral diseases (bluetongue, West Nile, African swine fever). These pests are conventionally controlled through massive insecticide treatments (sprays, pour-ons), which are not very effective and result in insecticide uptake in foods and dissemination in the environment. To reduce this pollution, the FlyScreen research program, conducted by CIRAD in collaboration with the University of Montpellier and Kasetsart University (Bangkok), the National Veterinary School of Toulouse (ENVT) and the AtoZ company, has developed blue and blue-and-white polyethylene screens (Photos A and B), which are specifically attractive to all hematophagous flies (Photo C). **These FlyScreens—pyrethroid-impregnated in an innovative way (patent pending)—enable targeted destruction of pest insects without insecticide dissemination in the environment.** A proof of concept of control efficacy by the Multi Targets Method (about 20 screens per farm) (Photo A) has been reported. FlyScreens will be used in Africa for controlling tsetse flies and in Asia against other hematophagous flies. This major breakthrough cannot, however, be implemented in Europe and America due to the widespread pyrethroid chemoresistance of flies. The new BioFlyTrap program (modelled on FlyScreen) set up by CIRAD, IRD, INRAE, ENVT and a private partner, aims to develop simple, light, insecticide-free, biodegradable and inexpensive capture traps to be used on farms within a "Multi Targets Method"—a promising project for efficient agro-ecological control, without plastic or insecticide pollution of the environment.



▲ ***Photo A.*** *Multi Targets Method: installation of 20 attractive FlyScreens for controlling hematophagous flies. © M. Desquesnes*

◀ ***Photo B.*** *A Polyethylene deltamethrin-impregnated screens used in Thailand. © M. Desquesnes*

▲ ***Photo C.*** *A FlyScreen coated with a sticky film, illustrating the high attractiveness to hematophagous flies (here* Stomoxys *spp., in Réunion). © Y. Grimaud*

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For further information

• Onju S., Thaisungnoen K., Masmeatathip R., Duvallet G., Desquesnes M., 2020. Comparison of blue cotton and blue polyester fabrics to attract hematophagous flies in cattle farms in Thailand. *J. Vector Ecol.*, 45(2): 262-268. doi: 10.1111/jvec.12397. https://pubmed.ncbi.nlm.nih.gov/33207049/

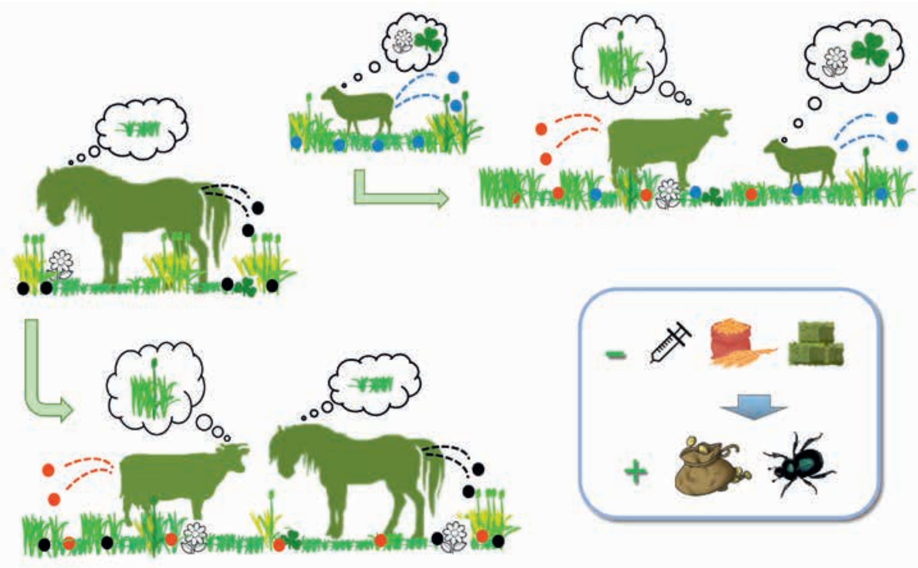
• Desquesnes M., Bouhsira E., Chalermwong P., Drosne L., Duvallet G., Franc M., Gimonneau G., Grimaud Y., Guillet P., Himeidan Y., Jacquiet P., Jittapalapong S., Karanja W., Liénard E., Onju S., Ouma J., Rayaisse J-B., Masmeatathip R., Salou E., Shah V., Shukri S., Thaisungnoen K., 2019. The multi targets method (MTM): an innovative strategy for the control of biting flies as vectors. *Ecology and Control of Vector-borne Diseases* (ECVD), 6. www.wageningenacademic.com/doi/epdf/10.3920/978-90-8686-895-7_5

• *FlyScreen* research program: https://umr-intertryp.cirad.fr/recherche-et-impacts/projets/flyscreen

Livestock co-grazing

A catalyst for the agroecological transition of grassland systems

Agroecology, as applied to livestock production, is based on the principle that animal-resource diversity within livestock farming systems can reduce farmer reliance on inputs (drugs and concentrates). In grassland-based systems, mixed grazing is assumed to make more efficient use of pastures because of the complementary of cattle, sheep and horse grazing behaviour. Grazing cattle—and even more so horses—create short vegetation patches in pastures, and thereby act as a facilitator for the other species, which will benefit from the subsequent high quality vegetation regrowth. Mixed grazing is also assumed to have a dilution effect on the livestock parasite load due to the host specificity of most digestive-tract strongyles—during the phase of the cycle when infesting larvae are in the sward, these parasites may be ingested by an animal from the other species, thereby interrupting the larval development cycle. More efficient use of grass resources was pointed out as being among the main advantages of mixed grazing by 84% of cattle-sheep farmers surveyed in Auvergne (France) during the new-DEAL project. A bioeconomic optimization model also predicted a 30% reduction in feed concentrate use. In beef cattle-saddle horse farms, we observed a 15% increase in stocking density, a clear reduction in feed purchases and in rotary slasher use than in specialized equine farms. Parasite excretion by ewe lambs grazing with heifers was twofold lower compared to monospecific grazing, and their growth was 40 g/day higher. Parasite excretion by young horses grazed with cattle was also twofold lower. A reduction in the frequency of anthelmintic treatments would reduce variable farm costs and benefit coprophagous insects. Our recent research aims to determine pasture management methods (species ratios, etc.) that would optimize the benefits of mixed grazing.



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• Dumont B., Fortun-Lamothe L., Jouven M., Thomas M., Tichit M., 2013. Prospects for agroecology and industrial ecology for animal production in the 21st century. *Animal*, 7: 1028-1043. https://doi.org/10.1017/S1751731112002418

• Forteau L., Dumont B., Sallé G., Bigot G., Fleurance G., 2020. Horses grazing with cattle have reduced strongyle egg count due to the dilution effect and increased reliance on macrocyclic lactones in mixed farms. *Animal*, 14: 1076-1082.

Ecological intensification in aquaculture

Aquaculture is the agricultural production sector with the highest growth rate. In 2030, it will have to provide more than 60% of all fish needed for human consumption. This increased production will induce greater input consumption. The resulting environmental impacts and the degradation of farm effluents highlight the need to design new aquaculture production systems. In this context, the ecological intensification of aquaculture systems proposes the use of the ecological processes and functions of the system as a way to boost production, reduce impacts, and enhance the ecosystem services of aquaculture. The challenge is to foster systems requiring few or no inputs, such as formulated feeds, while maximizing the outputs by relying on natural productivity and the development of associated ecosystem services.

Aquaculture practices for ecological intensification are highly diversified and often integrated within the ecosystem or territory. In Brazil, an ecological intensification scenario that included lagooning with macrophytes in integrated systems called MAPIVI (pigs/tilapia or carp polyculture) was studied. **Effluent quality was improved alongside greater acceptability of the system. This validated scenario was thus incorporated in the national framework for fish farming in the Brazilian state of Santa Catarina**. In Indonesia, a combined *Pangasius*/gourami/duckweed system was tested in ponds. **This scenario—based on nutrient recycling, water quality management, and diversification of produced species—performed better in terms of eutrophication and acidification, as calculated by life cycle analysis.** Nevertheless, adapting scientific knowledge to the diverse range of aquaculture operations and creating a sociocultural environment conducive to innovation appropriation remain the key challenges of ecological intensification in aquaculture.

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Aubin J., *et al.*, 2017 Implementing ecological intensification in fish farming: definition and principles from contrasting experiences. *Reviews in Aquaculture*, 11(1): 149-167. https://doi.org/10.1111/raq.12231

◀ *Agro-aquaculture ecosystem in West Java, Indonesia.*
© D. Caruso/IRD

Chapter 3

Redesigning agroecosystems on the basis of a new set of ecological processes from farm and landscape

This chapter focuses on the redesign, implementation and management of agroecosystems that differ from current systems. This redesign process is driven by a transformation commitment (less dependence on pesticides, more efficient in the use of water, decent work and improved wellbeing, adaptation to climate change, landscape quality and biodiversity preservation, etc.). It may represent a real break with the past while being geared towards long-term change. It draws on certain agroecological principles: diversifying varieties/breeds, crop rotations, fostering complementarity between livestock and crop production, reintroducing trees in farms and landscapes, and reconsidering agroforestry systems in terms of their multifunctionality. Although often having a specific focus, it soon strives to reconsider all agroecosystem functions and services, and their sustainability and resilience in response to the highly variable nature of external constraints (climate, prices, etc.). This redesign process may take place on the farm or in the landscape, within the scope of collective management (watershed, small management area), or within a broader territorial project involving non-farmer stakeholders (public authorities, environmental protection or tourism agencies). This chapter is devoted to five major themes, the first four of which approach agroecosystem redesign from a specific standpoint, while the last one calls for a review of all agroecosystem functions and services.

Enhancing biological interactions: Insight into the importance of biological diversity and biotic interactions in agroecosystems has led to the development of strategies based on the introduction of new biological diversity, the analysis of its effects and its role in disease resistance and control, and in pollination. A literature review has highlighted interactions between crop protection practices and viral zoonotic diseases, with a One Health vision (Ratnadass & Deguine). Redesign research regarding banana agroecosystems in the West Indies takes the functional traits of plants into account, with the aim of selecting these so-called service plants and combining them as multifunctional cover crops for weed control, while also optimizing nitrogen resource acquisition (Dorel *et al.*). An ecological engineering approach promotes biological control for sustainable pest management by enhancing natural enemy survival and action by increasing floral diversity in rice landscapes (Zaidi *et al.*). On a larger scale, Farming with Alternative Pollinators (FAP) strategies use marketable habitat enhancement plants consisting (in small areas) of spices, oil seeds or other vegetables that attract and sustain higher abundance and diversity of wild pollinators and natural enemies over time (Christmann).

Functions and ecosystem services of agroforestry: Agroforestry systems—combining woody species and annual crops—are very diversified. They range from traditional tree monocultures (coffee, cocoa, rubber, fruit orchards, etc.), where the challenge is to enhance diversity within and between species so as to ensure their resilience and sustainability, to multispecies agroecosystems including *bocage* systems (trees-crops-livestock), to natural agroforestry parks, which must be preserved in the light of the various pressures exerted on them. The issues and intended redesigns are dealt differently in these systems. In traditional cropping systems, research focuses on the functional traits of agroforestry systems, particularly in view of the need for better pest control, but also of the diversity of the ecosystem functions and services of these systems (Avelino *et al.*; Penot). The idea is to optimize natural resource use (a unit of agroforestry area produces more than the sum of crops grown in pure stands) and to generate functional synergies (Winowiecki *et al.*; Rodenburg *et al.*). An example regarding cocoa systems illustrates the impacts of the introduction of a mixture of fruit and forest trees chosen for their varied assets (cocoa yield, biological pest control, product diversity, etc.) (Jagoret). The contribution of these systems to climate change mitigation through carbon sequestration in wood and soil—as illustrated in the case of hedges and hedgerows—is a challenge that needs to be accurately and spatiotemporally quantified (Viaud & Thenail). Water management is also important, as demonstrated here in fruit tree-crop intercropping systems implemented in Mediterranean and dryland regions to manage scarce water resources (Wery *et al.*). Regarding nature parks, the aim is to renew interest in tree products, in line with current socioeconomic priorities, while developing forest product value chains and establishing new governance rules (Cardinael; Seghieri *et al.*).

▼ *Restoration of an agrosylvopastoral production system of the Ouled Sbaihia community located in a semiarid area in Tunisia.* © *Slim Slim*

Enhancing the complementarity of crop and livestock farming: The status of livestock is questioned in this redesign process: animals enhance the value of certain highly stressed environments (drylands, mountains, etc.) and enable biogeochemical cycles to be completed by enhancing the value of certain resources, returning nutrients to the soil and stimulating the soil biological activity (Louhaichi & Hassan; Rekik *et al.*). Livestock-crop integration can also be an adaptation option in a climate change setting (products and additional food resources), yet also a constraint, i.e. providing livestock feed resources even in drought conditions (stocks, new resources) (Novak *et al.*). Management of the water and soil moisture status is a common focal point. Some examples illustrate this introduction in agroforestry systems and agropastoral systems requiring water management. The conversion of mixed crop-livestock systems into organic farming systems can reduce farm vulnerability through more autonomous nutrient management (Martin). Mixed fish-rice production systems are also part of this loop mindset, but this time at the field level (Freed *et al.*).

Redesigning landscapes: Agroecosystem redesign initiatives often have to take the landscape scale into account, including production and interstitial areas, which can have a regulatory role (specific habitat, refuge, etc.), including a broad range of environments (diverse soils, access to water resources according to the hydrological conditions) (Petit-Michaut; Omondi *et al.*). Closer adaptation of agroecosystems to their environment, including possible synergies and complementarities between cultivated and natural biodiversity, farmers, landscape management stakeholders and the territory also sometimes have to be considered in this process (Yadav *et al.*). The territory is a socioecosystem in which environments, activities and societies coevolve—ecosystem services such as cultural, memorial and historical amenities are particularly attached to it.

These different aspects are partly illustrated with regard to the landscape level and geared towards enhancing the regulatory services of the landscape against pests and diseases. This is achieved by taking semi-natural spaces and their functions into consideration, while sometimes preserving certain spaces within the landscape (Deconchat *et al.*). The landscape dimension is particularly important in agropastoral systems, which use areas that vary according to the seasons, rainfall and soil moisture conditions (Mekuria & McCartney; Romero *et al.*; Strohmeier *et al.*).

Building resilience through ecosystem services: Redesign calls into question all agroecosystem functions and services. There are numerous examples of participatory design approaches—also known as open innovation—to identify acceptable innovative solutions, drawing on academic and field knowledge to identify agroecosystem transition scenarios (Scopel; Saj & Demenois; Sourisseau *et al.*). Conceptual frameworks have been formalized to account for ecosystem service function value chains (Rakotovao *et al.*; Lescourret *et al.*). Many examples derive from India, sub-Saharan Africa (West Africa, Madagascar), France, etc., regarding various systems, illustrating ways of accounting for GHG emissions, carbon sequestration, soil function conservation, reduction of energy or water consumption (Ruiz & Sekhar), etc., thereby mitigating the weak aspects of each system. Agroecology constitutes a lever for climate change adaptation and mitigation (Kebede *et al.*). It is vital to take agricultural work and the role of the actors, particularly women (Crossland *et al.*), into account in this innovative concept in order to address and even overturn well-established practices.

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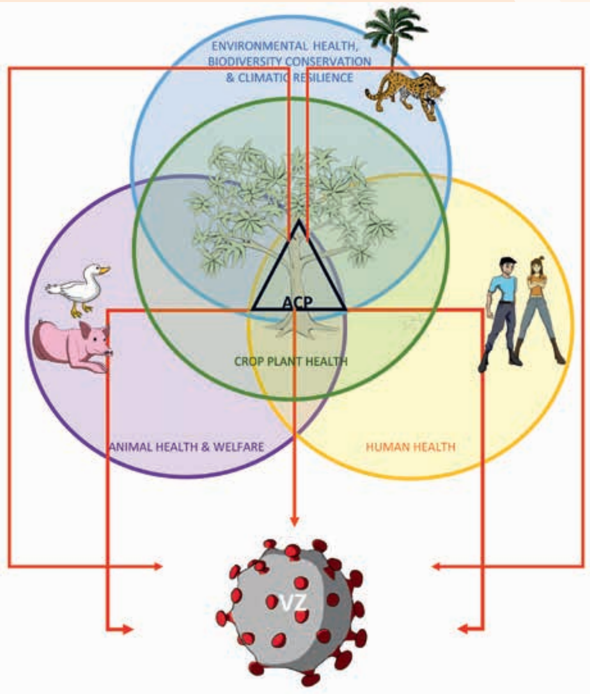
Enhancing biological interactions

Agroecology for crop protection and zoonotic disease control

Recent viral zoonotic outbreaks have been partially attributed to the negative impact of human activities on ecosystem biodiversity. A review of the scientific literature on interactions between crop protection (CP) practices and viral zoonoses (VZs) encompassed over 200 references. This review highlighted actual or potential interactions between VZ and CP practices based (for the latter) on efficiency improvement (conventional practices with agrochemical insecticides and rodenticides), substitution (physical/mechanical or biopesticide-based methods), or redesign (biological control via habitat conservation and management, including some forms of crop-livestock farming integration). CP practices covered in the literature review primarily targeted vertebrate pests (rodents and bats) and insects, but also plant pathogenic microorganisms and weeds. Methods based on efficiency improvement and substitution (partly), as well as some crop-livestock integration practices, have shown negative, mixed or conflicting impacts on VZ risks. Conversely, **redesign-based practices in the agroecological crop protection (ACP) framework generally resulted in VZ prevention via different processes** (Figure). Several examples concerned cropping systems studied by research units of the Occitanie region scientific community, e.g. rice cropping-duck rearing integration, the fostering of vertebrate predators in oil palm plantations, or of weaver ants in fruit tree orchards. The literature review also revealed that ACP, while helping integrate plant health within the broader One Health concept, also addresses other major global challenges, given its positive impacts in terms of enhancing climate resilience, animal welfare and biodiversity conservation (Figure).



◀ ***Agroecological crop protection (ACP) (central black triangle): direct or indirect reduction (red arrows) of viral zoonotic risks (VZ), contribution to the One Health concept extended to the four health types (circles), including global climatic resilience, biodiversity conservation and animal welfare challenges.*** *Adapted from Ratnadass & Deguine (2021)*

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Ratnadass A., Deguine J.P., 2021. Crop protection practices and viral zoonotic risks within a One Health framework. *Science of the Total Environment*, 774. https://doi.org/10.1016/j.scitotenv.2021.145172

Biodiversification enhanced by service plants

A lever for the agroecological transition of banana agrosystems

In the 1980s, banana agrosystems in the French West Indies were based on intensive monoculture systems with little diversity and heavy use of synthetic pesticides (particularly nematicides and insecticides) and mineral fertilizers. The necessary agroecological transition of these systems first involved prophylactic cropping strategies based on the use of healthy planting materials (micropropagated plantlets) combined with fallowing and crop rotations that had a sanitizing effect against soilborne pests. The plant biodiversity initially introduced in these systems was underpinned by crops or herbaceous plants initially selected for their service plant role to control the endoparasitic nematode *Radopholus similis* thanks to their non-host status.

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▲ ***A banana-*Crotalaria *association.*** *© R. Domergue*

A generic approach was then developed, based on the functional traits of these plants, i.e. their individual features related to their functioning in the agrosystem. The aim was to select these so-called 'service plants' for a supplementary broader range of ecosystem services, and to combine them as multifunctional cover crops for weed control, nitrogen resource optimization, soil structure enhancement, erosion mitigation, etc. **This new pathway has oriented French West Indian banana systems towards plurispecific agrosystems spatiotemporally combining plant species with complementary traits.** These banana systems—enriched by this chosen functional biodiversity—are shifting to an increased extent towards organic agriculture, conservation agriculture and agroforestry while seeking functional complementarity with trees. This transition is under way in a partnership framework involving banana growers' groups and their R&D technical services. It could also concern, in a contextualized manner, countries of the Global South in a quest for banana agrosystem sustainability.

▲ ***A banana**-Desmodium ovalifolium-Arachis repens **association**. © H. Tran Quoc/GECO*

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For further information

• Damour G., Dorel M., Tran Quoc H., Meynard C., Risède J.M., 2014. A trait-based characterization of cover plants to assess their potential to provide a set of ecological services in banana cropping systems. *European Journal of Agronomy*, 52: 218-228.

• Risède J.M., Achard R., Brat P., Chabrier C., Damour G., Guillermet C., De Lapeyre de Bellaire L., Loeillet D., Lakhia S., Meynard C., Tixier P., Tran Quoc H., Salmon F., Côte F.X., Dorel M., 2019. The agroecological transition of Cavendish banana cropping systems in the French West Indies. *In* Côte F.-X. *et al.* (eds), *The agroecological transition of agricultural systems in the Global South*. Ed. Quae, Versailles: 107-126. Agricultures et défis du monde.

• X International Symposium on Banana: ISHS-ProMusa Symposium on Agroecological Approaches to Promote Innovative Banana Production Systems (October 2016): www.ishs.org/ishs-book/1196

Ecological engineering-based interventions for sustainable pest management in rice-based cropping systems

▲ ***Habitat manipulation with marigolds to maintain natural enemies in rice ecosystems.*** *© Chitra Shanker/IIRR, Hyderabad India*

Ecological engineering is a habitat management approach aimed at providing shelter and food for natural pest control agents while promoting biodiversity and structural complexity within the agroecosystem. Ecological engineering involves modification to enhance biological control for sustainable pest management. It includes habitat management to foster natural enemy survival and action via increased floral diversity on rice field bunds, for instance. Unlike other flowering plants, rice lacks floral and nectar resources to attract natural enemies. **Planting additional floral/nectar-rich flowering plants on rice bunds can ensure year-round resources for natural enemies.** Border plants have been shown to increase parasitization of yellow stem borer and leafhopper egg masses[1,2].

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Flowers of five different plant species, i.e. green gram (*Vigna radiata*), marigold (*Tagetes erecta*), sunn hemp (*Crotalaria juncea*), cowpea (*Vigna unguiculata*) and okra (*Abelmoschus esculentus*), were tested against a control only or their effectiveness in attracting predatory mirid bug (*Cyrtorhinus lividipennis*) and coccinellid predators (*Micraspis discolor*, *Harmonia octomaculata* and *Coccinella transversalis*) in a six-arm olfactometer. *C. lividipennis* attraction was high in sunn hemp, followed by cowpea, marigold and okra. All three predatory coccinellids were attracted more to cowpea, followed by okra and green gram[3]. The different parasitoids occurring in rice ecosystems include *Oligosita* sp., *Anagrus* sp., *Drynid* sp., *Charops* sp., *Tetrastichus shoenobii, Xanthopimpla* sp. and *Gryon* sp. An increased abundance of natural enemies including predators and parasitoids was noted, while the parasitism rate also increased significantly in eco-engineered plots compared to control plots.

During 2017-2020, ecological engineering-based pest management interventions were conducted across different agro-climatic zones in Odisha state, India. It would be essential to elucidate the compounding effects of eco-engineered interventions on cropping systems overall. Scaling of such eco-engineered interventions could enhance farmers' productivity and profitability, thereby boosting their income, livelihoods, while helping restore agroecosystem functioning, reducing pest infestations and improving environmental protection.

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(1) Chitra S., Amudhan S., Lydia Ch., Sampathkumar M., Gururaj K., 2012. Effect of flowering plants on longevity and fecundity of the parasitoids of the Green Leafhopper, *Nephotettix virescens* on rice. *In* Gururaj K. et al. (eds.): *International conference on plant health management for food security: abstracts of the international conference, held at DRR, Hyderabad, India*, Abst. N° OP7: 21-22.

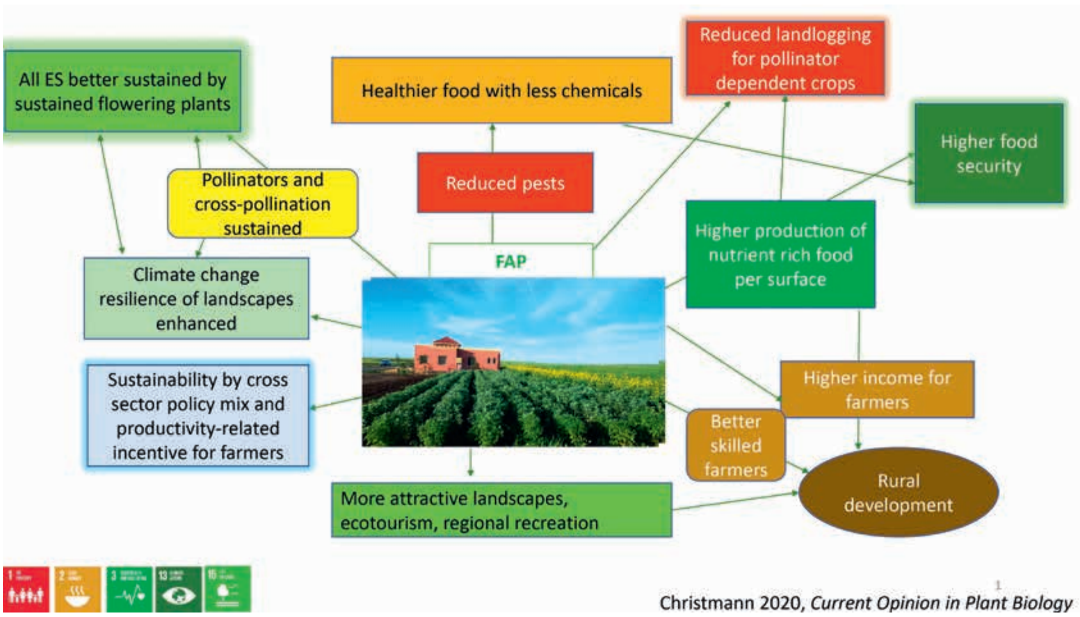
(2) Chitra S., Sampath Kumar M., Jhansirani B., Lydia Ch., Amudhan S., Gururaj K., 2015. Impact of ecological engineering on egg parasitisation of the yellow stem borer, *Scirpophaga incertulus* (Walker) in rice in the National meeting on New/safer molecules and biocontrol technologies for integrated pest management in crops, Bengaluru, Feb. 23, 2015.

(3) Vijayaraghavendra R., Vijaya Lakshmi K., Chitra S., Malathi S., Jagadeeshwar R., Damodar Raju C., 2019. Olfactory response of insect predators of rice brown plant hopper (*Nilaparvata lugens* (Stal.)) to flower volatiles. *Journal of Entomology and zoology studies*, 7(1): 1095-1099.

Farming with Alternative Pollinators (FAP) increases productivity by sustaining beneficial insects

A strategy for ecological transformation of agriculture in low- and middle-income countries

Agriculture still threatens pollinators most, but 75% of human food crops, 87% of flowering plants and all ecosystem services provided by these flowering plants depend on pollinators[1]. Therefore, pollinator loss can cause interlinked spirals of degradation and impoverishment[1]. While Europe invests billions to reward farmers for seeding wildflower strips to protect pollinators, low- and middle-income countries cannot afford such rewarding schemes[2,3]. Farming with Alternative Pollinators (FAP) was developed to address this problem[2,3]. **FAP avoids opportunity costs associated with wildflower strips by using only marketable habitat enhancement plants (MHEP) and low-cost nesting materials**. Small areas of spice, oil seed or other vegetable plants attract and sustain higher abundance and diversity of wild pollinators and natural enemies over a long period. They markedly increase the productivity of the main crop and reduce pest abundance, thereby minimizing the need to invest in chemicals[2,3,4]. Farmers gain significantly higher income from the main crop and additional income from MHEP[2,3]. MHEP provide a buffer against income loss if the main crop is attacked by pests or diseases[2,3]. Instead of environmentally-unfriendly external inputs, FAP uses two ecosystem services for intensification, i.e. pollination and pest control. FAP substantially increases crop production per surface and thus contributes to food security (SDG 2), while combating poverty (SDG 1) and promoting human health and wellbeing due to the reduced need for chemicals (SDG 3)[4]. Higher production per surface reduces the need for agricultural land expansion. For biodiversity conservation both are necessary: agroecological intensification in fields and reduced expansion of agricultural areas. In dry areas experiencing rapid climate change —as in the MENA region—FAP is even more essential than elsewhere, because: (i) 87% of flowering plants need cross-pollination to adapt to climate change (SDG 13, 15)[4]; and (ii) most pollinator-dependent crops generate higher revenue per water unit than pollinator-independent crops[4]. Landscapes with flowering FAP fields are also attractive for recreation, so FAP adoption can further benefit rural communities by offering the possibility of generating income from ecotourism (SDG 1)[4].



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For further information

(1) Christmann S., 2019a. Do we realize the full impact of pollinator loss on other ecosystem services and the challenges for any restoration in terrestrial areas? *Restor. Ecol.,* 27(4): 720-725.

(2) Christmann S., Aw-Hassan A., Rajabov T., Khamraev A.S., Tsivelikas A., 2017. Farming with alternative pollinators increases yields and incomes of cucumber and sour cherry. *Agron. Sust. Dev.,* 37: 24. doi:10.1007/s13593-017-0433-y

(3) Christmann S., Aw-Hassan A., Güler Y., Sarisu H.C., Bernard M., Smaili M.C., Tsivelikas A., 2021. Two enabling factors for farmer-driven pollinator protection in low- and middle-income countries. *Int. J. Agr. Sustain.*, doi: 10.1080/14735903.2021.1916254

(4) Christmann S., 2019b. Climate change enforces to look beyond the plant. The example of pollinators. *Curr. Opin. Plant. Biol.,* 56: 162-167.

Trees are pivotal in the agroecological management of coffee pests and diseases

The presence of trees within and in the vicinity of coffee stands impacts pest and disease development. **Trees may stimulate three agroecological pathways: (i) they modify the physical environment and directly or indirectly curb pest and disease development by enhancing the development of natural enemies or changing the physiology of crop plants; (ii) they modify the biological environment and favor natural enemies (birds, certain arthropods and microorganisms); and (iii) they create physical barriers that hamper pest and pathogen movement.** It is essential to gain insight into these different pathways so as to be able to effectively use trees as a lever in the agroecological management of pests and diseases of coffee or other crops.

▲ Croton *windbreaks in coffee plots under Inga tree shade, Apaneca, Salvador.* © *J. Avelino*

Some diseases are almost absent in coffee-based agroforestry systems because the trees regulate extreme ambient temperatures (e.g. brown eyespot disease caused by *Cercospora coffeicola*). Shade trees help regulate fruit load on coffee trees, while avoiding imbalances conducive to the development of other diseases such as dieback, associated with *Colletotrichum* spp., or coffee leaf rust caused by *Hemileia vastatrix*. Trees host predators of insect pests, such as birds and ants, while providing moist and shady conditions that are favorable for fungal natural enemies (*Beauveria bassiana* and *Lecanicillium lecanii*). In this way, trees enable the regulation of the coffee berry borer (*Hypothenemus hampei*) and rust. Moreover, tree windbreaks help avoid coffee blight caused by *Phoma costarricensis*, which penetrates coffee leaves via wounds inflicted by cold winds. Finally, the presence of forest stands in coffee landscapes reduces the impact of coffee berry borer, probably by making it harder for this pest to access resources during non-fruit bearing periods. Trees can have complex and sometimes unwanted impacts on pests and diseases, some of which are unstable due to interactions with the environment. Moreover, not all trees are equivalent. A current research challenge is to identify trees with functional traits that will help curb unwanted impacts while maintaining the sought-after effects.

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• Avelino J., Allinne C., Cerda R., Willocquet L., Savary S., 2018. Multiple-disease system in coffee: from crop loss assessment to sustainable management. *Annual Review of Phytopathology*, 56: 611-635.

• Avelino J., Ten Hoopen G.M., DeClerck F.A.J., 2011. Ecological mechanisms for pest and disease control in coffee and cacao agroecosystems of the Neotropics. *In* Rapidel B. *et al.* (eds): *Ecosystem services from agriculture and agroforestry measurement and payment*. e Earthscan: 91-117.

Rubber agroforestry systems in Kalimantan, Indonesia

A survey was conducted by CIRAD in 2019 on the evolution of rubber agroforestry system (RAS) trial plots that had been set up in the 1990s in West Kalimantan as part of the Smallholder Rubber Agroforestry Project[3]. In 1994, most farmers relied mainly on jungle rubber, i.e. a seedling-based agroforestry system with low crop productivity (500 kg/ha/year) but high biomass and biodiversity. Most farmers wanted access to clonal rubber planting material to improve land productivity (expected yields of up to 1,800 kg/ha/year) while retaining the advantages of their agroforestry practices.

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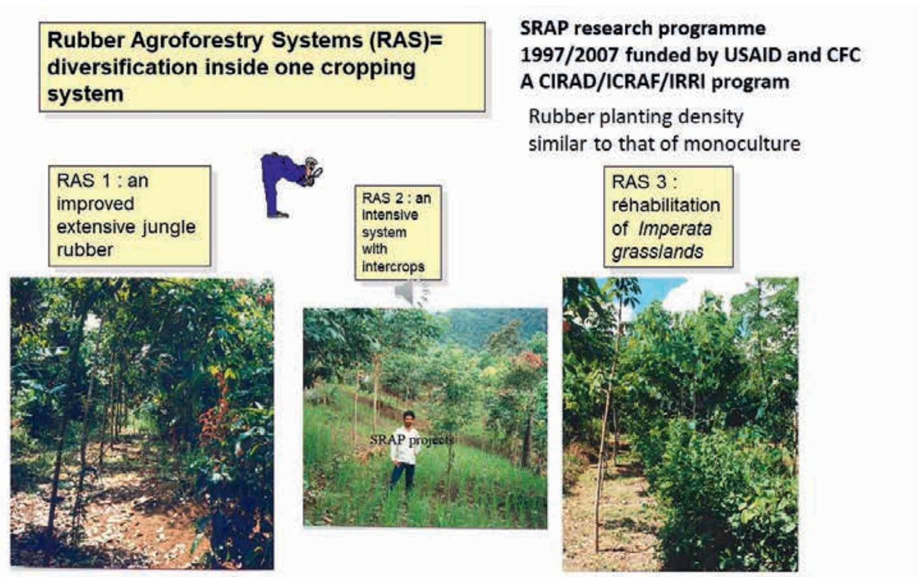

Farm trials were originally set up with local farmers for multiple reasons: (i) to provide clones and generate high rubber yields; (ii) to maintain agroforestry practices to benefit from positive externalities and ecosystemic services in the long run; and (iii) to diversify income via timber, fruit, resin and other forest products. In 1997, oil palm emerged in the landscape through the very rapid development of private concessions, which provided local farmers with an opportunity to gain access to good quality oil palm plots (2 ha) in exchange for land for the estate concession (5 ha, mainly oil palm). Oil palm became the priority crop for most smallholders in the 2000s. All forest and most jungle rubber stands have disappeared. In 2019, roughly two-thirds of the area was cropped with oil palm and one-third with clonal rubber. Meanwhile, smallholder farmers' interest has shifted away from rubber cultivation due to the low rubber prices prevailing since 2013—they are now relying on several crops yet have not abandoned rubber definitively. Rubber is still planted for income diversification, mainly in monoculture and RAS 2-type systems (i.e. with 550 rubber trees/ha, and 250 associated fruit/timber trees/ha in the inter-rows). Most local farmers favor agroforestry practices as long as they do not jeopardize the rubber production potential and can significantly increase their gross margin/ha (by 30% on average in 2020). **The long-term sustainability of RAS systems is recognized.** The recovery of wood from rubber and associated timber trees at the end of rubber lifecycle helps cover replanting costs. RAS therefore significantly contributes to the agroecological transition and provides a serious alternative to oil palm monoculture.

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(1) Penot E., 2001. *Stratégies paysannes et évolution des savoirs : l'hévéaculture agroforestière indonésienne.* Thèse de doctorat, Faculté des Sciences économiques, Montpellier, Université Montpellier I, 360 p.

(2) Penot E., Courbet P., Chambon B., Ilahang I., Komardiwan I., 1999. Les agroforêts *à hévéas a2éliorées en Indonésie : mythe ou réalité. Plantations, recherche, développement*, 6(6): 400-414. http://agritrop.cirad.fr/476652

(3) Penot E., Ilahang I., Asgnari A., 2019. *Rubber agroforestry systems in Kalimantan, Indonesia. Which changes from 1994 to 2019 for SRAP/RAS (Smallholder rubber agroforestry project/ Rubber agroforestry systems)?* CIRAD//CIFOR. Montpellier, Bogor, December 2019.

Implementing farmer-centered approaches to scale agroecological principles in smallholder systems in Niger and Kenya

Smallholder farming is a critical contributor to global food security but is highly threatened by land degradation, loss of soil function/fertility and corresponding low crop yields. Land degradation must be addressed through active engagement of farmers to integrate restorative agricultural practices on their farms. Farmers in Kenya and Niger implemented planned on-farm comparisons to test and innovate land management practices able to restore agricultural productivity and ecosystem health. These planned comparisons—which differ radically from past development approaches—embed research into the development[1] and scaling process, while empowering farmers to restore degraded lands. Research in Development ensures colearning for multiple stakeholders throughout the project cycle to ensure adaptive management. Farmers and local communities compare the performance of promising practices across differing contexts.

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▲ *Farmer centred planned comparison approach.* © S. Chesterman.

In Kenya, farmers compared different soil water conservation measures alongside tree planting and tree management practices. Specifically, they tailored different sized planting basins (with and without manure) for the various crops to meet their needs while integrating multipurpose tree species. In Niger, farmers compared farmer managed natural regeneration (FMNR), crop residue composting and integrated management options. Over 10,000 farming households were monitored for 3 years to track and document the impact of land restoration options on socioeconomic and environmental aspects[(2)]. **The combined application of FMNR and mineral fertilizer microdosing associated with manure produced the highest yields across all five regions in Niger**[(3)]. FMNR involves regenerating native trees within crop fields, thereby contributing wind protection, organic matter from leaf and root decomposition, while enhancing the hydrological cycle. Given the lack of mineral fertilizer—which is a constraint for farmers—FMNR application with microdosing of manure in millet/cowpea intercropping systems could be an interesting alternative. Results obtained in Kenya showed that—**relative to farmers' usual practices—two- to four-fold crop yield increases were achieved in basins with manure, whereas a two-fold increase was obtained in unamended basins. Furthermore, farmers reported increased food security and income as well as, most notably, decreased reliance on food aid thanks to the increased yields and diversified products**.

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(1) Coe R., Sinclair F., Barrios E., 2014. Scaling up agroforestry requires research "in" rather than "for" development. *Curr. Opin. Environ. Sustain.*, 6: 73-77. doi:10.1016/j.cosust.2013.10.013

(2) World Agroforestry, 2020. *Restoration of degraded land for food security and poverty reduction in East Africa and the Sahel: employing a farmer-centered approach in Ethiopia, Kenya, Mali and Niger.* World Agroforestry, Nairobi, Kenya. www.worldagroforestry.org/output/full-brochure-2020-using-planned-comparisons-east-africa-and-sahel

(3) Bado B.V., Whitbread A., Sanoussi Manzo M.L., 2021. Improving agricultural productivity using agroforestry systems: performance of millet, cowpea, and ziziphus-based cropping systems in West Africa Sahel. *Agric. Ecosyst. Environ.*, 305. https://doi.org/10.1016/j.agee.2020.107175

Agroecological intensification of low yielding rice production systems by integrating trees

Integrating trees in rice production systems can contribute to agroecological transitions by increasing soil health, nutrient cycling and economic diversification, but rice is often considered as a weak competitor and may thereby not yield well when grown with trees. A literature review distinguished six rice agroforestry practices: long-term rotations, hedgerow intercropping, green manuring, long-term rice–tree intercropping, traditional agroforestry practices, and forest or fallow management, involving 188 tree species[(1)]. Trees provide a range of products and services, but rice yield is the only quantitative performance indicator with sufficient reported data to enable meta-analysis. Across the types of agroforestry practice, the average effect of adding trees compared to a no-fertilizer and no-tree control was found to be +20%.

When trees were combined with fertilizers, rice yields were on average 24% higher than fertilized rice without trees, under low yielding conditions (control < 1.5 t ha^{-1}), but 13% lower under higher yielding conditions (control > 1.5 t ha^{-1}) (Figure). Hedgerow intercropping and biomass transfer were the most beneficial practices in terms of enhancing rice yield. Several tree species were identified that combined rice yield enhancement (in addition to other products and services) with wide environmental adaptability across the African continent, including: *Sesbania rostrata, Acacia auriculiformis*, *Gliricidia sepium*, *Acacia nilotica* and *Leuceana leucocephala*. There has been relatively little concerted effort by the international research and development community to investigate and promote rice agroforestry, particularly in Africa, where a range of policy and institutional factors may discourage farmers from integrating trees in their fields and farming landscapes. Accelerated climate change and increasing demand on natural resources warrant greater investment in this area. Judicious evidence-based promotion of tree integration in rice-based production systems in the tropics calls for basic agronomic and farmer-participatory research to support local innovation on tailored best practices and tree species.

▲ ***Rice yield with trees plotted against the corresponding yield without trees for observations with and without fertilizer.***

The 1:1 line (black) indicates equality between yield with and without trees. The mean yield with trees conditional on yield without (blue line) is a smoothing curve with approximate 95% confidence interval (grey band). Different coloured points distinguish observations from different studies. Total of 40 studies. Source: Rodenburg et al., in review.

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(1) Rodenburg J., Mollee E., Coe R., Sinclair F. (in review). Yield benefits from tree integration in smallholder rice cropping systems. *Field Crops Research*.

Agroforestry – a viable option for sustainable cocoa production in Africa

Associations of cocoa trees with other trees—or so-called cocoa agroforestry systems—can contribute to the agroecological transition of this crop in Africa. Pure cocoa crop stands with little or no shade still prevail, but they are currently showing their limits. Technical solutions are thus urgently needed to consolidate the current cocoa-growing areas, reduce the pressure on forests and adapt to climate change. Farmers have been advised against agroforestry practices in recent years due to possible competition they could generate within cocoa farms, yet recent studies conducted in Cameroon have, conversely, shown that a balance can be struck between cocoa trees and fruit and forest trees chosen by farmers for their various uses, while maintaining a good cocoa yield in the long term. This balance, which farmers achieve through careful management of trees associated with cocoa trees, also enables the provision of ecological services such as carbon storage, biodiversity maintenance and cocoa pest control. **To achieve these trade-offs, cocoa agroforestry stands can be managed using a straightforward indicator, i.e. measurement of the relative basal area of cocoa trees calculated from the measurement of basal area of cocoa trees and that of associated trees.** In Cameroon, this indicator is on average 40% in adult cocoa agroforestry farms producing 1 t/ha of marketable cocoa. Roughly the same value is noted in cocoa farms offering the best trade-off between cocoa yield, carbon storage and pest control. This easy-to-use indicator must be tailored to the cocoa growing area. It could also be adopted for sustainable cocoa production certification purposes, while the convergence between local know-how and scientific results could also facilitate joint drawing up of technical recommendations.

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▲ ***View of a typical cocoa agroforestry system in the central Cameroon (Obala).***
Cocoa trees are dominated by an intermediate stratum consisting mainly of fruit trees, with the whole stand dominated by a canopy of tall forest trees. © *P. Jagoret*

Hedgerows – functions in agroecosystems and contributions to carbon sequestration in France

IPCC stresses that the inclusion of trees in agricultural areas is an effective lever for climate change mitigation and boosting soil carbon stocks. Although hedgerows are widespread throughout the world, there is still little data on their contribution to carbon sequestration, particularly in temperate environments. Recent research in western France (Brittany, Pays de Loire)[1,2] assessed soil carbon stocks in the vicinity of recent (20 year old) and older (40 to 120 year-old) hedgerows. **The findings revealed a significant effect of hedgerows on soil carbon stocks in adjacent plots (up to 3 m away). The annual increase in carbon stocks was estimated at between 9 and 13 ‰ in the immediate vicinity of hedgerows, i.e. 2- to 3-fold higher than the 4‰ targeted annual increase in soil carbon stocks that could offset human-related CO_2 emissions[2].** Otherwise, the impact of hedgerows on carbon storage on a landscape scale was found to be under the 4‰ objective—in a theoretical landscape consisting of 1 ha square plots, planting hedgerows all around the plots would only boost annual carbon storage by 1 to 1.5 ‰, which suggests that such planting should only be viewed as a complement to other practices.

Our research—focused on the environmental function of hedgerows—is now conducted to increasing extent in an interdisciplinary framework so as to dovetail farmers' management systems with long-term preservation of multiple targeted functions (ecological, agronomic), and with the design of sustainable hedgerow agroforestry systems(1). Yet hedgerows are still solely viewed as environmental elements. Assessments of these environmental functions must now be linked to their agroecological production functions associated with crops and livestock in farming areas.

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For further information

(1) Thenail C., Aviron S., Viaud V., Guehenneuc T., Menguy C. 2017. *Multi-functional hedgerows in the bocage systems of France. Rejuvenating a traditional system through farmer-led innovation.* AGFORWARD project leaflet. www.agforward.eu/index.php/fr/bocage-agroforestier-bretagne-france.html?file=files/agforward/documents/leaflets/09_Multi-functional_hedgerows_in_thebocage_system_in_France.pdf

(2) Viaud V., Kunnemann T., 2021. Additional soil organic carbon stocks in hedgerows in crop-livestock areas of western France. *Agriculture Ecosystems and Environment*, 305. https://doi.org/10.1016/j.agee.2020.107174

▲ ***15-year-old multistrata hedgerows in the Côtes d'Armor region (France), composed of chestnut, hazelnut, beech, oak and hornbeam trees.***
These hedgerows are planted and managed by the Terres et Bocages *farmers' association (http://terresetbocages.org/) in a bocage agroforestry approach, which is based on the integration of hedgerows in agricultural activities while fostering their multifunctionality.* © *V. Viaud*

▲ ***A 20-year-old hedgerow in Finistère region (France), composed of oak, hornbeam, hazelnut, chestnut and elder trees.*** © *V. Viaud*

Intercropping fruit trees and field crops in water scarcity conditions for nutrition-sensitive and climate-resilient agricultural transformation

Intercropping fruit trees and field crops is a traditional practice in Mediterranean and dryland regions, yet this practice has been disappearing with the advent of agricultural mechanization and intensification. However, in Europe it is increasingly promoted as a component in the agroecological transformation of agrifood systems. **Selecting, designing and managing the crop-tree combination in line with the prevailing water availability and product value chain conditions offers an opportunity for nutrition-sensitive and climate-resilient dryland agriculture**.

On-farm assessment, field experiments and modelling[1] were used to analyze competition and facilitation between crops and trees to define the conditions required for intercrop system success when water supplies are scarce. In Morocco, intercropping barley-faba bean rotations with mature olive trees increased the total land productivity compared to sole cropping, but reduced crop production by 50% over a water availability gradient. The negative effects of mature trees on the crop vegetative stage was not fully offset by the positive effects during the reproductive phase[4]. However, in peach orchards in southern France, when the association was set up at the tree plantation stage with regulated deficit drip irrigation, it was possible to stimulate tree and crop root system separation in different soil horizons, thereby limiting water–nutrient competition while ensuring early leaf and branch growth[2,3]. In central India, guava trees planted in pea-mung bean rotation led to a 12.5 kg/tree fruit yield 3 years after plantation, and yield increased with subsequent flowering. Compared to conventional rainfed wheat-soybean rotation, the economic water productivity of the system increased by 41% in the guava/pea-mung bean system. These results and the research approach provide a solid basis for **designing and managing agroforestry systems under water scarcity, cereals and pulses providing income and food during the first unproductive orchard plantation years (3-10 years) while creating the good conditions for positive field crops and trees interactions once the orchard has reached maturity**.

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For further information

(1) Bertrand N., Roux S., Forey O., Guinet M., Wery J., 2018. Simulating plant water stress dynamics in a wide range of bi-specific agrosystems in a region using the BISWAT model. *Eur. J. Agron.*, 99: 116-128.

(2) Forey O., Metay A., Wery J., 2016. Differential effect of regulated deficit irrigation on growth and photosynthesis in young peach trees intercropped with grass. *Eur. J. Agron.*, 81: 106-116. https://doi.org/10.1016/j.eja.2016.09.006

(3) Forey O., Temani F., Wery J., Jourdan C., Metay A., 2017. Effect of combined deficit irrigation and grass competition at plantation on peach tree root distribution. *Eur. J. Agron.*, 91: 16-24. https://doi.org/10.1016/j.eja.2017.08.008

(4) Temani F., Bouaziz A., Daoui K., Wery J., Barkaoui K., 2021. Olive agroforestry can improve land productivity even under low water availability in the South Mediterranean. Agriculture. *Ecosystems and Environment*, 307(Oct. 2020): 107234. https://doi.org/10.1016/j.agee.2020.107234

▲ *Experimental intercropped young peach orchards managed with drip regulated deficit irrigation in Montpellier (southern France).* © O. Forey

▲ *Comparison of olive orchards and barley-faba bean rotation as sole crops or intercropped in Morocco.* © F. Temani

Preserving and restoring soil functioning via agroforestry

Proper soil functioning is directly linked to the organic matter content of this substrate, 58% of which is organic carbon—a food source for a wealth of diverse organisms. This carbon enables recycling and enhances the supply of essential plant nutrients. Yet a third of the world's soils are considered to be degraded. The 4 per 1000: Soils for Food Security and Climate Initiative launched at COP21 (2015) has highlighted that soils are a pivotal element of global challenges. **Various agricultural practices can restore soil fertility and functioning, including agroforestry, or associations of trees and crops.** A recent report by CIRAD and INRAE(1) provides an updated review on the topic: leaf litterfall and tree root turnover boost the soil carbon content, while tree roots increase the soil porosity, promote water infiltration, and take nutrients from deep soil horizons that are inaccessible to crops and cycle them to the surface. The so-called hydraulic lift also facilitates nocturnal soil water redistribution from wet to drier horizons, which is crucial for crops, especially in drylands. The presence of trees in agricultural plots enhances soil biodiversity, including macrofauna (especially earthworms) and microfauna, such as mycorrhizae. A recent publication by CIRAD and FAO(2) on carbon storage in agroforestry systems and its role in climate change mitigation has helped the Intergovernmental Panel on Climate Change (IPCC) take this practice into greater account. IRD, CIRAD and INRAE are currently working on the topic, particularly in the framework of the DSCATT 'Agricultural intensification and dynamics of soil carbon sequestration' in tropical and temperate farming systems project.

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(1) Cardinael R., Mao Z., Chenu C. Hinsinger P., 2020. Belowground functioning of agroforestry systems: recent advances and perspectives. *Plant Soil*, 453:1-13. https://doi.org/10.1007/s11104-020-04633-x

(2) Cardinael R., Umulisa V., Toudert A., Olivier A., Bockel L., Bernoux M., 2018. Revisiting IPCC Tier 1 coefficients for soil organic and biomass carbon storage in agroforestry systems. *Environ. Res. Lett.*, 13: 124020. https://doi.org/10.1088/1748-9326/aaeb5f

• DSCATT Project, Soil carbon sequestration in farming systems: https://dscatt.net/

▲ *Agroforestry system with hybrid walnut trees and durum wheat, France.*
© R. Cardinael/CIRAD

▲ ***Study of soil and root profiles in a 4 m deep pit in an agroforestry system with hybrid walnut trees and durum wheat, France.*** *© R. Cardinael/CIRAD*

How to revive social and economic interest in agroforestry parklands in West Africa?

Parklands represent the archetypical agricultural landscape in the Sudano-Sahelian region of Africa. Some trees growing in cultivated and grazed areas are selected and spared during land clearing (crop/fallow rotations) and then utilized for the multiple services they provide. Under suitable demographic thresholds, different types of parklands had been set up in accordance with the prevailing agroecological and socioeconomic contexts. Most of these parklands are now degrading. The causes are complex, multifactorial and contextual. Fallow land is gradually disappearing due to population growth, land pressure and the expansion of crop farming. The increase in tree harvesting and agricultural mechanization impedes tree cover regeneration. Finally, traditional land governance systems that underpinned the management of these parklands have been eroded by socioeconomic changes.

▲ Faidherbia albida *parkland in an area inhabited by Serer communities, Senegal.* © C. Clermont-Dauphin

It would be pointless to try to reverse this trend solely through local technical innovations. A system-based multiscale approach seems necessary to foster the renewal of parklands by promoting the services provided by trees within an agroecological intensification framework[1,2]. Participatory approaches geared towards designing viable pathways for change while taking current socioeconomic priorities into account should—in a single negotiation process—pool all stakeholders, including those with sometimes antagonistic (farmers and herders) or often overlooked (women and youth) interests, as well as agricultural and forestry technical services and representatives of customary and administrative authorities. **Some promising avenues include the joint design of projects to support the development of value chains for tree products in which women are key actors, consultation on new rules for the governance of these areas, and the promotion of approaches that combine technical innovations and local know-how to foster appropriation and dissemination.** Assisted natural regeneration approaches have thus now been successfully adopted in several West African countries.

▲ *Women, children and deforestation. Niger.* © H.A. Issoufou

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For further information

(1) Seghieri J., Brouwers J., Bidou J.E., Ingram V., Droy I., Bastide B., Sanogo D., 2020. Research and development challenges in scaling innovation: a case study of the LEAP-Agri RAMSES II project. *Agroforestry Systems*. doi: 10.1007/s10457-020-00532-3

(2) Smith M.S., Mbow C., 2014. Editorial overview: sustainability challenges. Agroforestry from the past into the future. *Current Opinion in Environmental Sustainability*, 6:134-137. doi: 10.1016/j.cosust.2013.11.017

Enhancing the complementarity of crop and livestock farming

Promoting cactus pear as a drought resilient multi-purpose crop in low rainfall agrosylvopastoral systems in MENA and South Asia

Semi-arid agrosylvopastoral systems are characterized by limited or erratic rainfall, poor soils and high temperatures. Yet these systems—when appropriately managed—have great potential to increase production, diversify income and support rural livelihoods. Under these conditions, **certain neglected species, such as spineless cactus pear (*Opuntia ficus-indica* L.), which is a promising multipurpose species with a Crassulacean acid metabolism, can grow well and help farmers cope with environmental and climatic variability**. Besides its tasty fruit and fodder value, cactus pear plays an important economic role as a subsistence agriculture option with minimal agronomic inputs and drought resistance. Moreover, it has proven potential to alleviate soil erosion, increase carbon sequestration and minimize livestock watering during hot summers.

Over a decade ago, ICARDA initiated an ambitious program in collaboration with NARS, development agencies, cactus research networks, NGOs, etc., to evaluate the performance of various cactus pear accessions across different agroecological sites, to conserve and multiply the most adapted ones, and promote cactus pear establishment at the farm level. **Cactus can make use of marginal lands** (so it does not compete with other crops requiring good cropland soil) **and produce livestock forage**. However, cactus should not be grazed directly (cut and carry) or fed alone, it must be mixed with other fiber- and protein-rich feed resources available on farms or purchased. In addition, the portfolio included social studies in South Asia to investigate farmers' viewpoints with regard to adapting cactus pear cultivation. It also promoted capacity building on appropriate agronomic practices for maximizing cactus pear yield and quality, conducting feeding trials for better cactus use with locally available feed resources, and mapping suitable agricultural zonation for cactus pear plantations. An outreach programme was implemented to boost awareness and inform decision makers, government officials and farmers beyond the CGIAR sphere of influence about the importance of growing cactus pear as a low-input income generating activity. All of these activities were conducted under the umbrella of efficient partnership with the national systems, thereby resulting in attracting the interest of more stakeholders and generating further demand for cactus pear planting materials.

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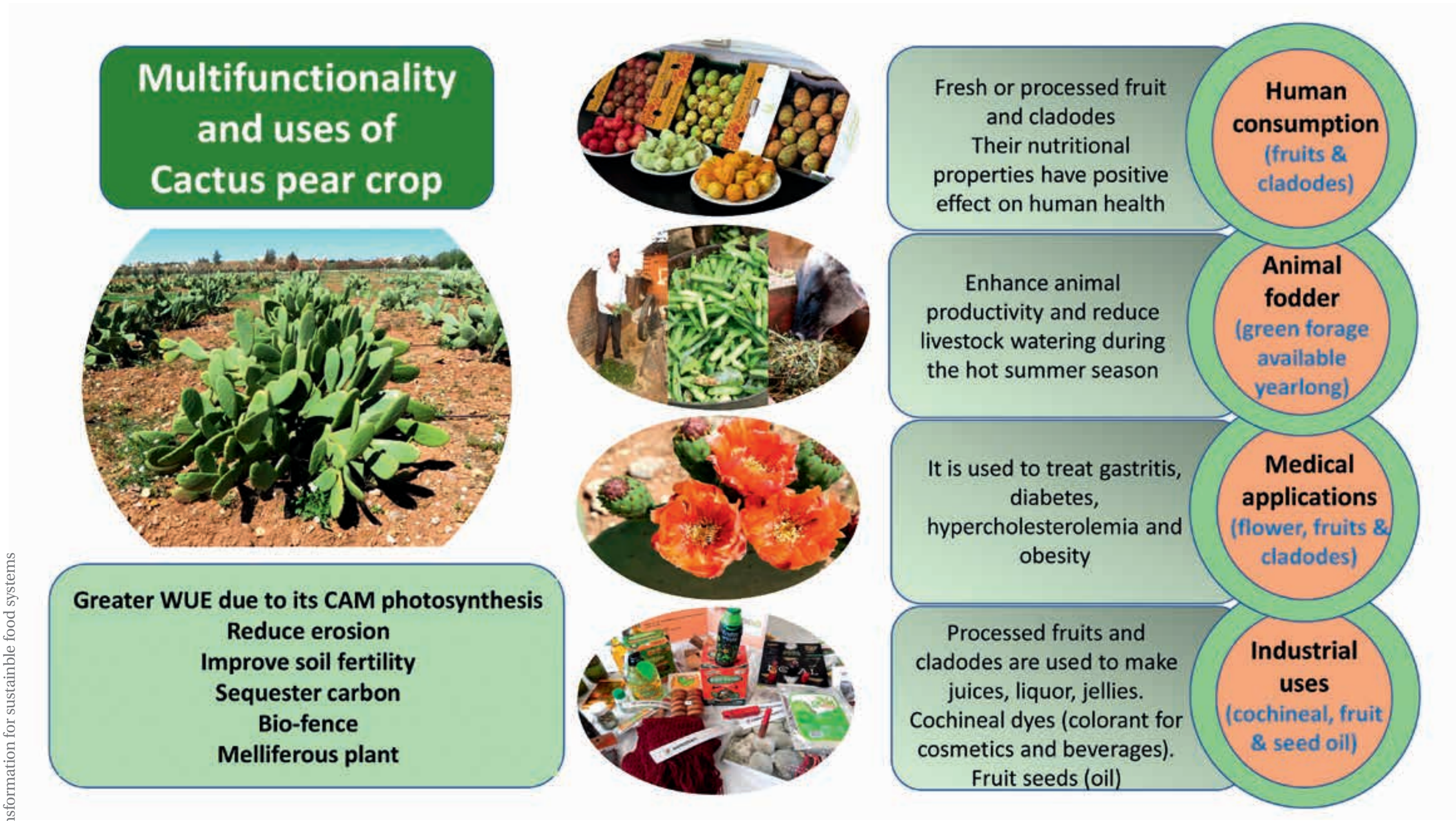
• Acharya P., Biradar C., Louhaichi M., Ghosh S., Moyo H., Sarker A., 2019. Finding a suitable niche for cultivating cactus pear (*Opuntia ficus-indica*) as an integrated crop in resilient dryland agroecosystems of India. *Sustainability*, 11: 5897. https://repo.mel.cgiar.org/handle/20.500.11766/10737

• Inglese P. *et al.* (eds), 2017. *Crop ecology, cultivation and uses of cactus pear.* FAO-ICARDA, Rome. 244 p. https://repo.mel.cgiar.org/handle/20.500.11766/8263

• Louhaichi M., Kumar S., Tiwari S., Islam M., Hassan S., Yadav O.P., Dayal D., Moyo H.P., Dev R., Sarker A., 2018. Adoption and utilization of cactus pear in South Asia. Smallholder farmers' perceptions. *Sustainability,* 10: 3625. https://repo.mel.cgiar.org/handle/20.500.11766/10737

• Louhaichi M., Hassan S., 2021. *Cactus pear, a drought-tolerant crop grown by millions of farmers in dry areas for nutritional and income generating purposes.* Panorama Solutions portal: https://panorama.solutions/en/solution/cactus-pear-drought-tolerant-crop-grown-millions-farmers-dry-areas-nutritional-and-income



Crop-livestock integration from an agroecological perspective

Conceptual framework and case study from a cereal-livestock production system in low-rainfall areas of North Africa

The agroecological transition of agrifood systems requires a holistic approach throughout the food system, combining agroecological and socioeconomic interventions. Promoting gradual and contextual agriculture-animal husbandry integration practices through resource-oriented and financially viable agroecological principles would allow better adhesion and transition, especially in small, mixed-sized farms where short-term viability prevails.

In a case study in Algeria and Tunisia, the crop-livestock under conservation agriculture (CLCA) initiative* addresses this conceptual dilemma by promoting conservation agriculture (CA) under semiarid crop-livestock systems (CLS). CA is not widely accepted because of critical tradeoffs related to biomass and soil resource use. Crop-livestock farmers experience an acute shortage of biomass and would therefore rely on grazing crop residues after harvest, hence not adopting stubble retention which is a CA mainstay. Moreover, farmers prefer to use land for growing wheat, a market secure commodity, thereby limiting forage space. **The CLCA initiative promotes smart livestock/crop management practices for climate-resilience and integrated CLS under CA in the fragile livestock-cereal belt of semiarid North Africa.** Crop-livestock integration options (CLIOs)[4] in these dry areas encompass forage inclusion in cereal rotation systems, crop management improvement to enhance grain and straw yield, dual-purpose crops and varieties, forage combinations for livestock, stubble management for mulching, feed and soil cover crops, herd health management, feed alternatives during the summer gap[1] and mechanization for alternative feed production. Not all CLIOs —ranging from pure productivism to conservative practices—have an agroecological basis. Filtering CLIOs using agroecological attributes and their short-term impacts on farmer livelihoods is needed for successful agroecological transitioning, while channeling agroecological CLIOs through existing CLCA initiative delivery systems. Furthermore, some agroecological CLIOs are relevant at the farm household level, while others are at the landscape/regional level —involving more collective action but also wider ecosystem services[3]. **Hence, interventions to strengthen farmers' organizations may ensure the successful implementation of agroecological CLIOs**.

* CLCA initiative: https://mel.cgiar.org/projects/clca2

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(1) Abidi S., Ben Youssef S., Ben Salem H., 2021. Foraging behaviour, digestion and growth performance of sheep grazing on dried vetch pasture cropped under conservation agriculture. *Journal of Animal Physiology and Animal Nutrition*, 105:51-58.

(2) Bahri H., Annabi M., Cheikh M'Hamed H., Frija A., 2019. Assessing the long-term impact of conservation agriculture on wheat-based systems in Tunisia using APSIM simulations under a climate change context. *Science of The Total Environment*, 692: 1223-1233.

(3) Louhaichi M., Slim S., Jilali K., 2020. Field day on sulla cultivation using a participatory community-based approach. *Agricultural Research Knowledge*, ICARDA. https://hdl.handle.net/20.500.11766/12367

(4) Rekik M., Idoudi Z., López Ridaura S., Frija A., 2020. *Use of conservation agriculture in crop-livestock systems (CLCA) in the drylands for enhanced water use efficiency, soil fertility and productivity in NEN and LAC Countries. Progress Highlights: Year II - April 2019 to March 2020*. ICARDA, Lebanon. https://hdl.handle.net/20.500.11766/11022

▲ *Clustering crop-livestock integration options (CLIO's) based on scale of implementation and resource-orientations.*

OasYs – an agroecological dairy farming system adapted to climate change in Northern Europe

Dairy farming, like all agricultural sectors, has to cope with the new challenges of the 21st century, particularly the need to adapt to climate change while remaining energy efficient and preserving natural resources. The so-called *OasYs* dairy farming system, based on agroecological principles, has been entirely designed in collaboration with multiple agricultural partners to meet these challenges. It aims to help Northern European farmers earn a living from their dairy farming system, in a context of climate constraints and hazards, by saving water and fossil energy resources, while contributing to sustainable agriculture. The forage system is based on year-round grazing, diversified forage resources (including trees) and widespread use of legumes. The livestock farming strategy seeks to meet livestock needs by grazing them on available forage, while limiting unproductive periods and health problems over the cow's milk production lifespan. This has been achieved by implementing two calving periods in spring and autumn, while extending lactation to 16 months and introducing a three-breed rotational crossing (Holstein, Scandinavian Red, Jersiaise). This new system has been tested at full scale (72 dairy cows, 90 ha) since late 2013 in Lusignan (Vienne department, France)*. We study the extent to which greater diversity of farming system components and their functions, combined with their optimal spatiotemporal management, could reconcile a high production level with high environmental performance, and enhance the resilience of the agrosystem to climatic hazards. The system is thus being evaluated in terms of its production performance, as well as its environmental and socioeconomic performance. The initial results are promising: **the diversity of grazing resources enables extension of the grazing period; the increased fat and protein contents offsets the decrease in milk production; and under this system 1.5 labor units may be remunerated at a rate equivalent to the income of two minimum wage earners (2018 data)****.

* Test carried out by the INRAE *Fourrages, ruminants et environnement* (FERLUS) experimental unit.
** Growth-indexed minimum wage, calculated on the basis of the gross hourly minimum wage of €9.88 (2018 value).

◀ *OasYs, a diversity-based agroecological dairy farming system adapted to climate change.* © *S. Novak/FERLUS*

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For further information

• Novak S., Audebert G., Chargelègue F., Emile J.-C., 2018. Sécuriser un système laitier avec des fourrages économes en eau et en énergie fossile. *Fourrages*, 233: 27-34. https://afpf-asso.fr/revue/securiser-son-systeme-d-elevage-avec-des-fourrages-complementaires-meteils-derobees-cruciferes-i?a=2154

• Novak S., Chargelègue F., Chargelègue J., Audebert G., Liagre F., Fichet S., 2020. Premiers retours d'expérience sur les dispositifs agroforestiers intégrés dans le système laitier expérimental OasYs. *Fourrages*, 242: 71-78.

• Novak S., Barre P., Delagarde R., Mahieu S., Niderkorn V., Emile J.C., 2020. Composition chimique et digestibilité *in vitro* des feuilles d'arbre, d'arbuste et de liane des milieux tempérés en été. *Fourrages*, 242: 35-47.

Evolution in the vulnerability of dairy farms upon conversion to organic farming

In the context of the European crisis in conventional milk production following the end of the milk quota system, many conventional farms converted to organic farming. This raised the issue of farm vulnerability during and after the conversion, i.e. the ability of farms to respond to the effects of technical, climatic and economic risks. Our objective was to show whether and how dairy farm vulnerability can decrease during and after conversion to organic farming. In partnership with local chambers of agriculture and organic farmers' associations, we surveyed dairy farms in Brittany and Aveyron regions (France) from their last year of conventional production to the first full year of organic production. We considered farm vulnerability as a function of the initial level of and trends in farm technical and economic variables (milk productivity allowed by feed resources produced on the farm, economic efficiency, net profitability per worker and independence from European Common Agricultural Policy subsidies) and farmers' satisfaction. We used partial least squares regressions to relate these vulnerability variables to explanatory variables illustrating farm exposure to climatic and economic variability (e.g. milk prices, daily mean difference between rainfall and evapotranspiration) and changes in farming practices (e.g. land use, grazing time, feed supplementation level).

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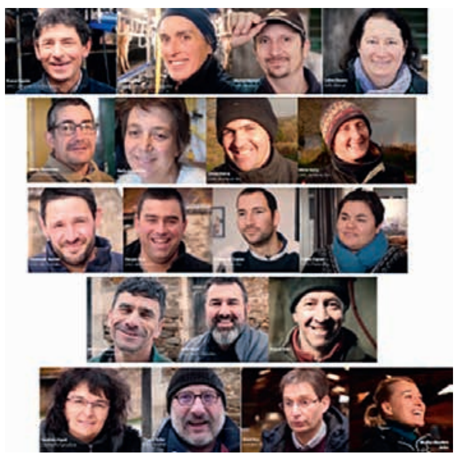

▲ *Portraits of farmers, advisors and researchers involved in the project.* © *M. Bouttes, A. Mansat*

The results revealed that **in most cases converting to organic farming improved farm economic efficiency, milk productivity allowed by feed resources produced on the farm and profitability per worker**. Overall, all farmers were satisfied after organic conversion. All observed conversion strategies were oriented towards pasture-based systems and a reduction in land-use and herd-management intensity. Conventional farms based on maize cropping for silage and on feed concentrate purchases changed drastically and benefited most from the conversion process, while also showing the greatest decrease in vulnerability. In showing the marked increase in farmers' satisfaction during the organic conversion process, our results strongly contrasted with previous studies that highlighted the multiple risks of converting to organic farming. We conclude that **changing farming practices by converting to organic farming can be a powerful mechanism for reducing farm vulnerability.**

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• Bouttes M., Bancarel A., Doumayzel S., Viguié S., San Cristobal M., Martin G., 2020. Conversion to organic farming increases dairy farmers' satisfaction independently of the strategies implemented. *Agronomy for Sustainable Development*, 40: 12.

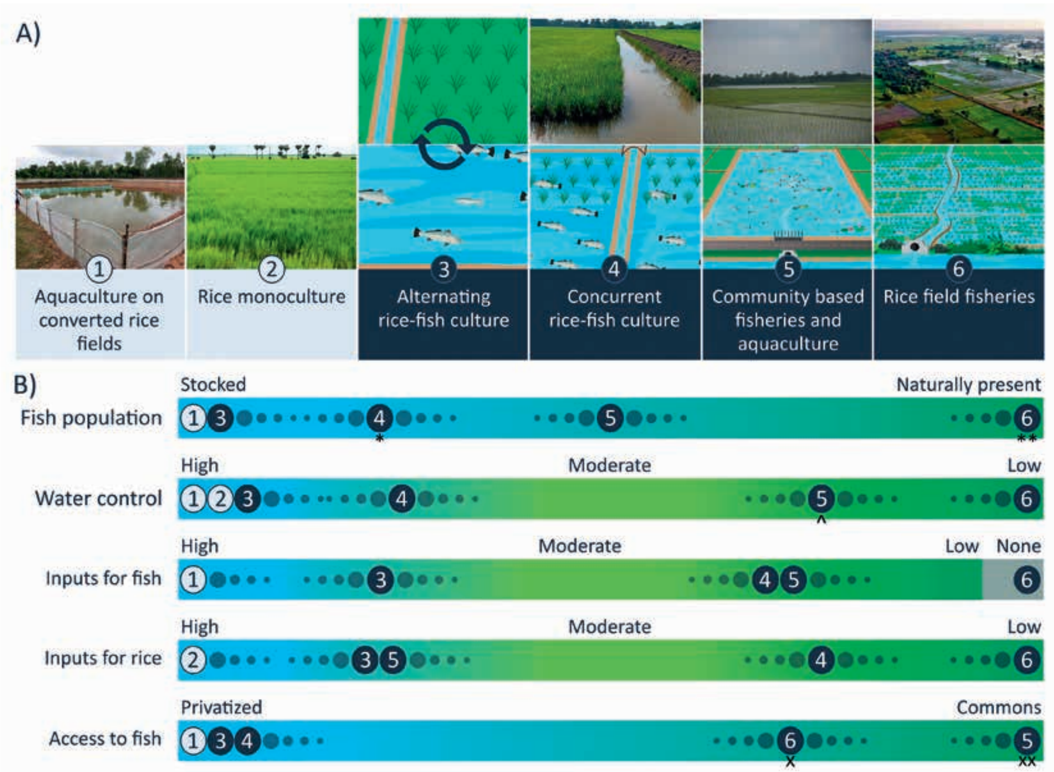
• Bouttes M., Bize N., Maréchal G., Michel G., San Cristobal M., Martin G., 2020. Conversion to organic farming decreases the vulnerability of dairy farms. *Agronomy for Sustainable Development,* 39: 19.

• Bouttes M., Darnhofer I, Martin G., 2019. Converting to organic farming as a way to enhance adaptive capacity. *Organic Agriculture,* 9: 235-247.

• Bouttes M., Mansat A., Martin G., 2019. Portraits of dairy farmers in conversion to organic agriculture. www.psdr-occitanie.fr/PSDR4-Occitanie/Le-projet-ATA-RI-accompagnement-de-la-transition-agroecologique/Productions-operationnelles/Autour-de-la-conversion-a-l-AB/Temoignages-d-eleveurs-en-conversion-a-l-AB

Agroecological dimensions in rice-fish production towards food system adaptability

Rice and fish are preferred foods, critical for healthy and nutritious diets, while providing the foundations of local and national economies across Asia. Agriculture and aquaculture over the past half-century have increasingly become intensified monocultures solely focused on increasing rice and fish production. However, agroecological approaches that support biodiversity and utilize natural processes can contribute to the transformation of food systems with more inclusive, nutrition-sensitive and ecologically sound outcomes. Rice and fish production are frequently integrated within the same physical, temporal, and social spaces, with variations in terms of production practices and their prevalence. In Cambodia, rice field fisheries that rely on natural processes prevail in up to 80% of rice-growing areas and include at least 150 aquatic species, whereas more input- and infrastructure-dependent rice-shrimp culture is increasingly popular in rice-growing areas of Vietnam. A novel typology differentiates integrated production practices by the nature and degree of application of agroecological principles (e.g. recycling, input reduction, biodiversity, synergy and natural resource governance) applied to: (i) fish stocking; (ii) water management; (iii) use of synthetic inputs; and (iv) institutions that control access to fish (Figure). A review of how integrated rice-fish production practices have evolved in line with changes to food systems associated with the Green Revolution in Bangladesh, Cambodia, Vietnam and Myanmar showed that integrated production practices continue to fulfil a range of objectives to varying degrees, including: food and nutrition security, diversified livelihoods, higher income and biodiversity conservation[1]. **We recommend regional policy shifts that recognize and support diverse, place-based and agroecological approaches to food production.** Successful implementation of these policy shifts should accelerate progress towards achieving SDG 2 – Zero Hunger by ensuring ecosystem maintenance, sustainable food production and resilient agricultural practices with a capacity to adapt to global change.



▲ *Typology of rice-fish production practices.*
A. Illustrations and photos that depict each of four exemplars (3–6) and their monoculture reference points (1,2).
B. Types distinguished by use of agroecological attributes along a continuum of (high to low) control and substitution of natural processes.
**May include some naturally present.*
***May include some stocking.*
^Water control is low during monsoon season and fish production, but irrigation is used during dry season for rice cultivation.
×May include privatization of fish remaining in ponds within rice fields after flood recession.
××Commons for small wild fish harvest, contractual shared access for cultured and wild fish.

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(1) Freed S., Barman B., Dubois M., Flor R., Funge-Smith S., Gregory R., Hadi B., Halwart M., Haque M., Jagadish K., Joffre O., Karim M., Kura Y., McCartney M., Mondal M., Nguyen V.K., Sinclair F., Stuart A.M., Tezzo X., Yadav S., Cohen P.J., 2020. Maintaining diversity of integrated rice and fish production confers adaptability of food systems to global change. *Front. Sustain. Food Syst*, 4:576179. https://doi.org/10.3389/fsufs.2020.576179

Landscape levers to enhance natural pest control services in France

The natural pest control service stems from trophic interactions between often mobile organisms in the landscape. The intensity of this control in a plot at a given time depends on local management initiatives, as well as those carried out in other parts of the agricultural area over the same period or on different time scales. Levers for boosting this service must therefore be considered at several spatiotemporal scales. This principle has underpinned research on the pest control service since 2014 in France, involving long-term monitoring while explicitly taking the properties of the landscape surrounding monitored plots into account. Data collected on 120 annual and perennial crop plots located in five French regions over several years on different types of pests (sentinel prey) have highlighted a generic effect of landscape levers on observed control levels. The analyses have also revealed that **the impacts of these landscape levers vary depending on the agricultural management strategy implemented in the monitored plot. The control service is more efficient when seminatural habitats are abundant, when the annual crops are more diversified or when there is a higher proportion of organic farming in the landscape. These impacts tend to be greater when pesticide treatments in the target plot are limited.** In the light of these results, scenarios of practical changes at the landscape level are currently being developed with stakeholders in each studied area. They will be used to determine landscape management options that could enhance natural pest control.

▲ *Landscapes.* © *INRAE*

◀ Lepidoptera *egg sentinel prey on wheat.* © *INRAE*

◀ Poecilus cupreus *beetle preying on aphids.* © *INRAE*

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• Petit S., Muneret L., Carbonne B., Hannachi M., Ricci B., Rusch A., Lavigne C., 2020. Landscape-scale expansion of agroecology to enhance natural pest control: a systematic review. *Advances in Ecological Research*, 63. https://doi.org/10.1016/bs.aecr.2020.09.001

• Ricci B., Lavigne C., Alignier A., Aviron S., Biju-Duval Bouvier J. C., Choisis J.-P., Franck P., Joannon A., Ladet S., Mezerette F., Plantegenest M., Savary G., Thomas C., Vialatte A., Petit S., 2019. Local pesticide use intensity conditions landscape effects on biological pest control. *Proc. R. Soc. B Biol. Sci.*, 286. https://doi.org/10.1098/rspb.2018.2898

• Sebiopag national network (*Réseau pour l'étude des services écosystémiques assurés par la biodiversité dans les paysages agricoles*): https://sebiopag.inrae.fr

Leveraging ecological processes and knowledge to recover banana production in BBTD-affected areas in sub-Saharan Africa

Guidelines and new scientific challenges

Rural communities in 14 sub-Saharan African countries are abandoning banana production due to banana bunchy top disease (BBTD) caused by the BBTV virus. BBTD is efficiently transmitted by the banana aphid (*Pentalonia nigronervosa*) and spreads in asymptomatic infected suckers. No sources of resistance are known for potential use in cultivar substitution or breeding. However, the well-documented ecology of banana aphids provided a starting point to test an agroecological approach to recover banana production lost to BBTD. First, aphids feed almost exclusively on banana mats, suggesting that area-wide mat eradication for 2-3 months where BBTD is present could minimize local sources of new infection. Second, the use of BBTV-free planting material would avoid the introduction of new infections. Third, aphid movement sharply falls from 50-100 m, so a banana-free buffer zone of this width around fields to replant would minimize aphid invasions.

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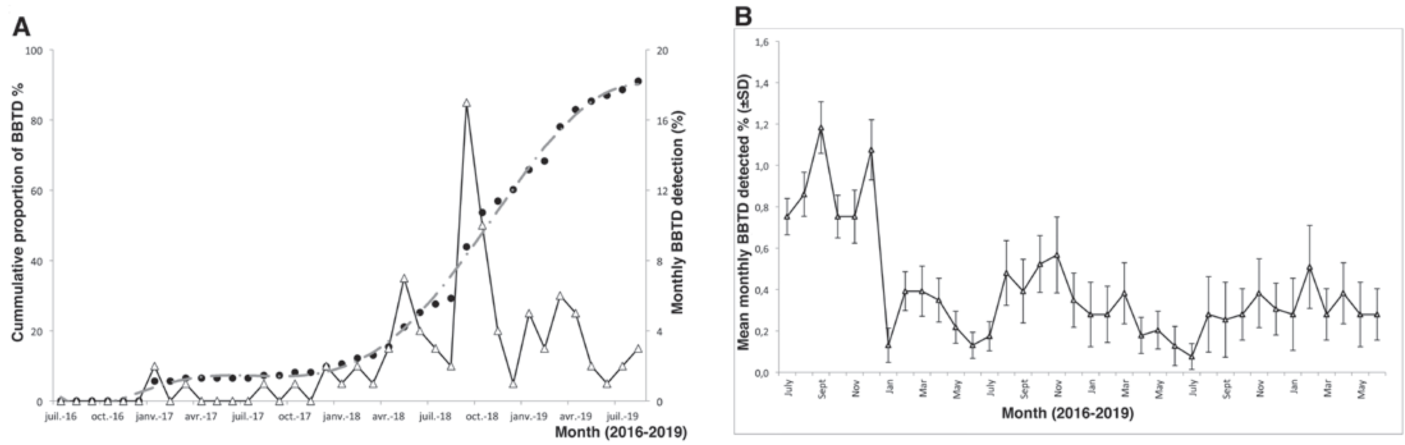
• Ajambo S., Rietveld A., Nkengla L.W., Omondi B.A., Niyongere C., Dhed'a B.D. *et al.*, 2018. Recovering banana production in banana bunchy top-affected areas in sub-Saharan Africa: developing gender-responsive approaches. *Acta Horticulturae*, 1196: 219-228.

• Lepoint P., 2016. *Recovering banana production in BBTD affected areas: Strengthening cross-site learning tools in epidemiology, gender and social relations, and participatory experimentation approaches.* CGIAR Research Program on Roots, Tubers and Bananas (RTB). RTB End of Project Workshop Report 2016. Lima: CGIAR.

• Omondi B.A., Soko M.M., Nduwimana I. *et al.*, 2020. The effectiveness of consistent roguing in managing banana bunchy top disease in smallholder production in Africa. *Plant Pathology*, 1754-176600:1-13. https://doi.org/10.1111/ ppa.1325

Since 2014, scientists from Bioversity International and IITA (CGIAR centers), CIRAD, and national institutes in 8 sub-Saharan countries have worked with pilot communities on three banana systems—perennial gardens and rotations with bush fallow or forest fallow with over 50 different cultivars in cultivation. Four results for application in banana recovery projects have emerged to serve as guidelines: (i) rigorous implementation of the complete banana aphid ecology-based model led to reduced field re-infection rates, increased banana yields and more BBTD-free suckers; (ii) community and household engagement—both men and women and different generations—and understanding of ecological management led to more effective peer pressure, more rigorous monitoring and more effective BBTD control; (iii) different seed production options—tissue culture and macropropagation with virus-free source material, sucker sourcing from BBTD-free areas and from recovered fields were useful to address the community demand for seed cultivar diversity; and (iv) rigorous early detection of initial BBTD symptoms and roguing in replanted fields contributed to very low disease levels and availability of low-risk suckers for further planting. Further studies are needed on early symptom expression and detection in local cultivars, ecological intensification strategies for greater productivity to support the field recovery process and landscape diversity to boost the effectiveness of buffer zones and curb BBTD and aphid build-up.

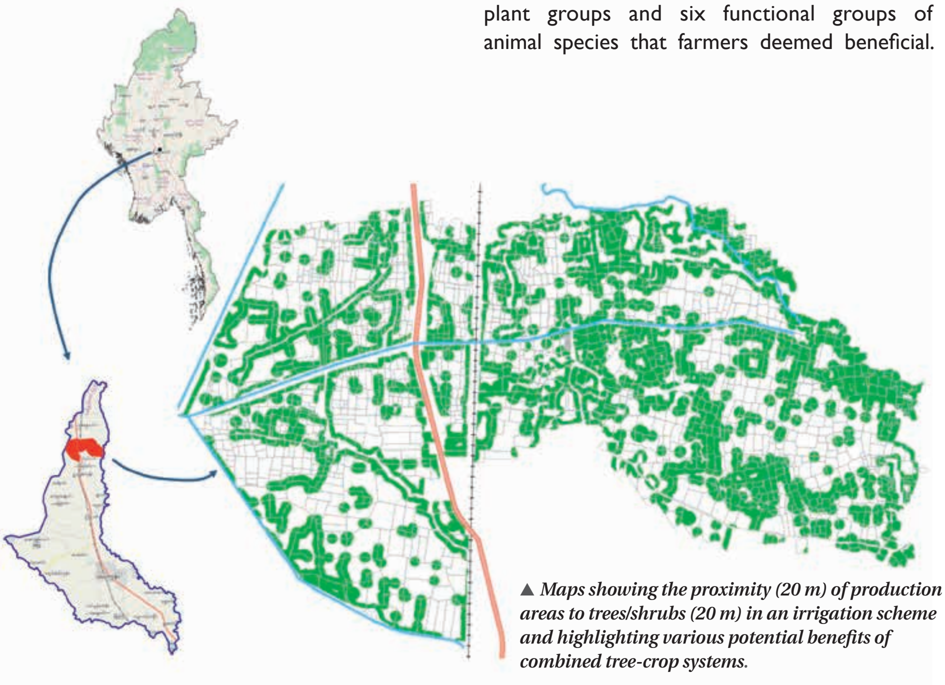


▲ *The incidence (%) of banana bunchy top disease (BBTD) increased from 2% to total plot infestation in 3 years in an unmanaged experimental field (Fig A). Under farmer cooperative roguing, an initial disease rate of 5% was reduced and maintained below 2% for 3 years (Fig. B).* Source: Omondi et al. (2020)

Characterizing landscape and diversity of food systems in Myanmar to analyze trade-offs and guide the agrifood system transition

Economic growth, land-use and livelihoods form a close-knit nexus. Myanmar—with 28.5 million ha of forest, representing approximately 42% of its total land area—is one of the largest countries in Southeast Asia untapped for agricultural intensification. With agriculture and agroforestry practices as dominant livelihood activities among smallholder farmers, the country is at a crossroads of land-use transition, agricultural intensification and environmental degradation. While many countries have lost significant forest areas and biodiversity, Myanmar could achieve a balance between human and ecosystem wellbeing by adopting an agroecological approach to guide the agrifood system transition.

In collaboration with the Swiss Agency for Development and Cooperation, we characterized the food system landscape and diversity, analyzed synergies among ecosystem functions, and developed pathways for food system transition. We monitored a watershed to gain insight into the cropping intensity, land cover, proximity to trees, and community perceptions on ecosystem services. Maps (covering ~ 339 ha) highlighting the proximity of crop production areas to trees showed that 13%, 25%, 49% and 89% of the area came within a proximity zone of 5, 10, 20, and 50 m, respectively. The cropping intensity (138%, mainly based on cereal, oilseed and vegetable crops) was low in 2019-2020. However, a survey of 210 farmers highlighted 13 functional plant groups and six functional groups of animal species that farmers deemed beneficial. Farmers cultivated up to 31 different species, thereby exemplifying potential diversification opportunities. Most farmers identified food provision (food-61%, medicinal-20%, livestock-3%) as a major ecosystem benefit, yet they also listed cultural (9%), and regulating (5%) services. Substantial food was sourced from trees. Achieving greater diversification within agrifood systems will require changes across value chains, supported by novel institutional arrangements and policies. **This will enable Myanmar to increase the resilience of its farming communities. Taken together, this assessment provides a framework to guide decisions on diversification towards a successful agroecological transition in Myanmar.**



▲ *Maps showing the proximity (20 m) of production areas to trees/shrubs (20 m) in an irrigation scheme and highlighting various potential benefits of combined tree-crop systems.*

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For further information

• FAO, 2018. *The 10 Elements of agroecology guiding the transition to sustainable food and agricultural systems.* Food and Agriculture Organization, Rome.

• MOALI, 2018. *Myanmar agriculture development strategy and investment plan 2018-2023.* Ministry of Agriculture, Livestock and Irrigation, Nay Pyi Daw.

Enhanced collective management of ecosystem services in semi-natural parts of rural landscapes in southern France

The DYNAFOR interdisciplinary joint research unit—through studies conducted over several decades in the *Coteaux de Gascogne* region (ZA PYGAR, *Pyrénées-Garonne*, France)—has highlighted some key roles of semi-natural spaces (hedges, woods, permanent grasslands, etc.) and of the diverse range of crops on biodiversity in farming landscapes. Some of this so-called 'beneficial' biodiversity also provides services to farmers, such as pest control and pollination.

The direct and indirect impacts of intensive conventional agricultural practices and the landscape setting on several biodiversity indicators and ecosystem services (biological control, pollination), as well as on crop yield, were recently analyzed in 54 field crop plots. While pesticide use and tillage directly bolstered yields, they were found to have negative impacts on biodiversity and ecosystem services measured in these plots, thereby resulting in negative indirect effects on yields. **These indirect effects of conventional farming practices on yields may reduce the direct beneficial effects by half. Moreover, the measured biodiversity did not solely depend on practices applied in the plot, but also on the landscape spatial organization. It has favored by the proportion of semi-natural habitats, reduced plot size and greater crop diversity**.

Collective supervision of crop rotations and semi-natural areas could enhance management of these factors and ecosystem services that can be harnessed for agroecological production. This requires collaborative processes between operators who shape these landscapes. Social science research is under way in partnership with these stakeholders to identify the barriers and levers of such processes. Remote sensing tools also generate very useful data at these extended organizational levels.

◀ ***Agricultural landscapes in the* Vallées et Coteaux de Gascogne *region (ZA PYGAR) are made up of a mosaic of field crops, meadows, hedges and small forests.*** *The topography dictates a landscape gradient ranging from valleys with the largest plots to hillsides with smaller plots more associated with woods and permanent grasslands.*

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• Barnaud C., Corbera E., Muradian R., Salliou N., Sirami C., Vialatte A., Choisis J.P., Dendoncker N., Mathevet R., Moreau C., Reyes-García V., Boada M., Deconchat M., Cibien C., Garnier S., Maneja R., Antona M., 2018. Ecosystem services, social interdependencies, and collective action: a conceptual framework. *Ecology and Society*, 23.

• Duflot R., San-Cristobal M., Andrieu E., Choisis J.-P., Esquerré D., Ladet L., Ouin A., Rivers-Moore J., Sheeren D., Sirami C., Fauvel M., Vialatte A., (submitted). Indirect negative effects of conventional farming practices on crop yields highlight the value of nature-based solutions. *Ecological Applications*.

• Sirami C., Gross N., Baillod A.B., *et al.*, 2019. Increasing crop heterogeneity enhances multitrophic diversity across agricultural regions. *PNAS*, 116: 16442-16447.

• Vialatte A., Barnaud C., Blanco J., Ouin A., Choisis J.-P., Andrieu E., Sheeren D., Ladet S., Deconchat M., Clément F., Esquerré D., Sirami C., 2019. A conceptual framework for the governance of multiple ecosystem services in agricultural landscapes. *Landscape Ecology*, 34: 1653-1673.

▲ ***Semi-experimental methods were used to assess levels of biological pest control and pollination in agricultural plots —(a) predation maps and (b) phytometers—related to the agricultural practices carried out on these plots and the landscape setting.*** *Workshops were organized with farmers and farm advisors on the issue of landscape organization (plot size, crop diversity, grasslands and semi-natural habitats) and the impacts in terms of ecosystem services (c). © DYNAFOR*

Exclosures for landscape restoration in Ethiopia

Restoring degraded ecosystems by setting up exclosures is an increasingly common practice in the Ethiopian Highlands. Exclosures are communal areas that were traditionally 'open access', but where wood cutting, grazing and other agricultural activities are now forbidden or strictly limited to promote restoration and natural regeneration (Photo next page). The overall area covered by exclosures is currently increasing by 2%/year and could reach 5-7 million ha by the early 2030s. Similar rehabilitation of degraded rangelands has been fostered by establishing exclosures in in different parts of Africa and Asia. This trend in exclosure expansion is attributable to their many benefits: restoring degraded landscapes, increasing carbon sequestration, and improving other ecosystem services. This can provide opportunities for livelihood diversification, and thus enhancement, decrease soil erosion and seed loss in farmlands located downslope of exclosures (Photo next page), thereby helping boost agricultural productivity over the medium to long term. Overall, **due to the cumulative benefits of exclosures in an agroecological setting, they can contribute to both environmental and community resilience by strengthening agricultural production at landscape levels***. The major agroecological transition fostered by setting up exclosures in degraded ecosystems is the shift from a free grazing system (i.e. natural) to a cut-and-carry system (i.e. knowledge/labor intensive agroecological system).

Although beneficial in the long term and at landscape scales, exclosures hamper poor households and communities from continuing their existing activities, including livestock grazing, and the loss of short-term economic benefits hence puts the success of exclosures at risk. **Balancing immediate short-term economic losses with longer-term economic and environmental gains is a challenge for many agroecological activities.** The adoption of a business model approach whereby potential economic opportunities are identified to enhance the immediate benefits of exclosures (e.g. by integrating beekeeping, livestock fattening, etc.) could be effective in bridging the gap between landscape restoration and ecosystem services in the long term and local economic losses in the short term.

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Initiatives that boost revenue flow to smallholder farmers managing exclosures (e.g. mobilizing financial resources for purchasing inputs and meaningful local community participation), and ensure the sustainability of small-scale businesses (e.g. regular follow-up and technical support; facilitating market opportunities in the value chain) are critical for the success of this approach.

* As defined by the HLPE (2019), exclosures pertain primarily to agroecological principles 3-7 (i.e. soil health, animal health, biodiversity, synergy and livelihood diversification), but importantly they also pertain to principles 8 (co-creation of knowledge) and 12 (land and natural resource governance).

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• HLPE, 2019. *Agroecological and other innovative approaches for sustainable agriculture and food systems that enhance food security and nutrition*. A report by the High Level Panel of Experts on Food Security and Nutrition of the Committee on World Food Security, Rome.

• Mekuria W., Gebregziabher G., Lefore N., 2020. *Exclosures for landscape restoration in Ethiopia: business model scenarios and suitability*. IWMI, Colombo, 62 p. (IWMI Research Report 175). https://doi.org/10.5337/2020.201

▲ *Exclosure-based landscape restoration—the vegetated upper slope represents exclosures.* © W. Mekuria

Silvopastoral systems for restoring ecosystem services and improving livelihoods in Amazonian landscapes (case of Colombia)

The Amazon is one of the world's richest regions in plant and animal species, yet fast changes in land use have led to the degradation of important ecosystem services. The main challenge in the Amazon landscape is how to generate opportunities for sustainable development that contribute to food security and wellbeing, while safeguarding the natural capital that is required to sustainably manage deforested landscapes. The Alliance of Bioversity International and CIAT has led the establishment of silvopastoral systems (SPS), codesigned with farmers, combining scientific and local knowledge, and farmers' assets, needs and preferences. **SPS implementation helps improve land productivity and fertilizer use efficiency, while releasing land area for conservation and restoration**.

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▲ *Sustainable Amazonian production system.* © N. Palmer

SPS improve resilience by promoting agricultural crop diversification using local crop and forage varieties and increasing water availability at the regional level, which contributes to reducing vulnerability to eventual extreme climatic events. Moreover, improved forage-based SPS stimulate soil macrofauna and biogenic soil macroaggregation while contributing to biodiversity conservation[3,4].

SPS has proven to improve socioeconomic indicators at the farm level by increasing milk production by up to 20%, resulting in a 1 to 1.31 increase in the cost-benefit ratio compared to traditional grazing. Even with moderate tree planting densities, the carbon sequestration potential of SPS was estimated at 5.8 Mg CO_2 ha^{-1} yr^{1} which, in addition to the reduction of enteric methane emissions, can mitigate GHG emissions by 2.6 Mg CO_{2e} ha^{-1} yr^{-1} compared to current practices[1,2]. By validating SPS on the ground and assessing the potential of SPS to deliver multiple benefits, the findings of these studies have contributed to public and international cooperation initiatives (e.g. NAMA*, NAPA*, NDC*, Sustainable Bovine Livestock Policy) aimed at enhancing the sustainable use of deforested areas in the Amazon while reducing pressure on forests, GHG emissions and improving smallholder resilience and livelihoods.

*Nationally Appropriate Mitigation Actions, National Adaptation Programmes of Action, Nationally Determined Contributions.

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For further information

(1) Aynekulu E., Suber M., van Noordwijk M., Arango J., Roshetko J.M., Rosenstock T.S., 2020. Carbon storage potential of silvopastoral systems of Colombia. *Land*, 9(9): 309. https://doi.org/10.3390/land9090309

(2) Landholm D., Pradhan P., Wegmann P., Romero M., Suárez J., Kropp J., 2019. Reducing deforestation and improving livestock productivity: greenhouse gas mitigation potential of silvopastoral systems in Caquetá. *Environ. Res. Lett.*, 14(2019): 114007. https://doi.org/10.1088/1748-9326/ab3db6

(3) Rodriguez L., Suárez J.C., Pulleman M., Guaca L., Rico A., Romero M., Quintero M., Lavelle P., 2021. Agroforestry systems in the Colombian Amazon improve the provision of soil ecosystem services. *Applied Soil Ecology*, 164: 103933 https://doi.org/10.1016/j.apsoil.2021.103933

(4) Vazquez E., Teutscherova N., Lojka B., Arango J., Pulleman M., 2020. Pasture diversification affects soil macrofauna and soil biophysical properties in tropical (silvo)pastoral systems. *Agriculture, Ecosystems & Environment*, 302: 107083. https://doi.org/10.1016/j.agee.2020.107083

Greening marginal agrosylvopastoral drylands in the Middle East, North Africa and the Horn of Africa

Recurrent droughts and unsustainable natural resource management practices accelerate land degradation and desert encroachment in vulnerable dry agroecological areas. Middle East, North Africa and the Horn of Africa are among the most affected regions, and projected climate change patterns will likely worsen the situation through increased heat stress and prolonged dryness. Meanwhile, erratic extreme rainfall and subsequent flooding may occur more frequently, which could further aggravate the conditions but also be a potential driver of solutions in the dryland degradation context.

ICARDA, in collaboration with international and national partners and target dryland communities, developed agrosylvopastoral watershed rehabilitation and sustainable management packages that capitalize on the upsides of the overall threatening conditions to foster agroecological transition. **Community-based interventions bridge scales from an individual farm-level focus to an integrated landscape-farming systems approach, while fostering changes in local perceptions and ecosystem service value appreciation**. In a watershed approach, multiple floodwater harvesting interventions are conducted to: (i) intercept excess (flood) water for *in situ* storage in water-stressed soils, thereby boosting native and cultivated vegetation growth; and (ii) mitigate land degradation on-site and in downstream areas. Community-based upland-watershed rehabilitation strategies through mechanized micro water harvesting[2]* and the establishment of well adapted species through reseeding and/or shrub transplantation enhance land cover, productivity and resilience. Local downstream floodwater-irrigated agriculture, or so-called *marabs*, is well-integrated in community-based watershed management and enhances cereal/legume production while generating dry livestock feed. Upland management revives traditional grazing systems involving herd mobility and accounting for vegetation physiological stages, resting periods, and facilitated successions of key choice species. The combined measures reduce agricultural input use and increase livestock/soil health and biodiversity. They also generally enhance local farmers' knowledge and ability to earn income from resilient and diverse ecosystem services. Community involvement and governance are key to sustain ongoing rehabilitation interventions. The socioecological conditions largely differ across areas potentially suitable for community-based watershed approaches. Current *ex ante* scaling procedures provide knowledge on the potential implementation scale/impact the technology might achieve across landscapes. This can in turn foster discussion among relevant stakeholders towards strengthening community-based concepts for enhanced local benefits, while combating desertification via greening vast vulnerable dryland buffer zones.

▲ *Community-based management (livestock grazing) of rehabilitated agrosylvopastoral areas at the ICARDA Badia Research Site (BRS) in the vicinity of Al-Majidyya village (Jordan).*
© K. Ibrahim Al Masardeh, from the Al-Majidyya community

* See: https://qcat.wocat.net/en/wocat/technologies/view/technologies_5860/

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For further information

(1) Sarcinella M., Strohmeier S., Haddad M., Yamamoto S., Evett S., Sterk G., 2020. *Suitability of arid land rehabilitation technologies: simulation of water harvesting based solutions in Middle Eastern agro-pastures.* Third Conference of the Arabian Journal of Geoscience (CAJG). Sousse, Tunisia, Nov 2-5, 2020 (Proceedings in print).

(2) Strohmeier S., Fukai S., Haddad M., Al Nsour M., Mudabber M., Akimoto K., Yamamoto S., Evett S., Oweis T., 2021. Rehabilitation of degraded rangelands in Jordan: the effects of mechanized micro water harvesting on hill-slope scale soil water and vegetation dynamics. *Journal of Arid Environments*, 185. https://doi.org/10.1016/j.jaridenv.2020.104338

(3) Slim S., Louhaichi M., Gamoun M., Ates S., Hassan S., Ben Romdhane O., Ouled Belgacem A., 2021. Assessment of soil surface scarification and reseeding with sulla (*Hedysarum coronarium* L.) of degraded Mediterranean semi-arid rangelands. *African Journal of Range & Forage Science*. www.tandfonline.com/doi/abs/10.2989/10220119.2020.1838608

Building resilience through ecosystem services

Transition to biodiversified agroecosystems

From process analysis to multiscale codesign with stakeholders

Functional plant biodiversity could be a way to enhance the agroecological transition of agroecosystems in tropical regions. A group of researchers studied the effectiveness of mobilizing and managing this biodiversity at different sites encompassing a broad range of conditions and types of systems*. **The holistic approach developed has led to the identification and hierarchical ranking of the main mechanisms linking biodiversity and ecosystem services.** The recycling function was thereby identified as predominant with regard to complex agroforestry systems on relatively poor soils in Cameroon, whereas pest control prevailed on rich Andosols in Central America. The plot spatial organization and biodiversity were found to be key levers for maximizing services. The quality of these services also depended on the long-term effects when plant biodiversity was introduced in rotations (e.g. weed control). **A generic analysis framework was drawn up to systemically unravel the direct or indirect impacts of plant biodiversity on agrosystem functioning and ultimately on ecosystem service provision.**

At the village community level, farmers should be supported in implementing specific design/adaptation mechanisms to modify their systems in favor of biodiversification. Participatory experimental approaches have been developed—sometimes using facilitation tools (foresight analysis, serious games)—to enhance learning and joint knowledge production, and ultimately to give farmers more freedom in these adaptive approaches. At the regional level, stakeholders having an influence on the conditions required for implementing these changes have been involved in co-innovation platforms. The aim is to give farmers more say and to ensure that all institutional actors are aware of their potential role in the transition process. Economic (for their market links) and political (for their policymaking weight) stakeholders are crucial in facilitating farmers' adoption of biodiversified agroecological systems.

* STRADIV project, System approach for the transition to biodiversified agroecosystems: www.agropolis-fondation.fr/STRADIV

▲ *Rotational rainfed rice cropping systems under legume cover* (Stylosanthes guianensis) *in Madagascar.*
© E. Scopel

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• Andreotti F., Speelman E.N., Van den Meersche K., Allinne C., 2020. Combining participatory games and backcasting to support collective scenario evaluation: an action research approach for sustainable agroforestry landscape management. *Sustainability Science*, *15*(5): 1383-1399.

• Resque A.G., Coudel E., Piketty M.G., Cialdella N., Sá T., Piraux M., ..., Le Page C., 2019. Agrobiodiversity and public food procurement programs in Brazil: influence of local stakeholders in configuring green mediated markets. *Sustainability*, *11*(5): 1425.

• Sauvadet M., den Meersche K.V., Allinne C., Gay F., de Melo Virginio Filho E., Chauvat M., Becquer T., Tixier P., Harmand J.-M., 2019. Shade trees have higher impact on soil nutrient availability and food web in organic than conventional coffee agroforestry. *Science of the Total Environment*, 649: 1065-1074.

The challenge of codesigning technically sound and polyefficient agroecosystems

Agroecosystem design (AED) currently has to take up the **triple challenge of diversification, climate change mitigation and adaptation, and food security**[1], while accounting for: (i) the multiple processes supporting ecosystem services (ES) at different scales—from field to landscape; and (ii) the diverse range of people involved—from farmers to regional stakeholders[2]. Such complexification calls for key paradigm changes in the way the R&D sector has been working so far.

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AED should be systematically built on the characterization of **biophysical processes,** with a focus on their interactions at relevant scales, e.g. product types and quantities, pest and disease regulation, and nutrient cycling. Moreover, AED also should account for **management processes** at field and farm scales, e.g. available time, space and money, field techniques, end-product types and qualities and their links to value chains. **Integrating this data constitutes a wager and often a lock-in** that hampers optimum sustainable use of available resources (biophysical or managerial). Yet such characterizations—beyond their complexity—very often underline **trade-offs** between these processes[3]. These trade-offs should systematically be discussed with stakeholders and, when agroecological management initiatives are implemented, **stakeholders' goals and perceptions** of sustainable/ecofriendly agricultural management reveal **another set of lock-ins.** For instance, when implementing practices to boost soil carbon sequestration, it is essential to address challenges like knowledge voids, increased difficulty in conducting fieldwork, or risk handling and social pressure[4]. Step-by-step, R&D is striving to tackle these lock-ins and open the way to inclusive local knowledge, (co)innovation support and on-field experimental setup. This involves rethinking both agroecosystem modeling and its integration at multiple scales, while developing new multicriteria assessment approaches. Such approaches are currently being implemented in a wide range of projects*.

*Projects

COCOA4FUTURE, Putting people and the environment back at the heart of cocoa growing: www.cirad.fr/en/news/all-news-items/press-releases/2021/cocoa-growing-agroforestry-west-africa

DSCATT, Agricultural intensification and dynamics of soil carbon sequestration in tropical and temperate agricultural systems: https://dscatt.net/

BOOST, Collaborative platform on agroecological transition: www.boost-ae.net/en/1/home.html

FAIR, *L'intensification agroécologique pour la résilience des exploitations dans le Sahel*: www.fair-sahel.org/

STRADIV, System approach for the transition to biodiversified agrosystems: https://stradiv.cirad.fr/

ASSET, Agroecology and safe food system transitions in Southeast Asia: https://ur-aida.cirad.fr/en/our-research/research-projects-and-expertises/asset

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(1) Saj S., Torquebiau E., Hainzelin E., Pages J., Maraux F., 2017. The way forward: an agroecological perspective for climate-smart agriculture. *Agriculture, Ecosystems & Environment,* 250: 20-24.

(2) Corbeels M., Cardinael R., Naudin K., Guibert H., Torquebiau E., 2019. The 4 per 1000 goal and soil carbon storage under agroforestry and conservation agriculture systems in sub-Saharan Africa. *Soil and Tillage Research*, 188: 16-26.

(3) Andreotti F., Mao Z., Jagoret P., Speelman E.N., Gary C., Saj S., 2018. Exploring management strategies to enhance the provision of ecosystem services in complex smallholder agroforestry systems. *Ecological Indicators,* 94: 257-265.

(4) Demenois J., Torquebiau E., Arnoult M.H., Eglin T., Masse D., Assouma M.H., Blanfort V., Chenu C., Chapuis-Lardy L., Medoc J.-M., Sall S.N., 2020. Barriers and strategies to boost soil carbon sequestration in agriculture. *Frontiers in Sustainable Food Systems*, 4.

Promises and limits of agroecology in sub-Saharan Africa

An illustration in the Hautes Terres *region of Madagascar*

There are three recognized ways of greening agriculture. Agroecology 'of practices' aims to transform 'conventional' systems but without affecting agrifood system governance or the priority of maximizing volumes and profits. Ecological intensification of practices concerns systems that have been barely or not at all impacted by the Green Revolution. Finally, integral agroecology, i.e. systemic and territorial, is more political and advocates a break with industrialization while striving to optimize a set of services in a balanced system. The prospects of these different approaches are presented with regard to their application in the *Hautes Terres* region of Madagascar. Despite the real potential for development, agricultural policies focused on conventional intensification (widely promoted) or on ecological intensification of farming practices have had little impact in this region.

▲ ***Along the road.*** © V. Lebourgeois/CIRAD

The Analamanga, Itasy and Vakinankaratra regions of Madagascar hosted more than 800,000 farms in 2018, compared to 540,000 in 2005. This led to an almost twofold decrease in the average size of family farms (currently less than 1 ha). Resources and production capacities are so limited that agricultural innovations in the form of simple technical packages have little impact. Innovations must apply to the overall and yet quite diversified activity system—including off-farm activities—in order to have an impact in the best-off family farms. Yet these innovations will not be sufficient unless accompanied by economic diversification within the the region. In the *Moyen Ouest du Vakinankaratra*, i.e. a less saturated region, agricultural development is hampered by the lack of elementary services, in quantity and quality (health, education, roads, market equipment and, above all, security). **Technical responses are therefore ineffective levers. Structural bottlenecks stand in the way of positive change without massive and coordinated public action at the farm, sectorial and territorial levels. Agroecological strategies must therefore be integral, jointly oriented towards systemic and territorial approaches.** Technical solutions will only be able to offer real leverage to families in the *Hautes Terres* region when a favorable socioeconomic environment prevails.

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• Sourisseau J.-M., Bélières J.-F., Marzin J., Salgado P., Maraux F., 2019. The drivers of agroecology in sub-Saharan Africa: an illustration from the Malagasy Highlands. *In* Côte F.-X. *et al.* (eds): *The agroecological transition of agricultural systems in the Global South*. Ed. Quae, Versailles: 179-197. www.quae-open.com/produit/114/9782759230570/the-agroecological-transition-of-agricultural-systems-in-the-global-south

• Rakotoarisoa J., Bélières J.F., Salgado P., 2016. *Intensification agricole à Madagascar : politiques publiques et trajectoires d'exploitations agricoles du Vakinankaratra*. Summary report. CIRAD-FOFIFA, Antananarivo, 135 p. https://agritrop.cirad.fr/583105/

Agroecological practices that benefit society and farmers

An example in Itasy region, Madagascar

▲ ***A rural landscape in Madagascar: crop and livestock farming.*** *Imerintsiatosika, Itasy region, Madagascar. © T. Chevallier/IRD*

Rural development projects should be assessed before large-scale farmer involvement. Scant data are available in African countries on the sustainability of farming systems to produce food, enhance smallholder incomes, and reduce greenhouse gas (GHG) emissions. This study* was based on a rural development project in Madagascar that promoted agroecological practices—agroforestry, compost and systems of rice intensification (SRI). The potential benefits of the project were quantified by three indicators: GHG balance, economic benefits to farmers and effectiveness of economic GHG mitigation investments. These indicators were projected over a 20-year period according to three scenarios, i.e. two that differed in terms of two agroecological practice adoption levels were compared to a baseline scenario with no project intervention. Socioeconomic, crop yield and soil data were collected on 192 farms over five crop seasons (2013-2018). The GHG balance was estimated with 2 calculators: the TropiC Farm Tool and the EX-Ante Carbon-balance Tool. **GHG emissions were reduced under both scenarios compared to baseline: -5.2 to -13.6 tCO_2eq farm^{-1} year^{-1} for scenarios 1 and 2, respectively. The amount of carbon saved per euro invested was estimated at -0.25 tCO_2eq euro^{-1} and -0.41 tCO_2eq euro^{-1} (or 4 to 2.5 euros tCO_2eq^{-1}) under scenarios 1 and 2. Agricultural production and farmers' cash flow increased over the course of 20 years.** This study highlighted the potential of agroecological practices to improve the productivity and profitability of smallholder farming systems, while contributing to climate change mitigation. The findings should fuel current international discussions on the relevance of family farming in the climate change mitigation agenda.

*This study was conducted with the support of the SoCa project funded by the Fondation BNP Paribas.

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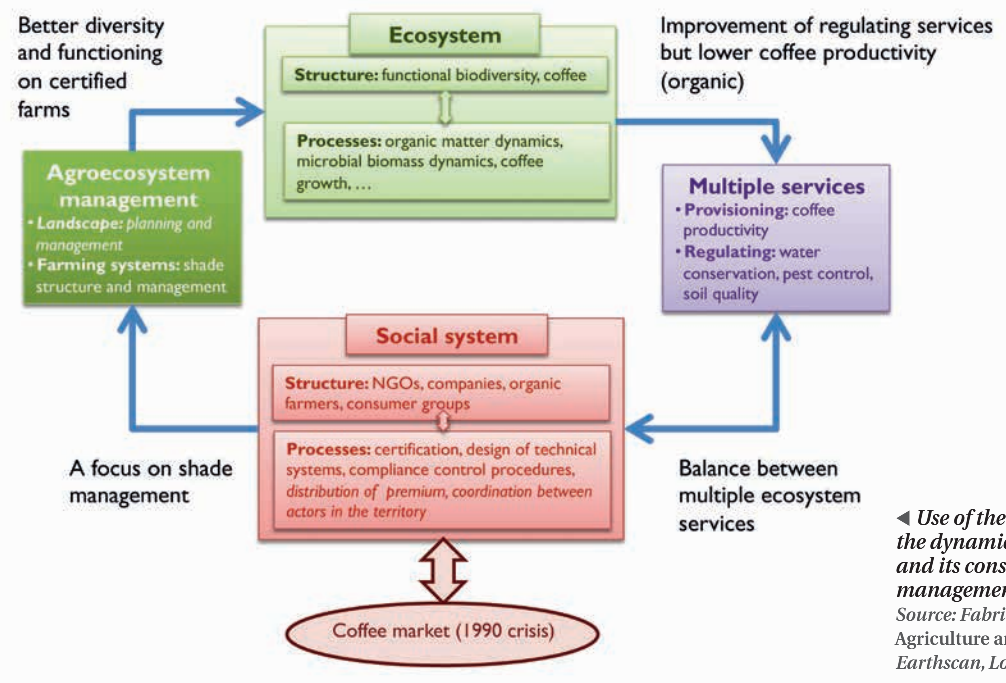
Rakotovao N.H., Chevallier T., Chapuis-Lardy L., Deffontaines S., Mathé S., Ramarofidy M.A., Rakotoniamonjy T.H., Lepage A., Masso C., Albrecht A., Razafimbelo T.M., 2020. Impacts on greenhouse gas balance and rural economy after agroecology development in Itasy Madagascar. *J. Clean. Prod.*, 291: 125220. https://doi.org/10.1016/j.jclepro.2020.125220

▼ ***Soil fertilization via composting.*** *Composting workshop, Imerintsiatosika, Itasy region, Madagascar. © T. Chevallier/IRD*

A conceptual framework for multiservice agroecosystem management

In order to foster research on ecosystem services in agroecosystems, the INRAE EcoServ Metaprogram has proposed a conceptual framework at the agricultural territory scale for the purpose of developing socioecological approaches to facilitate implementation of multiservice management in agroecosystems. We designed this framework on three fundamental bases. First, we defined a **novel symmetrical representation of the ecosystem and social system via each of their structural and functional components** in order to broaden the scope of possible interactions between these systems. The ecosystem structural components are its physical, geochemical and biological compartments, including both domesticated and wild biodiversity. The functional components are biophysical processes (soil, water and nutrient cycles) and biological processes, involving individuals and populations, while also encompassing metacommunity dynamics. The social system structural components take the diversity of individual stakeholders (e.g. farmers, foresters), organizations and institutions into account, thereby incorporating the diverse range of beneficiaries of the bundle of interacting services. The functional components correspond to diverse socioeconomic processes. Second, **an explicit management-oriented feature is included in the framework that specifies potential management targets and levels** (landscape, farming systems, seminatural habitats, and natural resources) to enable service regulation. Third, the framework proposes **a dynamic iterative representation of interactions between the social system, ecosystem and agricultural practices**, regardless of the entry chosen at the outset. The relevance of this dynamic conceptual framework was illustrated by its application to the reanalysis of two case studies published elsewhere: the dynamics triggered by environmental certification in the coffee value chain in Central America (Figure), and the set-up of collective management in a French cereal growing area to reconcile agricultural production and biodiversity.



◄ ***Use of the EcoServ conceptual framework to represent the dynamics of coffee certification in Central America and its consequences on agroecosystem service management.***
Source: Fabrice DeClerk et al., *2011.* Ecosystem Services from Agriculture and Agroforestry Measurement and Payment. *Earthscan, London.*

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Lescourret F., Magda D., Richard G., *et al.*, 2015. A social-ecological approach to managing multiple agro-ecosystem services. *Current Opinion in Environmental Sustainability*, 14: 68-75. https://doi.org/10.1016/j.cosust.2015.04.001

Redesigning agrosystems in southern India to optimize water resource use

In India, the excesses of the Green Revolution led to an agrarian crisis that has impacted food security, energy consumption, water and soil resources, and even the survival of farms. Alternative models based on agroecological principles are currently being fostered, but the tools to adapt them locally are lacking. A multidisciplinary consortium of Indian and French researchers is monitoring and modeling the hydrological, geochemical, agronomic and socioeconomic functioning of an experimental watershed in southern India (Berambadi, an Indian site of the National Observation Service 'Multiscale Tropical Catchments', SNO M-Tropics), where excessive groundwater tapping for irrigation is undermining farm sustainability. Scenarios are being jointly developed with local stakeholders to come up with ways to improve the situation.

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► ***Individual borehole in Berambadi.***
This photo shows the small size of the crop plots.
© M Sekhar

The first scenarios proposed by stakeholders essentially had a technological bent, i.e. improving irrigation productivity (e.g. microirrigation) and increasing available water resources (e.g. artificial groundwater replenishment, hillside reservoirs). An integrated model developed on the RECORD platform (see page 136) indicates that these solutions are insufficient, and may even accelerate groundwater depletion by spurring the extension of irrigated areas (rebound effect). Moreover, irrigation pricing would make it possible to consolidate water resources but would wipe out many vulnerable farms. **The new scenarios proposed require a deep redesign of the systems so as to tailor them to the local soil-climate conditions and to ensure optimal agricultural production while preserving water resources.** For example, crop rotations could be modified (complementarity between irrigated and rainfed crops) while discouraging the planting of high water-consuming crops during the hot and dry season, which are primarily responsible for the annual water deficit. **Generic diagnostic and assessment tools developed in this framework could help devise solutions under a wide range of soil-climate conditions.**

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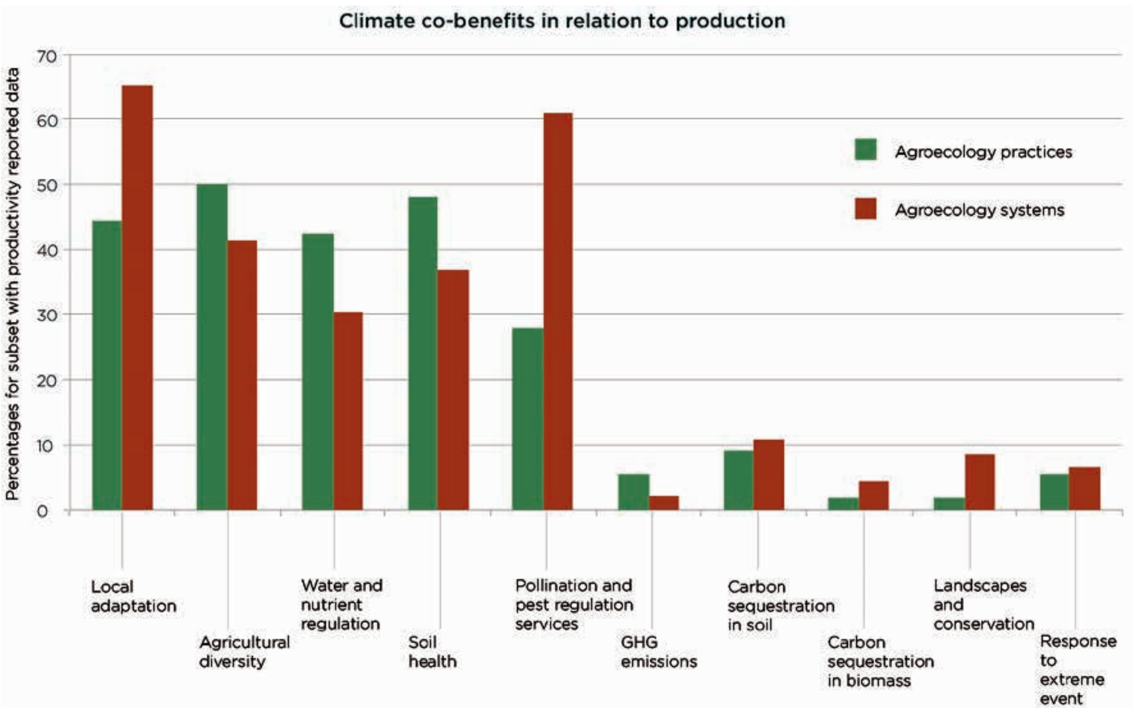
• Robert M., Thomas A., Sekhar M., Badiger S., Ruiz L., Raynal H., Bergez J.E., 2016. Adaptive and dynamic decision-making processes: a conceptual model of production systems on Indian farms. *Agricultural Systems*. https://10,1016/j.agsy.2016.08.001

• Sekhar M., Riotte J., Ruiz L., Jouquet P., Braun J.J., 2016. Influences of climate and agriculture on water and biogeochemical cycles: Kabini critical zone observatory. *Proc. Ind. Nat. Sci. Acad.*, 82: 833-846. http://dx.doi.org/10.16943/ptinsa/2016/48488

Agroecology as a lever for climate change adaptation and mitigation

A review of the evidence

Agroecology is to an increasing extent being showcased as a means to transform food systems and achieve global food and nutrition security in the current climate change setting. However, scientific evidence supporting this strategy is modest. We conducted a rapid evidence-based review to gain insight into the impacts of agroecological practices on climate change adaptation and mitigation[2]. We focused on: (i) the impact of agroecological approaches on climate change mitigation and adaptation in low- and middle-income countries; and (ii) programming approaches and conditions supporting large-scale agroecological transitions. We reviewed 18 synthesis and meta-analysis papers on agroecological approaches and climate change adaptation, mitigation, and scaling (representing over 10,212 studies). We also reviewed 15,674 articles regarding agroecological approaches related to nutrient management and climate change outcomes, in addition to 5,498 articles on agroecological approaches related to pests and diseases and climate change outcomes. We identified 138 papers that also considered some aspects of scaling, adoption, and farmer innovation. **Substantial evidence is available on the impacts of agroecology on climate change adaptation, as well as on climate change mitigation to a lesser extent**. This included positive impacts of diversification on pollination, pest control, nutrient cycling, water regulation and soil fertility[3]. Soil carbon sequestration was the most frequently observed form of mitigation. Farmers' co-creation and knowledge sharing underpinned their capacity to adapt to local conditions[1], improving both adaptation and mitigation to climate change. **Evidence gaps were noted for agroecological approaches**: (i) involving livestock integration; (ii) landscape scale redesign; and (iii) response to extreme weather events. **Data on greenhouse gas emissions in the tropics is also very limited**. **Scaling evidence is sparse**, except regarding approaches that support agricultural diversity and enhance the local adaptive capacity (use of participatory and farmer-to-farmer processes) and the role of policy.



▲ *Percentage of papers reporting evidence on co-benefits and production (100 papers) regarding climate change adaptation and mitigation of agroecological nutrient and pest management for agroecology practices and systems*. Source: Snapp et al. (2021)

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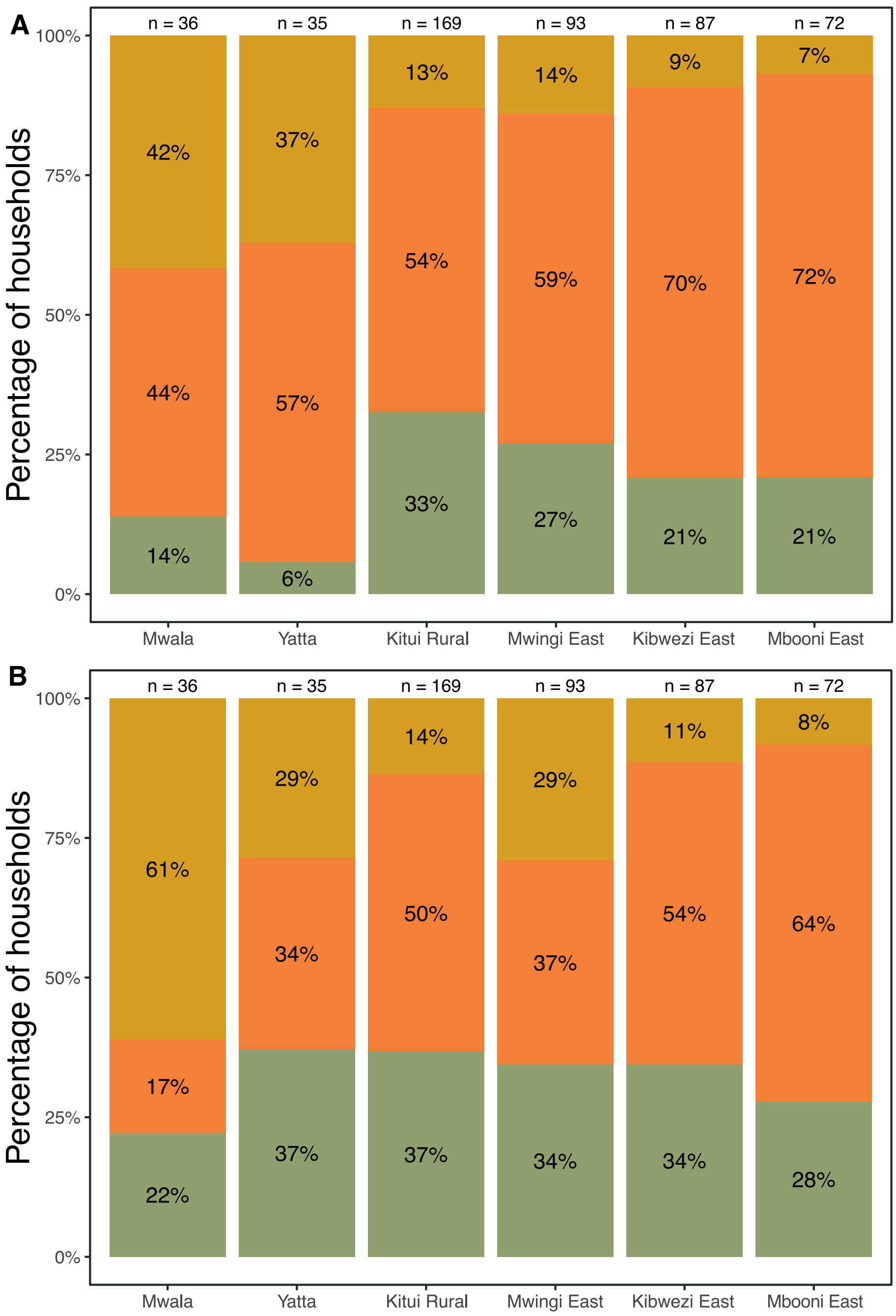
(1) Mier y Terán Giménez Cacho M., Giraldo O.F., Aldasoro M., Morales H., Ferguson B.G., Rosset P., Khadse A., Campos C., 2018. Bringing agroecology to scale: key drivers and emblematic cases. *Agroecology and sustainable food systems*, 42(6): 637-665. doi: 10.1080/21683565.2018.1443313

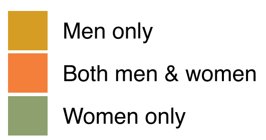
(2) Snapp S, Kebede Y, Wollenberg E, Dittmer KM, Brickman S, Egler C, Shelton S., 2021. *Agroecology and climate change rapid evidence review: performance of agroecological approaches in low- and middle- income countries*. Wageningen, the Netherlands: CGIAR Research Program on Climate Change, Agriculture and Food Security (CCAFS). https://ccafs.cgiar.org/news/agroecology-key-piece-climate-adaptation-mitigation

(3) Tamburini G., Bommarco R., Wanger T.C., Kremen C., van der Heijden M.G., Liebman M., Hallin S., 2020. Agricultural diversification promotes multiple ecosystem services without compromising yield. *Science advances*, 6(45). doi: 10.1126/sciadv.aba1715

Uptake of agroecological practices is conditioned by intrahousehold dynamics and changes in women's labor profiles

Planting basins (pits dug in crop fields to hold water in which crops are then planted) are an effective agroecological response to increased drought frequency and severity but their creation and maintenance are labour intensive[(1)]. The research reported here examined intrahousehold decisions and gender relations surrounding the use of planting basins by over 2,500 farmers in the eastern drylands of Kenya. **The results reveal that decisions regarding the uptake of agroecological practices, although initiated by women who attend agricultural workshops, are often made on the basis of discussions between husbands and wives and that multiple social dimensions, including gender norms surrounding the use and control of household resources, intersect to shape men's and women's interest in, contribution to and benefits from different practices[(2)].** The adoption of basins shifted the labor task from men to women because, before taking up the basins, women had been less involved in land preparation (Figure). Despite the fact that basins increased the land preparation time, many farmers reported they reduced the overall amount of time spent working on their farm because less weeding was required. Many also noted that the use of basins spread the labor demand more evenly throughout the year. Men and women reported that basins were more productive because of their ability to capture runoff, control erosion and increase soil fertility, and so they were worth the required labor investment, especially when rainfall was sparse. **Intrahousehold relations were shaped by women's increased participation in innovation processes**, such as training events, as well as broader societal changes, particularly the outmigration of many rural men. The uptake of on-farm restoration practices in eastern Kenya is likely to be enhanced by the explicit consideration of intrahousehold roles and relations when designing and disseminating agroecological innovations. In many contexts, achieving inclusive and gender-equitable outcomes, also requires deliberate action to shift gender relations so that women will have increased voice in farming decisions.





▲ *Gender of those involved in (fig. A) digging planting basins, and (fig. B) preparing land using farmers' usual cultivation practices, at six locations across three semiarid counties in Kenya.*
Source: Crossland et al.*, (2021)*

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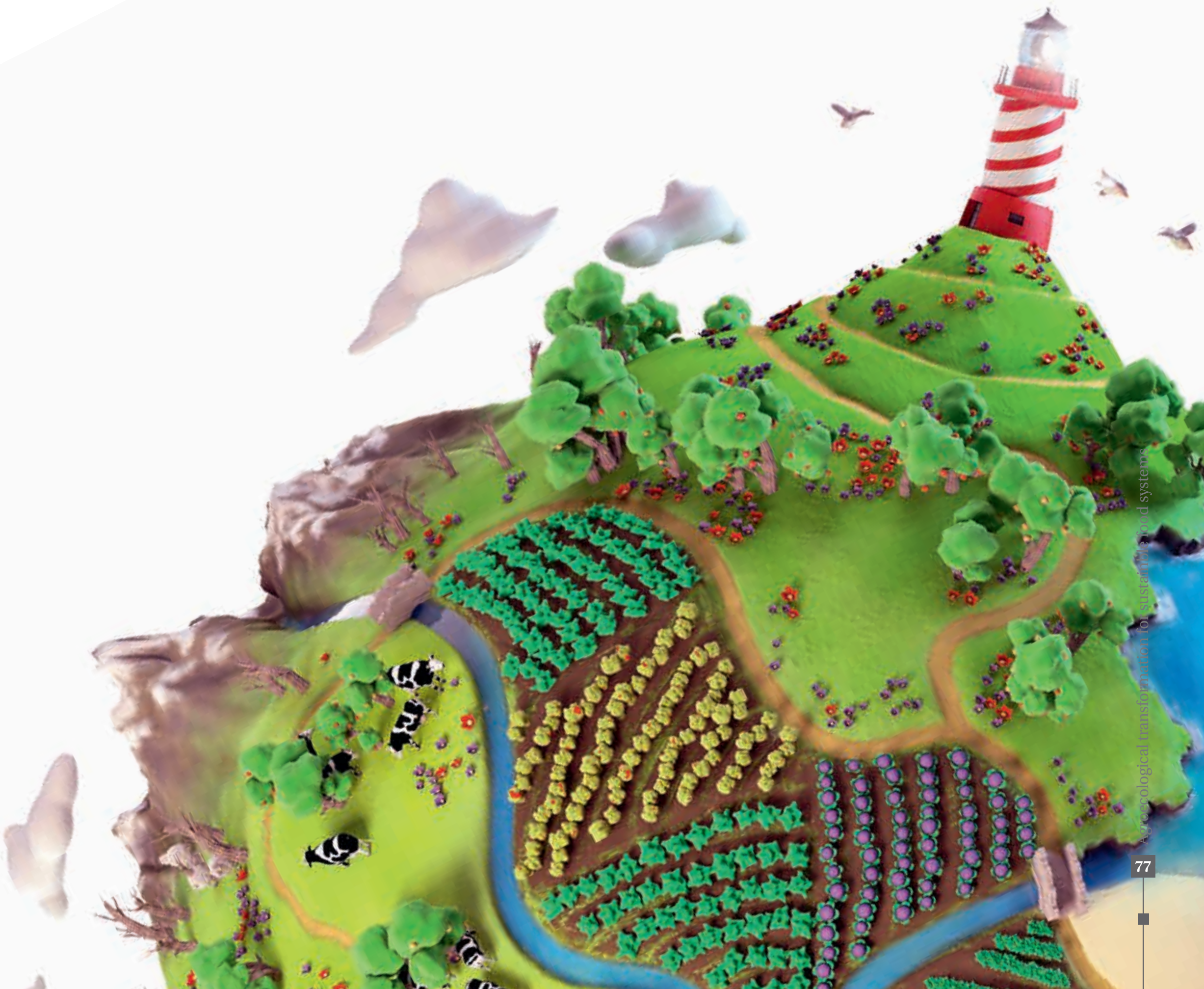
(1) https://forestsnews.cifor.org/65320/agroforestry-basins-stir-up-big-benefits-for-women-in-kenya-drylands?fnl=en

(2) Crossland M., Paez Valencia A.M., Pagella T., Magaju C., Kiura E., Winowiecki L., Sinclair F., 2021. Onto the farm, into the home: how intrahousehold gender dynamics shape land restoration in Eastern Kenya. *Ecological Restoration*, 39 (1&2): 90-102.



PART 2

Food systems

Chapter 4

Identifying and overcoming constraints within food systems to achieve agroecological transitions at scale – reconnecting producers and consumers

The development, implementation and scaling of agroecological practices (see chapters 1, 2 and 3) requires an appropriate enabling environment. This often means overcoming structural constraints that hamper conventional agricultural improvement models, thereby necessitating fundamental shifts in the way food systems are organized and function. This chapter addresses the issue of identifying and surmounting constraints within agricultural, food and land systems to achieve agroecological transitions at scale. The research presented here is organized around five main issues: (i) the economic environment around farms, linked to value chains, markets and regulations; (ii) the innovation environment around farms and farming systems; (iii) the role of markets in re-establishing a more direct connection between producers and consumers; (iv) leveraging nutrition objectives and food traditions for agroecology; and (v) designing territorial food systems. These issues are in line with Gliesmann's transition level #4 ("Re-establish a more direct connection between those who grow our food and those who consume it"), while fulfilling the requirements of an overall enabling environment that favors agroecological transitions.

Some of these constraints are found in the economic environment around farms and in the way production and value chains are currently organized and regulated. First, are there farm, land or tree tenure related constraints that need to be overcome and how? Then, what are the key constraints and bottlenecks for change at scale in systems beyond the farm? How does farm and household labor play a role (e.g. as shown by Agazhi *et al.* in legume intercropping)? How is land and tree tenure a constraint and how can it be overcome (as shown by Chomba *et al.*)? What are the social and economic forces and factors, that generally favor uniformity, standardization and concentration along food value chains, that hinder agroecological transitions, and how can they be addressed? What is the role of input markets, cooperatives, output and standardization, quality control, constraints linked to transformation, and to market regulation? Can specific institutions such as rural resource centers play a role as shown by Carsan *et al.*? Are there specific constraints for specific value chains that need to be overcome? Can local value chains play a role, as shown by Faye for camels? Can industrial business models be tweaked to integrate smallholder production systems, as shown by Miccolis *et al.* with regard to oilpalm agroforestry in the Brazilian Amazon? How can markets be transformed to work for agroecology at larger scales to, for instance, reach large populations in megacities with agroecological products, including supplying big trade volumes? Can national policies be put in place to enable all this, as Rizvi *et al.* show for agroforestry in India?

Another set of issues is linked to the way **the knowledge and innovation environment around farms function.** What is the role of farmer advisory services and how can they help? Are current local farm innovations and knowledge exchange platforms conducive to agroecological transitions? How do value chain innovations enhance the transition potential at the farm level (as shown by Jeuffroy & Meynard)? How can agricultural research fit into this scheme in new ways with new roles, from a traditional 'off farm piloting and on farm upscaling' model, towards a new model of on-farm research experimentation at scale to embrace the wider range of context-specific and farmer-tailored transitions (as shown by Coe & Sinclair), while ensuring that innovations are demand-driven (Yila *et al.*)? This is exemplified with regard to the co-design of dairy systems in Burkina Faso (Vall *et al.*), and by new scientific platforms working together with actors, as shown by Bertrand and Rapidel for coffee agroforestry, or in France by Cerf and Jeuffroy. Are there gender-specific issues that may hinder or accelerate the agroecological transition (as shown by Yila and Sylla)?

An important dimension of agroecology is to **reconstruct links between producers and consumers**. Are emerging market types (e.g. local markets, local procurement, but also more distant markets for agroecological produce, etc.) conducive to this, what are these markets, can they be favored and how? How can distant markets work

▼ *A kiosk-type food shop*. © *Y. Kameli/IRD/MOISA*

to enable this connection, when food needs to be sourced from greater distances (e.g. megacities, or for internationally traded commodities like coffee, cocoa, etc.)? Can quality labels, certification or other schemes be made to work for agroecology, as for quality peanuts in Kenya (Hauser & Edel) or cocoa certification in Cameroon (Lescuyer)? How is it possible to ensure that the information on key attributes of products and the way they have been produced (e.g. production modes, social footprints, nutritional values, biodiversity, energy intensity, etc.) will be transmitted from farm-to-fork and thereby influence consumer preferences and inform their choices, as shown by Cuong and Nelson for rice? And conversely, can consumers' sustainable consumption choices bring rewards to producers, and if so, how?

Better nutrition is a fundamental objective for food system transitions, but nutrition is not only an end, it can also be a means. A better understanding, consideration, and integration of nutritional dimensions into farming, marketing and consumption decisions can be conducive to agroecology. How can this work in practice? For instance, can we gain insight into and promote the benefits of underutilized crops to improve nutrition and fight under/malnutrition (Termote & Meldrum)? Can farm production systems be devised to ensure a portfolio of products that year-round could provide a balanced supply of diverse nutritious foods, harness the diversity of crop and tree harvesting calendars (as shown by Dury *et al.* in Mali and Burkina-Faso, and by McMullin *et al.* concerning fruit tree portfolios in East Africa)? Manners and Remans show that farm-scale crop diversity can be managed to meet nutritional objectives without tradeoffs with regarding total yield or income in the Central African Great Lakes region. Knowledge on the nutritional value of native food plant species can enhance interventions and policies (Borelli & Hunter). Food culture and traditions are key dimensions of agroecology but are often at risk of being lost, therefore it is important to ensure a continued transmission of knowledge around local, nutritious foods, their cultivation and use including traditional cooking methods. This includes the protection, use and management of wild food plant species across mosaic landscapes, including croplands and forests (Ickowitz *et al.*). How can this be best preserved and leveraged?

Finally, a key way to ensure that enabling environments will be favorable for agroecology is to better link food value chains, food system actors and **territorial or landscape scale development.** What forms of organization are conducive to local innovation systems, and what examples are available? Is there a role of jurisdictions in landscapes to construct territorial food systems that bring together all stakeholders in a participatory way to structure the food system/environment organization in a given landscape, while tackling issues of rural, periurban and urban land tenure for production, markets, sales and distribution channels, etc.? What is the role of local food systems and to what extent and how can they provide some form of self-sufficiency (e.g. Sanz-Sanz *et al.*)? How can we better understand and connect human and environmental health issues around cities, as exemplified by Le Bars and Kameli with regard to pesticide reductions in Bamako (Mali)? What forms of social organizations in cities can enhance rural-urban connections? Territorial food projects represent an innovative solution developed in Mirecourt, France (Barataud & Coquil). Can these channels leverage the opportunity of recycling waste and the nutrients they contain to benefit agroecological production, and how (e.g. Wassenaar and Feder for Réunion)? Resilience to shocks and crises such as COVID-19 must be enhanced to cope with issues regarding rural, urban and territorial development, social, economic and physical infrastructures to link with food systems (as shown by Homann-Kee Tui *et al.* in Zimbabwe). Moreover, longer time horizons should be taken into consideration in policy making, such as by mobilizing foresight approaches (see Dorin in India).

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Economic environment around farms and farming systems

Impact of introducing food legumes in cereal-based monocropping systems – inter- and intra-household analyses

Agroecological diversification strengthens ecological and socioeconomic resilience, often by creating new market opportunities[(1)]. Empirical studies have shown that farms with high agrobiodiversity, food security and social engagement can be considered as more advanced in the agroecological transition process and to have a presumably high potential for the provision of a wide range of ecosystem services[(3)]. The introduction of legumes in cereal dominated monocropping systems is among the most common strategies farmers use to increase the efficiency and productivity of their farms. There is limited empirical information on the economic impacts of introducing food legume crops in cereal dominated monocropping systems in Ethiopia. Based on a random sample of 600 farm households and using different specifications of the propensity score matching model (PSM)*, this study investigated the impact of the intensity of adoption of newly introduced food legume technologies in wheat dominated crop production systems. The binary treatment effect model results showed that adopters generate 25% higher income from their crop farming than non-adopters. The generalized propensity score matching model results also indicated that the adoption intensity has a positive effect on income and calorie intake. However, the daily consumption expenditure was found to decrease as the adoption intensity increased. An age and sex disaggregated analysis revealed that households with a higher productive labor force benefit from better causal effects while they are less beneficial for those with a higher number of economically dependent female members. This implies that the impact of the adoption of improved food legume varieties varies among households according to their intra-household dynamics. The adoption of improved food legume varieties has a promising welfare impact, yet this significantly differs among household members due to age and sex variations. **The evidence highlights that introducing legume crops in monocropping systems dominated by wheat can generate interesting opportunities and that gender differentials need to be focused on to take full advantage of the potential benefits from introducing legumes.**

* PSM is a treatment effects model based on the propensity score concept. Propensity score is the conditional probability of assignment to a particular treatment given a vector of observed covariates[(2)].

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(1) FAO, 2021. *Agroecology knowledge hub*. Food and Agriculture Organization of the United Nations. www.fao.org/agroecology/knowledge/10-elements/diversity/en/ (accessed: 22 April 2021).

(2) Rosenbaum P.R., Rubin D.B., 1983. The central role of the propensity score in observational studies for causal effects. *Biometrika*, 70(1): 14. http://links.jstor.org/sici?sici=0006-3444%28198304%2970%3A1%3C41%3ATCROTP%3E2.0.CO%3B2-Q

(3) Teixeira, H.M. *et al.*, 2018. Understanding farm diversity to promote agroecological transitions. *Sustainability (Switzerland)*. MDPI AG, 10(12). doi: 10.3390/su10124337

▲ *Faba beans growing in the predominantly cereal crop Bale administrative zone, Southern Ethiopia.*
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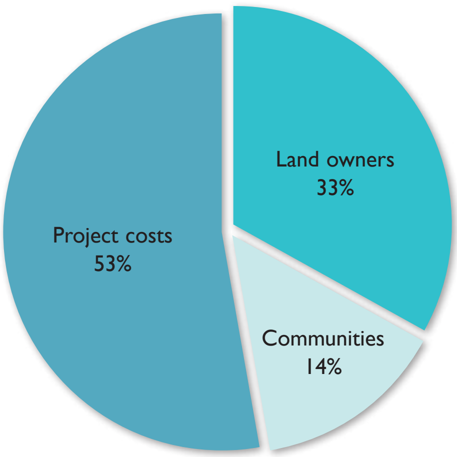
How land and tree tenure condition agroecological transitions at scale

Land and tree tenure are critical for the adoption and scaling of agroecological approaches that ensure sustainable, socially just and secure global food systems. In many regions, land and tree tenure remain weak, contentious and insecure, thereby hampering smallholder farmer adoption of agroecological practices, sustainable investment and equitable benefit sharing mechanisms. Where land ownership is skewed in favor of a few individuals, food system transitions—long-term by nature—risk entrenching inequalities in production and benefit-acquisition from agroecology (Figure). In the Kasigau project (Kenya), three equal shares of benefits were expected amongst groups, but landowners had a guaranteed third share and project costs were met before the remainder was allocated to communities who had been previously dispossessed of tenure rights and access to resources, including people excluded from economic activity on land as it became part of the scheme (such as charcoal makers, grazers and squatters on abandoned ranches evicted as land ownners rights were re-asserted). Weak and insecure tenure is disproportionately affecting women, indigenous people and the poorest landless members of society. These people often do not have an opportunity to engage in productive agroecological approaches, to defend their agroecology-friendly sociocultural norms or to benefit equitably. Targeted institutional mechanisms are required to remediate these structural factors[1]. Small land holding sizes could require disproportionate agroecological transition costs, with smallholder farmers disadvantaged over large-scale producers through economies of scale.



▲ *Average distribution of revenues from carbon sales in 2010 and 2011 from the Kasigau Corridor REDD Project in Kenya.*

Innovative land tenure arrangements that make land available to women and the underprivileged, ensure security for indigenous people and support aggregation and collective marketing, can help overcome some of these challenges[1]. In the Peruvian Amazon, the government has granted formal land titles (40-year renewable leases) to farmers who had encroached on forest land prior to passing of the law, provided that they commit to conserving forest remnants, maintain or establish agroforestry stands on at least 20% of their land, while implementing soil and water conservation measures. Different agroecological approaches were identified —consistent with current farmer livelihoods and land/tree conservation strategies—that could be carried out by farmers on their securely held land. These include forest cover restoration, promotion of successions in fallows, agroforestry and enrichment of fallows in areas devoted to crop production[2]. This provision could provide land acquisition rights to tens of thousands of farmers, pending their implementation of agroecological practices[3].

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(1) Chomba S., Kariuki J., Lund J.F., Sinclair F., 2016. Roots of inequity: how the implementation of REDD+ reinforces past injustices. *Land Use Policy*, 50: 202-213.

(2) Robiglio V., Reyes M., 2016. Restoration through formalization? Assessing the potential of Peru's agroforestry concessions scheme to contribute to restoration in agricultural frontiers in the Amazon region. *World Development Perspectives,* 3: 42-46. https://doi.org/10.1016/j.wdp.2016.11.013

(3) Sinclair F., Wezel A., Mbow C., Chomba S., Robiglio V., Harrison R., 2019. *The contribution of agroecological approaches to realizing climate-resilient agriculture*. GCA: Rotterdam, The Netherlands.

Rural resource centers provide extension support for diversified food production options

Declined investment in agricultural and forestry extension services in Africa is negatively affecting the ability of farmers to adopt novel food production practices that involve perennial trees, since they are knowledge intensive. The use of rural resource centers (RRC) as local- or farmer-oriented dissemination hubs—set up on a need or local resource availability basis to promote the use of agroforestry technologies in some West and East African areas—provides new opportunities to improve farmer access to new knowledge, improved germplasm, nursery practices, grafting skills and tree management practices. RRC, ideally established via projects and including local community ownership plans, provide farmers and local extension staff with peer learning opportunities, training, links with input suppliers, demonstrations and planting material exchange possibilities that help improve and diversify local food production options.

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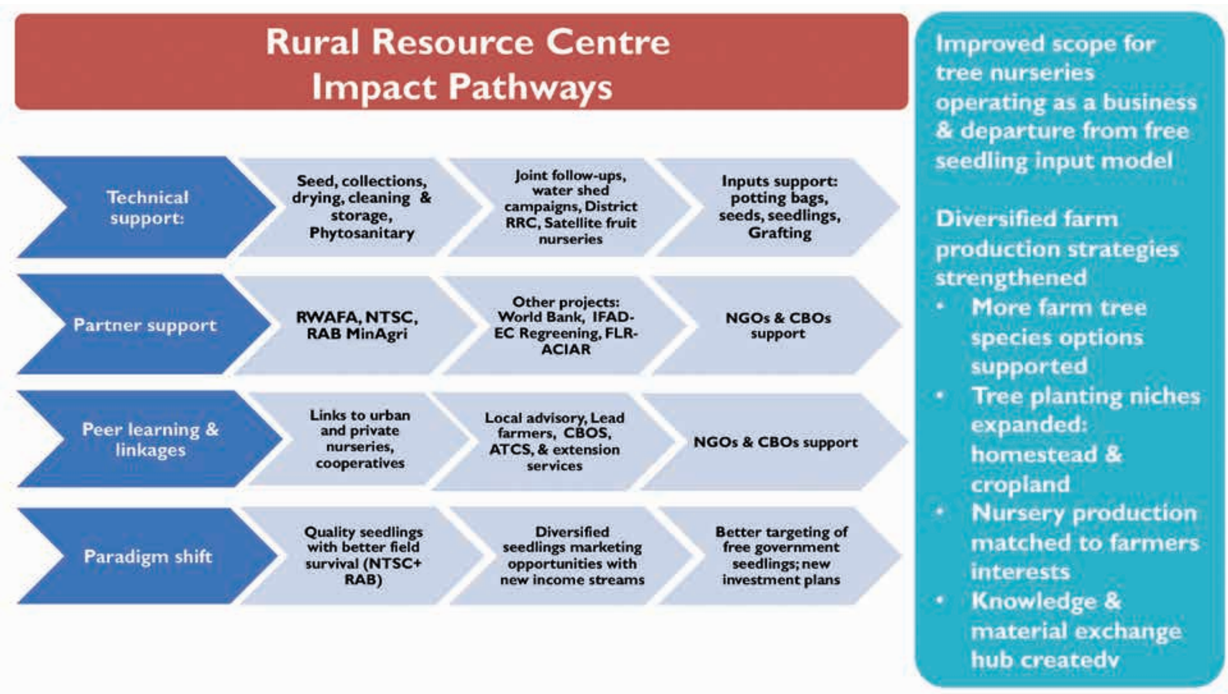

◀ ***Illustration on the contribution of rural resource centers (RRC) to improved food systems.***
ATCS: agricultural training centres
CBO: community-based organization
EC: European Commission
FLR-ACIAR: Forest and Landscape Restoration - Australian Centre for International Agricultural Research
IFAD: International Fund for Agricultural Development
NGO: non-governmental organization
NTSC: National Tree Seed Centre
RAB MinAgri: Rwanda Agriculture Board, Ministry of Agriculture and Animal Resources
RWAFA: Rwanda Water and Forest AuthoritySource: own compilation.

They complement traditional forestry nurseries focused on timber seedlings by helping farmers produce diverse food trees of their choice for on-farm planting or sale to other community members. Members can also diversify tree production with leafy vegetables at the hub or produce planting materials for home gardening. This often creates opportunities that especially benefit youth and women through income generating activities. These activities may involve marketing tree seedlings, supplying fruit scions and providing skills such as fruit grafting for a fee. In sum, **RRC serve complementary rural advisory roles, helping local communities to better: (i) diversify food tree planting materials; (ii) multiply and disseminate diverse food trees; (iii) secure income generation activities; and (iv) scale food production options with fruits and leafy vegetables**. Marshalling knowledge and materials on local food genetic resources boosts appreciation of diverse local foods, while also helping to fill hunger gaps caused by over reliance on a few staple crops prone to drought problems that arise in Africa.

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For further information

• Takoutsing B., Tchoundjeu Z., Degrande A., Asaah E., Tsobeng A., 2014. Scaling-up sustainable land management practices through the concept of the rural resource centre: reconciling farmers' interests with research agendas. *International Journal of Agricultural Extension Education*, 20(5): 463-483. http://dx.doi.org/1 0.1080/1389224X.2014.913984

• Major impacts and outcomes of RRC: www.worldagroforestry.org/node/105018

Innovative camel production systems and insertion in local value chains

Camel rearing has long been associated with low-input mobile herding. However, this livestock sector has been undergoing a marked change towards intensified milk and meat production and sports performances (camel races) in many parts of the world (Middle East, Central Asia, China and North Africa). This change is reflected in the modernization of production practices (mechanical milking, feed-lots), the use of reproductive biotechnologies (artificial insemination, embryo transfer) and enhanced integration in local or national markets, thereby substantially boosting the value of camel products (milk, meat) that were not previously marketed. There have also been major changes in feeding methods, with a clear shift away from exclusive rangeland grazing to rational feeding with fodder sourced mainly from irrigated areas in regions markedly impacted by water shortages. The pressure of this feeding system on water resources is not comparable to that exerted by Holstein dairy cattle farming in desert regions, but the use of irrigated fodder crops still seems hard to maintain in the dryland conditions that generally prevail in 'camel countries'. **A potential alternative could include the systematic use of by-products of oasis agriculture (date and olive waste), as well as the development of salt-tolerant forage crops.** Indeed, camels very well tolerate salt-rich rations and some more or less halophytic forage species such as *Sporobolus virginicus* and *Chloris gayana*, which may grow on plots irrigated with otherwise unusable brackish water. When associated with forage shrubs such as *Moringa oleifera*, these halophytic crops could provide sufficient feed for camels.

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For further information

• El-Shaer H.M., 2010. Halophytes and salt-tolerant plants as potential forage for ruminants in the Near East region. *Small Rumin. Res.*, 91(1): 3-12. https://doi.org/10.1016/j.smallrumres.2010.01.010

• Faye B., 2016. The camel, new challenges for a sustainable development. *Trop. Anim. Health Prod.*, 48: 689-692. https://doi:10.1007/s11250-016-0995-8

▲ *Signboard for pasteurized camel milk on El-Oued market (Algeria).*
© B. Faye

▲ *Mechanical milking of dairy camels in the Kharj farm (Saudi Arabia).*
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Scaling up oil palm agroforestry in the Brazilian Amazon

Tailoring production systems and business models to the context of family farmers in Tomé Açu (Pará State)

Globally, oil palm is mainly produced in monocrop plantations, which can be highly productive but have been historically associated with negative environmental and mixed livelihood impacts. Oil palm agroforestry (AFS) can provide an agroecological pathway for palm oil production. We studied key factors underlying the expansion of AFS in northeastern Pará State, in the Brazilian Amazon, and highlighted pathways to achieving more socioenvironmentally sustainable oil palm production. The methodology involved: an analysis of secondary socioeconomic and land-use data; and a household survey (203 farms) focused on livelihoods, value chains, agroforestry types and practices (152 plots). The preliminary findings showed **ample interest in expanding AFS, as compared to a very low interest in oil palm. AFS represent a key component of livelihoods, as measured by the area occupied, income, and wellbeing.** Family farmers had highly heterogeneous livelihoods and land-use strategies, averaging 9 ±5 land uses per farm. Despite high overall species diversity across farms, a few key species were common to the vast majority of AFS: cocoa, açaí palm (*Euterpe oleracea*) and black pepper, which have solid marketing pathways. **Key motivations for adopting AFS included resilience to market risks, price fluctuations and extreme climate events, and the well-established markets for agroforestry products**. The main constraints for upscaling biodiverse oil palm agroforestry among family farmers were: negative perceptions about oil palm, i.e. viewed as a poor companion crop; resistance to the prevailing business model/technological package practiced by companies; and low access to technical assistance, rural credit, inputs and processing facilities for some agroforestry products, especially açai palm and cassava. The potential expansion of mixed oil palm agroforestry in this context could thus be hinged on more flexible contracts by including provisions that take into account farmers' aspirations, available land and labor, agroforestry species management, input use, and technical assistance geared not just to oil palm but also to agroforestry and agroecological practices overall.

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For further information

- Batistella M., Bolfe É.L., Moran E.F., 2013. Agroforestry in Tomé-Açu: an alternative to pasture in the Amazon. *In* Brondízio E., Moran E. (eds): *Human-environment interactions, vol 1*. Springer, Dordrecht. https://doi.org/10.1007/978-94-007-4780-7_14
- Brandão F., Schoneveld G., 2015. *The state of oil palm development in the Brazilian Amazon: trends, value chain dynamics, and business models*. CIFOR Working Paper, 45 p. https://doi.org/10.17528/cifor/005861
- Khasanah N., van Noordwijk M., Slingerland M., Sofiyudin M., Stomph D., Migeon A.F., Hairiah K., 2020. Oil palm agroforestry can achieve economic and environmental gains as indicated by multifunctional land equivalent ratios. *Frontiers in Sustainable Food Systems, 3* (January): 1-13. https://doi.org/10.3389/fsufs.2019.00122
- Miccolis A., Robiglio V., Cornelius J.P., Blare T., Castellani D., 2019. Oil palm agroforestry: fostering socially inclusive and sustainable production in Brazil. *In* Jezeer R., Pasiecznik N. (eds.): *Exploring inclusive palm oil production*. Tropenbos International: Wageningen, the Netherlands: 55-62. www.etfrn.org/publications/exploring+inclusive+palm+oil+production

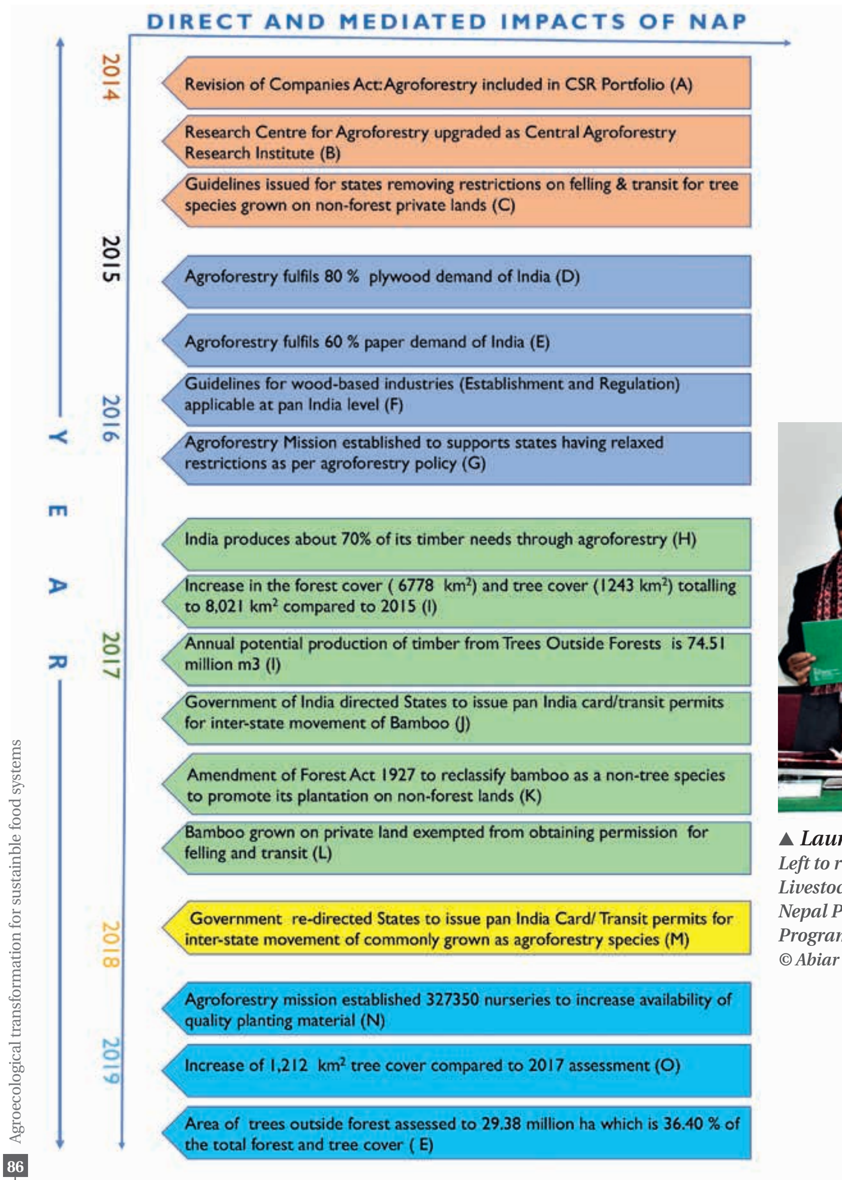
▲ ***Oil palm agroforestry in Tomé Açu, Pará, Brazil.*** *© H. Marques*

National agroforestry policy design and implementation in India and beyond

Agroforestry is immensely beneficial, yet unfavorable national policies hamper realization of its full socioeconomic and environmental benefit potential. India implemented the world's first National Agroforestry Policy (NAP) in 2014[1]. Besides assisting in policy formulation, World Agroforestry (also called ICRAF) continues to be part of the high level Inter-Ministerial Committee overseeing policy implementation. The latter has: led to the **establishment of a sub-mission on agroforestry with a $146.3 million allocation to facilitate NAP implementation; removed bottlenecks on growing, felling and transporting 650 agroforestry species in 25 Indian states; facilitated upgrading of a national research institute of agroforestry*; and creation of a national bamboo mission with a $197 million allocation**. Further, inclusion of agroforestry in the Indian corporate social responsibility (CSR) portfolio has opened a new window of investment. **More than 260 Indian companies invested around $1.59 billion in 2020.**

Some major practical impacts of NAP include: an estimated 70% timber requirement of the country is being met through agroforestry (valued at about $20 billion); and 'out of forest' tree cover increased by 1.8% over the 2015-2019 period, 86% of which was credited to agroforestry (Figure). Such successes have caused ripple effects in the region and beyond. The Government of Nepal, with support from ICRAF and the Climate Technology Centre and Network (CTCN), developed and launched its NAP in 2019[2] (Photo). FTA evaluated the Nepalese NAP as a high impact initiative[3]. ICRAF has supported the Association of Southeast Asian Nations (ASEAN)[4] and Rwanda to develop agroforestry strategies; and it is currently working with Maldives and some other countries for the same purpose. The ripple effect has even reached Belize, in Central America, which is currently developing its own NAP.

* ICRA-Central Agroforestry Research Institute: http://cafri.res.in



▲ *Direct and mediated impacts of the National Agroforestry Policy (NAP) in India.*

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For further information

(1) Singh V.P., Sinha R.B., Nayak D., Neufeldt H., van Noordwijk M., Rizvi J., 2016. The national agroforestry policy of India: experiential learning in development and delivery phases. ICRAF *Working Paper*. www.worldagroforestry.org/publication/national-agroforestry-policy-india-experiential-learning-development-and-delivery

(2) Climate Technology Centre and Network, Technical support to formulate a National Agroforestry Policy for Nepal (2019). www.ctc-n.org/technical-assistance/projects/technical-support-formulate-national-agroforestry-policy-nepal

(3) CAS Secretariat (CGIAR Advisory Services Shared Secretariat), 2020. *CGIAR Research Program 2020 Reviews: Forests, Trees and Agroforestry*. Rome: CAS Secretariat Evaluation Function: 22-23. https://cas.cgiar.org/sites/default/files/images/FTA%20CRP%20Review%202020%20Report.pdf

(4) ICRAF, 2018. *ASEAN Guidelines for Agroforestry Development*. Association of Southeast Asian Nations, Jakarta. www.recoftc.org/sites/default/files/publications/resources/recoftc-0000330-0002-en.pdf

▲ ***Launch of the National Agroforestry Policy.***
Left to right: Honourable minister, Chakra P. Khanal, Ministry of Agriculture and Livestock Development (MoALD); Secretary of Agriculture, Yubak Dhoj GC; Member, Nepal Planning Commission, DB Gurung; and Javed Rizvi, Director South Asia Program, ICRAF.
© Abiar Rahman/ICRAF

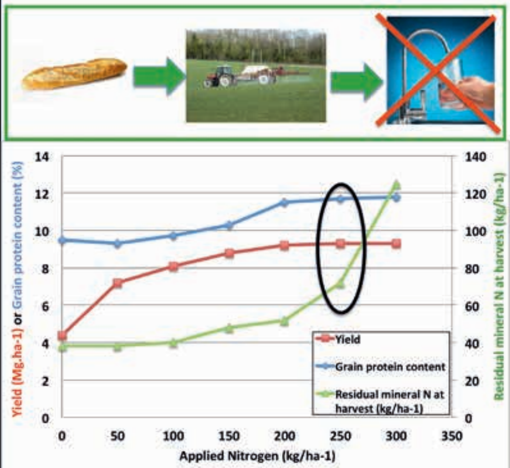
Innovation environment around farms and farming systems

Reconnecting innovation dynamics in agriculture and food sectors

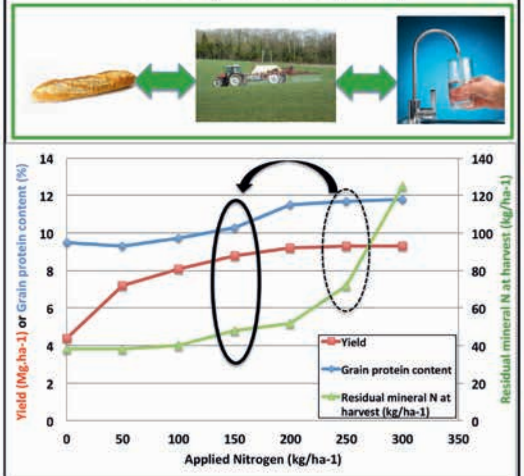
Rather than striving to enhance the sustainability of the agriculture and food sectors separately, reconnecting the innovation dynamics in these two fields is essential. The idea is to solve an agricultural problem by building a change at the food processing step of the value chain, and *vice versa*. For instance, to make high-quality bread, the milling industry currently requires wheat grain with a high protein content. To achieve this, the wheat crop must be supplied with high quantities of nitrogen fertilizer, a part of which is not used by the crop, is lost and likely to pollute the air, surface and ground waters. Yet research on the bread-making process has shown how to make bread with low-protein wheat. This bread-making innovation would enhance the sustainability of agriculture while reducing its negative environmental impacts.

The transition of agrifood systems can only be managed collectively, with close involvement of public authorities. Another example concerns the development of grain legumes in crop rotations in France, with a view to increasing the availability of plant proteins for human consumption, and to reducing (due to symbiotic fixation) fossil energy use and greenhouse gas emissions (CO_2 and N_2O). The potential comeback of legumes in crop fields and on consumers' plates requires a combination of various innovations: cropping systems that incorporate legumes in rotations, mixtures or cover crops; precooked preparations facilitating their use in cooking; organizational innovations for collection and distribution in short supply chains; and productive stress-resistant varieties. These two examples[1,2] demonstrate that **it is essential to design clusters of coupled innovations (i.e. mutually coordinated) involving the different chain links, but also to support the reorganization of stakeholder networks, learning, along with changes in standards and regulations that will facilitate the operational rollout of these innovations.**

Bread manufacturing with current processes requires wheat grain with a high protein content (>11.5%, blue curve), which is achieved through high doses of nitrogen fertilizer (x-axis). This increases the risk of N loss into the environment (green curve, soil mineral N at harvest).



Bread may be produced with low-protein wheat grain, provided that the bread-making process is changed. This could help reduce the risk of N loss into the environment (green curve), without significantly changing the yield (red curve). From Meynard *et al.* (2017)



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For further information

(1) Meynard J.M., Jeuffroy M.H., Le Bail M., Lefèvre A., Magrini M.B., Michon C., 2017. Designing coupled innovations for the sustainability transition of agrifood systems. *Agricultural Systems*, 157: 330-339.

(2) Brun J., Jeuffroy M.H., Pénicaud C., Cerf M., Meynard J.M., 2021. Designing a research agenda for coupled innovation towards sustainable agrifood systems. *Agricultural Systems*, 191(2021): 103143.

Using the options by context approach to support local agroecological innovation

Innovation by large numbers of smallholder farmers will need to accelerate if global commitments to end hunger are to be achieved in the face of climate change and other global changes that are caused by and impact agriculture. Conventional agronomic research and development have involved a research process that produces technologies, which are then promoted for adoption by large numbers of farmers through extension—these research and extension phases are more or less participatory. The performance of agroecological practices, which rely on natural processes rather than making the environment more uniform through forcing monocultures with chemical inputs, varies hugely across the geographical spectrum covered by development programmes, depending on the social, economic and ecological context.

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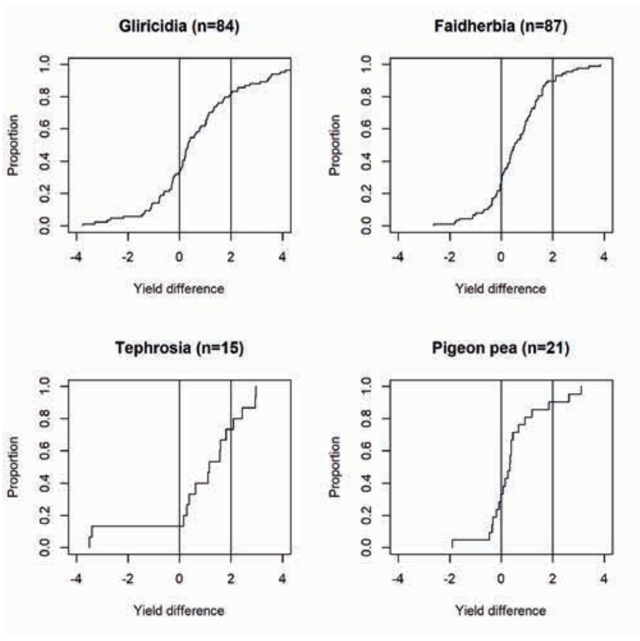

◀ ***Distribution of maize yield differences ($t\ ha^{-1}$) between four agroforestry options (different fertilizer trees in crop fields) and a no tree control, in real farm conditions across Malawi, for a sample of farmers (n) who had adopted the practice for at least 4 years.***
Vertical lines at yield differences of 0 and 2 $t\ ha^{-1}$ are provided for reference, showing that while the majority of farmers obtained up to a 2 $t\ ha^{-1}$ yield advantage some experienced a yield penalty or advantage of > 2 $t\ ha^{-1}$ (up to 4 $t\ ha^{-1}$ with Gliricidia*).*

We illustrate this with an example showing the cumulative proportion of farmers in Malawi achieving yield penalty or benefit from incorporating different fertilizer tree species in their crop fields (Figure, previous page)[1]. **This performance variability limits the viability of recommendations generated for large areas and numbers of farmers. It also highlights the need for new ways of supporting innovation based on the real-world heterogeneity of farmers' circumstances by exploring the contexts in which particular practices perform well[2].** Addressing this widespread options by context interaction (OxC) phenomenon has profound implications for how agronomic research and development are organized[3]. Sixteen papers from a wide range of agricultural research providers have been pooled in a special issue of *Experimental Agriculture*, revealing the nature and implications of such interactions, while suggesting that participatory research is needed in multiple contexts to support locally relevant innovation which is both novel and challenging[4]. **A paradigm shift is underway, with researchers embracing new modes of thinking and action to address OxC interactions, but these also need to be taken up and further developed by public and private sector extension and change agents**. It is only through continued co-development of methods involving both of these constituents, while working closely with farmers, that it will be possible to ascertain which agroecological practices work where and for whom.

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(1) Coe, R., Njoloma, J., Sinclair, F., 2019. Loading the dice in favour of the farmer: reducing the risk of adopting agronomic innovations. *Experimental Agriculture,* 55(SI): 67-83.

(2) Sinclair F., Coe R., 2019. The options by context approach: a paradigm shift in agronomy. *Experimental Agriculture,* 55(S1): 1-13. https://doi.org/10.1017/S0014479719000139

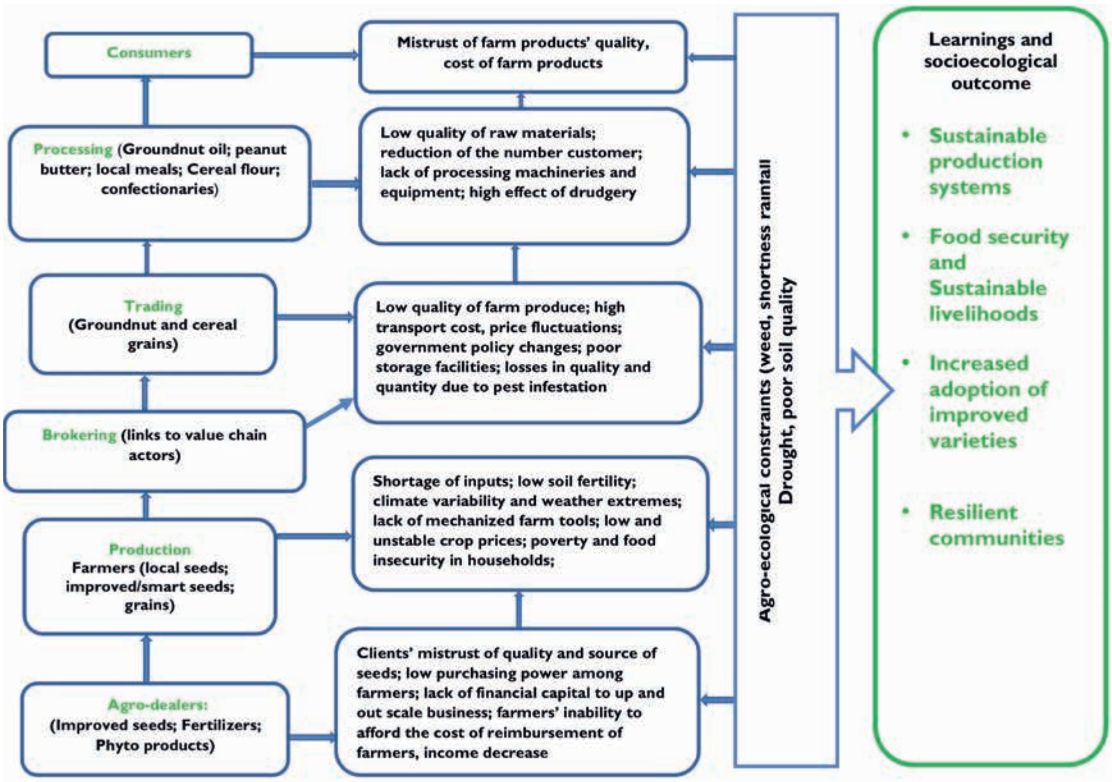
(3) Coe R., Sinclair F., Barrios E., 2014. Scaling up agroforestry requires research 'in' rather than 'for' development. *Current Opinion in Environmental Sustainability*, 6: 73-77. www.sciencedirect.com/science/article/pii/S1877343513001437

(4) Cambridge University Press (eds), 2019. *Experimental Agriculture,* 55(S1). www.cambridge.org/core/journals/experimental-agriculture/issue/B7FAFD0A37A4177E37CD9C5062528DEA

Learning, opportunities and agronomic constraints of smallholder sorghum and groundnut production systems in Mali

The multifaceted climate change, population pressure and natural resource degradation crises underway in West Africa are challenging agroecosystem sustainability, in turn leading to reductions in crop yields and biodiversity, with implications for food and ecosystem security. Two major approaches for enhancing food production have been focused on increasing the 'area under crops' and 'production per unit area'. Plant breeding innovations are geared towards promoting higher yields and efficient resource management (e.g. soil and water). In Mali, groundnut and sorghum are cash and food crops grown under marginal conditions where farming activities rely primarily on manual labour because of a very low mechanization level. Identifying cultivars with climate-smart traits that farmers like can support sustainable production of foods that households depend on, while enhancing agroecosystem management efficiency.

Constraints and opportunities in sorghum and groundnut production systems in Mali were examined alongside how this learning may influence demand-driven breeding to improve food security and sustainable socioecological outcomes. The studies were conducted in 2019 and 2020 among 449 groundnut (224 women/225 men) and 352 sorghum (97 women/255 men) growers randomly selected in Kayes, Koulikoro, Sikasso and Segou regions. The studies aimed to assess farmers' preferences of cultivar traits suitable for the production environment of men and women involved in the production, processing, marketing and consumption of these crops (Figure). The findings revealed that **farmers preferred groundnut and sorghum varieties with traits that can be tailored to and mitigate key production constraints while boosting agroecological system resilience. The sensitivity of varieties to weeds, drought, shorter rainfall seasons and low soil fertility was identified as a major production constraint.** Growing crop varieties that thrive in such marginal environments could lower the need for environmentally disruptive chemical fertilizers and herbicides that threaten production system sustainability. If farmers' preference for high-yielding varieties with low fertilizer requirements, weed and drought resistance traits were to be considered in breeding pipelines, crop productivity, genetic gain and sustainability could be simultaneously enhanced.



▲ *Opportunities and challenges of value chain actors in groundnut and sorghum production systems in Mali.*

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For further information

• Nair P.K.R., 2014. Grand challenges in agroecology and land use systems. *Front. Environ. Sci.*, 2: 1. doi: 10.3389/fenvs.2014.00001

• Nyadzi E., Nyamekye A.B., Werners S.E., Biesbroek R.G., Dewulf A., van Slobbe E., Long H.P., Termeer C.J.A.M., Ludwig F., 2018. Diagnosing the potential of hydro-climatic information services to support rice farming in northern Ghana. *Journal of Life Sciences,* 86: 51-63.

• Shepard D., 2019. De graves répercussions du réchauffement climatique pour l'Afrique. *Afrique Renouveau*, décembre 2018-mars 2019.

Step-by-step co-design of agroecological innovations in dairy farming systems in Burkina Faso

In West Africa, the demand for dairy products is growing rapidly, but local value chains are struggling to emerge due to competition from imported powdered milk. Agroecology offers a promising option for strengthening the competitiveness of local dairy chains by reducing on-farm production costs and promoting the inclusion of actors, especially women, in emerging chains. Since 2005, we have been conducting step-by-step co-design work with milk producers, collectors and processors in the Bobo-Dioulasso region (Burkina Faso) to support them in a change process driven by agroecological values. Our approach involves supporting these actors in technical and organizational 'steps' geared towards redesigning the production system, while also fostering the emergence of an enabling environment for local production. This approach is based on discussion forums involving researchers and local sector stakeholders, and on an *in situ* action research process. At the dairy production systems scale, techniques for the conservation of crop co-products, multipurpose forage crops, shrub fodder banks, a rationing tool for female dairy cattle tailored for pastoral systems and manure management methods were tested. We have assisted dairy sector actors in initiating innovations concerning the organization of collection (efficient and inclusive collection scenarios), and in the pursuit of new outlets (*Wagashi* cheese). These different interventions also gave rise to the Bobo-Dioulasso Dairy Innovation Platform initiated in September 2020. **One of the lessons learned from these 15 years of research is that the art of step-by-step co-design lies in the ability to link initiatives aimed at developing promising agricultural systems and to build an enabling environment that includes policymakers and economic stakeholders driven by the determination to develop local dairy sectors.**

▲ *During a training session on yogurt production with a group of Fulani women (2012, Koumbia, Burkina Faso).* © *E. Vall*

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• Blanchard M., Vall E., Tingueri Loumbana B., Meynard J.M., 2017. Identification, caractérisation et évaluation des pratiques atypiques de gestion des fumures organiques au Burkina Faso : sources d'innovation ? *Autrepart*, 2017/1(81): 115-134. doi: 10.3917/autr.081.0115

• Vall E., Blanchard M., Coulibaly K., Ouédraogo S., Dabiré D., Douzet J.M., Kouakou P.K., Andrieu N., Havard M., Chia E., Bougouma Y.B., Koutou, M., Marambiri M.S., Delma J.D., Sib O, 2019. Co-design of innovative mixed crop-livestock farming systems in the cotton zone of Burkina Faso. *In*: Côte F.-X. *et al.* (éd.): *The agroecological transition of agricultural systems in the Global South.* Agricultures et défis du monde collection, AFD, CIRAD, Éditions Quæ, Versailles: 17-37.

• Sib O., González-García E., Bougouma-Yameogo V.M.C., Blanchard M., Vall E., 2020. Co-development, establishment and assessment of shrub fodder banks for dairy cow feeding in Western Burkina Faso. *Rev. Elev. Med. Vet. Pays Trop.*, 73(1): 27-35. doi: 10.19182/remvt.31841

Designing innovative coffee agroforestry systems

Increased pest pressure, global warming, biodiversity loss and pesticide overuse are major challenges facing world coffee cultivation. Agroecological development of the system must therefore be favoured, while not losing sight of the profitability for producers. Strategies to ensure adaptive management of coffee agroforestry systems have been implemented through an agroforestry-oriented scientific platform(1). This involves adapting plantations (coffee varieties, shade tree species) and management practices (e.g. coffee pruning and/or shade tree pollarding). **Plantation fertilization and shade management can be tailored to the prevailing coffee price situation**, i.e. when prices are high, shading is reduced and fertilization is increased, but when prices drop, denser shading is promoted to increase nutrient recycling while reducing production and production costs. Selection of the best suited coffee varieties is a further strategic tool.

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▲ C. arabica *F1 hybrids planted in agroforestry systems (Matagalpa, Nicaragua).* © *B. Bertrand/CIRAD*

Coffee varieties have until now been selected for very low shading conditions or full sun cultivation. New coffee breeding programs have been geared towards offering varieties specifically adapted to agroforestry system conditions (www.breedcafs.eu). A new F1 hybrid coffee variety called Starmaya(2) has dramatically enhanced coffee productivity, disease-resistance and bean quality in agroforestry systems.

A new concept has been developed to promote these innovations, i.e. **the creation of clusters of growers to jointly produce coffee for roasters that are fully compliant with environmental and agronomic standards while meeting traceablity standards**. Coffee production quality and quantity levels are set according to the requirements of the coffee company, which in return commits to a minimum price. Moreover, agroforestry clusters comply with shade tree planting specifications. A 'business driven' agroforestry cluster is: a terroir + agroforestry practices (Rainforest certified) + fully controlled postharvest processing + 100% traceability.

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(1) Mesoamerican Scientific Platform For Agroforestry: www.pcpagroforestry.com/pcp-researchers.html

(2) Georget F., Marie L., Alpizar E., Courtel P., Bordeaux M., Hidalgo J.M., Marraccini P., Breitler J.-C., Déchamp E., Poncon C., Etienne H., Bertrand B., 2019. Starmaya: the first Arabica F1 coffee hybrid produced using genetic male sterility. *Frontiers in Plant Science*, 10: 1344. doi:10.3389/fpls.2019.01344

(3) https://dailycoffeenews.com/2017/03/13/new-starmaya-hybrid-could-reshape-the-industry-says-world-coffee-research/

(4) www.cirad.fr/en/news/all-news-items/articles/2019/science/agroforestry-clusters-a-model-to-complement-fair-trade

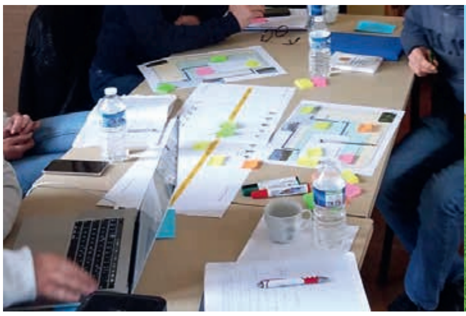
IDEAS platform

Supporting actors and researchers in designing innovations enhancing the agroecological transition

The much-needed agroecological transition of agrifood systems, which are now facing multiple challenges, calls for unprecedented changes: (i) systemic and disruptive innovations; (ii) involvement of actors from the entire agrifood system in designing and assessing solutions, and, most often; (iii) revamped coordination of activities and relationships between these actors, including researchers. Innovative design, in open innovation systems, has proven to be a relevant approach to combine these three objectives and foster innovation to feed transitions towards greater sustainability, even if this approach is still uncommon and not well handled by agrifood system actors. Based on a network of scientists focusing research on and for design, through interdisciplinary projects (agronomy, food sciences, social sciences), **the IDEAS platform, supported by INRAE and AgroParisTech, aims to raise awareness and provide training in innovative design and its use in research and innovation activities, while supporting agrifood system actors in implementing the approach in renewed innovation ecosystems.** It offers researchers and socioeconomic actors *methods* to: (i) spur the creativity of agrifood system stakeholders (*innovation tracking, co-design workshops*); (ii) facilitate the dialogue regarding desired and possible achievements from the actors' standpoint (*diagnosis of uses, step-by-step design, prototype testing under real-life conditions*); (iii) produce, hybridize and formalize disseminated expert and scientific knowledge (*digital design-support tools*); (iv) imagine new modes of production or processing, and changes in activity, required to implement them (e.g. *land-use scenarios*); and (v) analyze actors' strategies, networks and knowledge (*diagnosis of the sociotechnical system*) in order to enhance new design organization strategies fostering systemic and disruptive innovations.

▲▶ *Designing coupled innovations for legume-based crop and food.*
© C. Gallagher and B. Schugt, 2012

▼ *Designing innovative farming systems targeting improved water quality management.* © R. Reau



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• IDEAS platform, Initiative for Design in Agrifood Systems: www6.inrae.fr/ideas-agrifood

• Meynard J.M., Jeuffroy M.H., Le Bail M., Lefèvre A., Magrini M.B., Michon C., 2017. Designing coupled innovations for the sustainability transition of agrifood systems? *Agricultural Systems*, 157: 330-339. http://dx.doi.org/10.1016/j.agsy.2016.08.002

• Cerf M., Jeuffroy M.H., Prost L., Meynard J.M., 2012. Participatory design of agricultural decision support tools: taking account of the use situations. *Agron. Sustain. Dev.*, 32(4): 899-910.

Gender sensitivity and responsiveness to accelerate innovation adoption in crop improvement programs

Sorghum is a highly valued income-generating food security crop that supports the livelihoods of many people in Mali and other West African countries. More than 50% of the farming population are involved in sorghum production, constituting up to 5-7% of all full-time jobs. Despite its importance, sorghum is produced under marginal and unpredictable climate conditions, with institutional regulations and norms that control women's and men's participation in the crop value chain. **Gender-specific crop trait preferences are seldom studied, understood or prioritized in breeding programs.** Given that farmers are the main beneficiaries of the breeding products, there is a growing need to understand their needs and preferences in order to develop varieties that meet end-users' needs/demands.

With growing concern regarding the low adoption of new improved varieties, this study examined the trait preferences of men and women actors in key sorghum value chains and, on the basis of the findings, generated evidence based information that could support gender-sensitive and demand-driven breeding initiatives. Using the value chain approach and mixed methods (semi-structured surveys, focus group discussions (FGDs) and key informant interviews (KIIs), data was collected from the main sorghum production areas in Mali (Koulikoro, Sikasso and Ségou) from 343 producers, 34 traders, 139 processors, 57 consumers, and 224 FGD and KII participants, for a total sample size of 797 respondents. The aim was to gain insight into why and how different groups and value chain actors make decisions on sorghum varieties and how these decisions can influence breeding product adoption. **The study identified preferred crop traits important for male and female value chain actors and which could be reflected and prioritized when designing new sorghum cultivars.** The findings revealed that, while the traits were almost identical between men and women in terms of marketing, processing and consumption preferences, there was clear trait differentiation at the production level, i.e. women preferred traits related to food preparation and quality while men preferred high yield, early maturity, drought resistance, pest and disease resistance. **Hence, varietal choice is related to resources and responsibilities differentially shared by men and women involved in sorghum production.**

◀ *Women processors working in a cereal processing mill in Karangana, Sikasso region of Mali, (29 November 2019). © A. Sylla/ICRISAT-Mali*

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CGIAR Gender and Breeding Initiative. *Gender-Responsive product profile development tool.* Workshop Report. November 12-13, 2018. Ithaca, USA. https://cgspace.cgiar.org/handle/10568/99094

Sorghum VC Segments	Driver	Three most important traits		Agro-zones
		Female	Male	
Farmers	Productivity	Yield (77%) Adaptable to low fertilizer requirement s (92%)	Yield stability (90%) Yield (51%) Early maturity (91%)	600 mm-1400 mm (Sudanese and Sahelian agrozones)
	Biotic stress resistance	-	Resistance to weeds (94%) Resistance to striga (87%) Resistance to diseases/ pests (94%)	600 mm-1400 mm (Sudanese and Sahelian agrozones)
	Grain quality & food quality	Easy for threshing (93%) Food consistency (92%) Food yield (91%)	Grain quality (77%)	600 mm-1400 mm (Sudanese and Sahelian agrozones)
	Abiotic stress resistance	Drought resistance (92%)	Drought resistance (82%)	600 mm-1400 mm (Sudanese and Sahelian agrozones)
Traders	Grain quality	Large grain size (98%) White grain color (96%) Absence of testa (100%)	Large grain size (100%) White grain color (100%) Absence of testa (100%)	600 mm-1400 mm (Sudanese and Sahelian agrozones)
	Architecture	Glume openness (96%)	Glume openness (100%)	600 mm-1400 mm (Sudanese and Sahelian agro-zones)
	Storability	Grain storability (90%)	Grain storability (95%)	600 mm-1400 mm (Sudanese and Sahelian agrozones)
Processors	End-product quality	Food yield (89%) Consistency (88%) Grain diverse utilization (74%)	Food yield (95%) Consistency (95%) Grain diverse utilization (94%)	600 mm-1400 mm (Sudanese and Sahelian agrozones)

▲ *Proposed gender sensitive sorghum customer product profile based on trait preferences data collected from regions of Koulikoro, Sikasso and Segou (Mali), November-December 2019.*

Role of markets to re-establish a more direct connection between producers and consumers

Linking urban consumers with rural producers through social businesses in Nairobi

▲ *Peanut stands in an informal street market in Mathare, Nairobi.* © I. Edel

Just about everyone eats peanuts in Kenya. They are used to make sauces and peanut butter, and are also a popular snack. These legumes are rich in protein, essential minerals, fat and are therefore key sources of energy. However, depending on the season, aflatoxins may develop on the outside and inside of the kernels. Aflatoxin prevalence on peanuts is high in the slums, which are home to 60-70% of the total urban population. Aflatoxins are carcinogenic and contribute to stunting in children. In Kenyan slums, stunting levels remain higher than the national average. How would it be possible to offer quality peanuts to low-income consumers on informal markets? Informal markets (i.e. unregulated and unprotected street food vendors and small shops) are an integral component of the foodscape in slums. We co-create ways to streamline relations between producers and urban consumers in Kenya through an agroecological lens.

As part of a partnership with Greenforest Foods Limited, a Kenyan peanut processor, ICRISAT is developing a business-to-sales model for aflatoxin-tested peanuts. The goal is to supply affordable safe peanuts to Mathare —a Nairobi slum with over 400,000 inhabitants— whilst maintaining distribution systems involving street food vendors, hawkers and small shops. Inspired by the solidarity economy, Greenforest builds value chains linking rural Kenya and Mathare, while ICRISAT supports Greenforest with expertise in agroecology, aflatoxin testing and quality management. Greenforest supports farmers in Baringo and Elgeyo Marakwet counties transitioning towards agroecology-compliant peanut production, e.g. effective seed selection, organic soil management, crop rotations while reducing external inputs. In 2021, we conducted market studies in Mathare and the results revealed low awareness of aflatoxin among consumers and vendors/retailers. **This highlights the need for increased awareness on food safety to reduce the risk of aflatoxin exposure through informal markets.** We also explore **ways for establishing direct connections between consumers and producers via a participatory guarantee system (PGS) while helping co-create sustainable linkages between producers and consumers. PGS creates trust between all value-chain actors.** Although limited to one slum, the scheme will potentially deliver safe peanuts to 10,000 consumers. This case study should provide stepping stones for scaling the impact pathway to accessible, high quality, nutritious, healthy peanuts to other low-income markets across Kenya.

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• African Population and Health Research Center (APHRC), 2014. *Population and health dynamics in Nairobi's informal settlements: report of the Nairobi cross-sectional slums survey (NCSS) 2012.* APHRC, Nairobi.

• Mupunga I., Mngqawa P., Katerere D.R., 2017. Peanuts, aflatoxins and undernutrition in children in Sub-Saharan Africa. *Nutrients*, 9(12): 1287.

Towards hybrid governance of the cocoa sector in Cameroon to enhance economic and environmental sustainability

The cocoa sector is facing a growing demand—mainly from European markets—to demonstrate the legality of its production, its sustainability and the neutrality of its impact on tropical forests. In Cameroon, the certification of cocoa according to private standards could be an effective way to facilitate the production of legal, sustainable and zero-deforestation cocoa. We tested this hypothesis by studying the impact of cocoa certification (UTZ-Rainforest Alliance, sustainable agriculture standard for farm and producer groups, v1.2, 2017) on the livelihoods of smallholder farmers (owning a cocoa plantation of 0.5-5 ha), who contribute to almost 90% of Cameroon's production.

Three production systems for smallholder cocoa farmers were compared:

1. Non-certified small producers have a net profit rate of 4% and an added value of FCFA471,984/t. This mode of cocoa production is a low profit-making activity and weakened by an increase in production costs.
2. Producers in shaded agroforests involved in certification receive support from purchasing companies of around FCFA80,000/year, thereby enhancing their financial performance. Their net profit rate is 24%. The added value is estimated at FCFA486,102/t.
3. Grassland farmers in the Mbam region involved in certification have much higher production costs than cocoa farmers in forest areas. The monetarization of certain costs lowers the net profit rate, which amounts to 15%, but reinforces the added value, which stands at FCFA660,544/t.

Certification can therefore be highly advantageous for smallholders by offering a higher purchase price for cocoa and above all by improving production through targeted support in terms of training, equipment and inputs. Overall, it has superseded the State in providing actual support to small producers.

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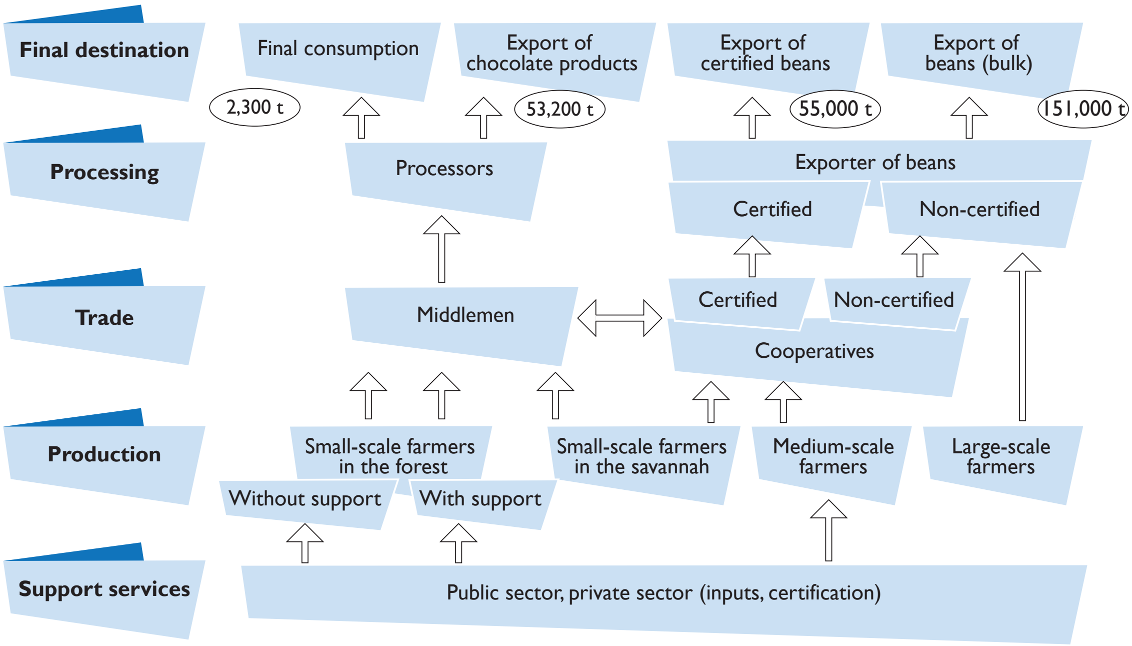

▲ *The main flows of the cocoa value chain in Cameroon in 2019. Source: Lescuyer* et al. *(2020)*

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• Camargo M.C., Hogarth N.J., Pacheco P., Nhantumbo I., Kanninen M., 2019. Greening the dark side of chocolate: a qualitative assessment to inform sustainable supply chains. *Environmental Conservation*, 46: 9-16.

• Lescuyer G., Boutinot L., Goglio P., Bassanaga S., 2020. *Analysis of the cacao value chain of Cameroon*. European Commission Report, DG-DEVCO, Value Chain Analysis for Development project, Brussels, 121 p. + annexes.

• Nlend Nkott A.L., Mathé S., Temple L., 2019. Analyse multi-niveaux des freins à l'adoption de la certification du cacao au Cameroun. *Économie rurale*, 370: 81-99.

Consumer preference for rice with ecological, social and health certification labels

Agroecological food production seeks to optimize interactions between humans and the environment, with consideration of social aspects that create a sustainable and fair food system. In Vietnam, the rice sector is characterized by a high carbon footprint, pesticide overuse and low farm labor wages(1). Reducing these negative impacts while also ensuring food sovereignty is essential to agroecological rice production. The importance of conveying these, along with health attributes, to rice consumers through food labels has been well documented(2). However, these components are often treated as a single sustainability attribute and relatively little research has been conducted to unravel the relative weight consumers place on individual traits driving their purchasing decisions.

We conducted a choice experiment with 410 supermarket patrons to analyze Vietnamese consumers' relative preferences and willingness-to-pay for four rice certification labels: low-emission, eco-friendly, ethically produced, and low glycemic index (Figures A and B). The results showed that **consumers were willing to pay a price premium for all certification labels, with the highest added value being a 66% increase in price for the low glycemic index trait in rice.** The findings for eco-friendly and ethical production labels were similar, with a price premium of just over 50%, while low-emission rice had a comparatively lower, yet still positive, value for consumers, with a 28% price increase. **Garnering a premium for rice produced according to agroecological principles helps ensure economic sustainability for producers, in turn prompting them to adopt practices that have widespread collective social and environmental benefits.** The results of this study could be used to gain further insight into the consumer value of different certification labels and to guide future policy and market recommendations promoting sustainably produced and healthier food, which is a crucial step in shifting food systems towards an agroecology paradigm.

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(1) Stuart A.M., Devkota K.P., Sato T., Pame A.R.P., Balingbing C., Phung N.T.M., Kieu N.T., Hieu P.T.M., Long T.H., Beebout S., Singleton G.R., 2018. On-farm assessment of different rice crop management practices in the Mekong Delta, Vietnam, using sustainability performance indicators. *Field Crops Research*, 229: 103-114.

(2) My N.H., Demont M., Van Loo E.J., de Guia A., Rutsaert P., Tuan T.H., Verbeke W., 2018. What is the value of sustainably-produced rice? Consumer evidence from experimental auctions in Vietnam. *Food Policy*, 79: 283-296.

Alternative A		Alternative B		Status Quo	
Low-emission		Low-emission	•	Low-emission	
Eco-friendly		Eco-friendly	•	Eco-friendly	
Ethically produced	•	Ethically produced		Ethically produced	
Low glycemic index	•	Low glycemic index		Low glycemic index	
Price (VND/kg)	24,000	Price (VND/kg)	22,000	Price (VND/kg)	20,000
- Ethical production meets safe and fair working conditions - Low glycemic index ensures a slower release of energy		- Low-emission has a reduced carbon footprint - Eco-friendly meets strict pesticide regulations			
					

▲ *Figure B. Cards showing alternative choices between rice labeled with different combinations of sustainability and health certifications at different price points and status quo rice with no certification labels.*

▲ *Figure A. Examples of certification labels representing, from left to right: ethical, low-emission, eco-friendly, and low-glycemic index rice.*

Leveraging nutrition objectives and food traditions for agroecology

Benefits of underutilized crop species to improve nutrition

Despite progress in mainstream agriculture, roughly 800 thousand people remain hungry and 2 billion suffer from micronutrient deficiencies, while overweight and obesity rates are increasing. Neglected and underutilized species (NUS) often have better nutrient content than generally adopted imported, counterparts and contain health-protective secondary metabolites which other crops might have lost during breeding. A highly diverse range of traditional foods can be considered NUS, including nutritious fruits, vegetables, nuts and pulses or whole grains that are currently consumed in insufficient quantities by populations to ensure protection against diet-related chronic diseases. Diet modelling studies have shown that integrating NUS in local diets could contribute to closing nutrient gaps and reduce the cost of nutritious diets[4].

Agroecology offers a holistic approach to help promote NUS production, marketing and consumption. Based on the 13 agroecological principles and focused on NUS consumption and nutrition: (i) agroecology fosters traditional knowledge, while substantial NUS production, harvesting, preservation, preparation and consumption knowledge remains confined to local populations[3]; (ii) agroecology promotes production diversity, including NUS production, which contributes to dietary diversity and thus quality; e.g. diversifying with traditional leafy vegetables, legumes and poultry in a community-led project significantly increased young child dietary diversity in Kenya[1]; (iii) agroecology—through its movement function—promotes social capital which in turn fosters: (a) exchange of NUS seeds and foods; (b) sharing of knowledge on NUS characteristics such as organoleptic qualities, recipes and health benefits; (c) dissemination of general information on healthy diets; (iv) agroecology promotes networks and alternative inclusive markets for nutritious NUS products to reach consumers in an equitable and safe way; and finally (v) in a study in Ecuador, agroecology fostered consumption of self-grown produce, thereby reducing purchases of ultra-processed unhealthy foods in convenience stores[2].

▲ *Display of food agrobiodiversity from the Cachilaya community, Bolivia.* © G. Meldrum/Bioversity International

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(1) Boedecker J., Oduor F., Lachat C., Van Damme P., Kennedy G., Termote C., 2019. Participatory farm diversification and nutrition education increase dietary diversity in Western Kenya. *Maternal and Child Nutrition*, 15(3): e12803.

(2) Deaconu A., Berti P.R., Cole D.C., Mercille G., Batal M., 2021. Agroecology and nutritional health: a comparison of agroecological farmers and their neighbors in the Ecuadorian highlands. *Food Policy* (in press).

(3) Padulosi S., Thompson J., Rudebjer P., 2013. *Fighting poverty, hunger and malnutrition with neglected and underutilized species (NUS): needs, challenges and the way forward.* Bioversity International, Rome.

(4) Sarfo J., Keding G.B., Boedecker J., Pawelzik E., Termote C., 2020. The impact of local agrobiodiversity and food interventions on cost, nutritional adequacy, and affordability of women and children's diet in northern Kenya: a modeling exercise. *Frontiers in Nutrition*, 7: 129. doi.org/10.3389/fnut.2020.00129

Diversifying crop and livestock production and arboriculture to foster varied diets and ensure food and nutrition security

African farm households are often hampered by food and nutrition insecurity, even in regions with relatively high agricultural production levels. This is the case in the cotton and cereal growing areas of Mali and Burkina Faso, where food systems do not provide enough quality food for farmers to stay healthy[1]. This situation—which is surprising at first glance—could be explained by: (i) the increase in women's farming work, which comes with new responsibilities without any direct benefits because of their subordinate status in the household; (ii) the reduction in the amount of space available for new cropfields and the limited rights of access to natural areas where food may be harvested; (iii) the specialization of production systems; and (iv) the lack of healthy food products with a sufficiently high nutrient content while remaining affordable on rural consumer markets[2].

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▲ *Women farmers in a cashew orchard, Burkina Faso.* © A. Lourme-Ruiz, 2014

These different factors are conducive to a poorly diversified diet. Two recent studies conducted in western Burkina Faso revealed that the daily diet of 80% of women does not meet their micronutrient needs[3]. Women living on farms with more nutritionally diversified production (including crops and agroforestry trees) generally have a more varied diet (self-consumption). Yet since access to markets or to natural areas cannot offset the lack of crop diversity, women on specialized farms (cotton) have a less diversified diet[4]. **In these regions, it is recommended that—to develop farming systems that are 'nutrition-sensitive' or at least likely to adequately feed women farmers—crops should be diversified according to their nutritional features.**

For instance, market garden crops should be promoted when water supplies are available, trees bearing highly nutritional seeds could be planted, and leguminous crops such as cowpeas could be produced in the light of their many agronomic benefits (atmospheric nitrogen sequestration, animal feed). More generally, agricultural biodiversity has nutritional, agronomic and ecological benefits, but systems for assessing the services provided by this agrobiodiversity are still siloed and would warrant interdisciplinary dialogue (agronomy, nutrition, ecology)[4].

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(1) Dury, S., Bocoum, I., 2012. Le paradoxe de Sikasso (Mali) : pourquoi « produire plus » ne suffit-il pas pour bien nourrir les enfants des familles d'agriculteurs ? *Cahiers Agricultures*, 21(5): 324-336.

(2) Lourme-Ruiz A., Maugérard E., 2014. *Le paradoxe des Hauts Bassins : produire plus pour nourrir mieux ?* Film documentaire (41 min), CIRAD, Montpellier, France. https://vimeo.com/120670833

(3) Lourme-Ruiz A., Dury S., Martin-Prével Y., 2016. Consomme-t-on ce que l'on sème ? Relations entre diversité de la production, revenu agricole et diversité alimentaire au Burkina Faso. *Cahiers Agricultures*, 25(6): 11.

RELAX project, Promoting resilience in African rural households: Food systems at a crossroads: https://relax.cirad.fr/le-projet/presentation

(4) Lourme-Ruiz A., Dury S., Martin-Prével Y., 2021. Linkages between dietary diversity and indicators of agricultural biodiversity in Burkina Faso. *Food Security*. https://doi.org/10.1007/s12571-020-01137-5

Delivering diversified diets year-round with customized food tree portfolios

Smallholder food production in sub-Saharan Africa is dominated by starchy staple crops. The availability of micronutrient-rich crops like fruits and vegetables is highly season-dependent, which is one reason for the low consumption. Limited value chain infrastructure, issues of affordability and lack of consumer awareness also hamper adequate consumption. Trees provide almost 60% of fruits globally, constituting an important supplier, particularly in local food systems. When considering production seasonality, tree food portfolios could be promoted to ensure year-round harvests and deliver key micronutrients for diets[1]. Through an iterative process, portfolios are codeveloped with local communities based on their species preferences, food priorities, income and other uses, and are customized for site suitability. Standardized tools, including surveys, are used to gather information on farm production diversity and food consumption, in addition to focus group discussions conducted to determine species for inclusion, their months of availability and nutritional value. This agroecological approach helps generate tailored recommendations for the cultivation of a diverse range of food tree species (including underutilized species), along with vegetables, pulses and staple crops. In addition to filling harvest gaps, certain nutrient gaps are addressed by mapping the nutritional value of selected species using food composition data.

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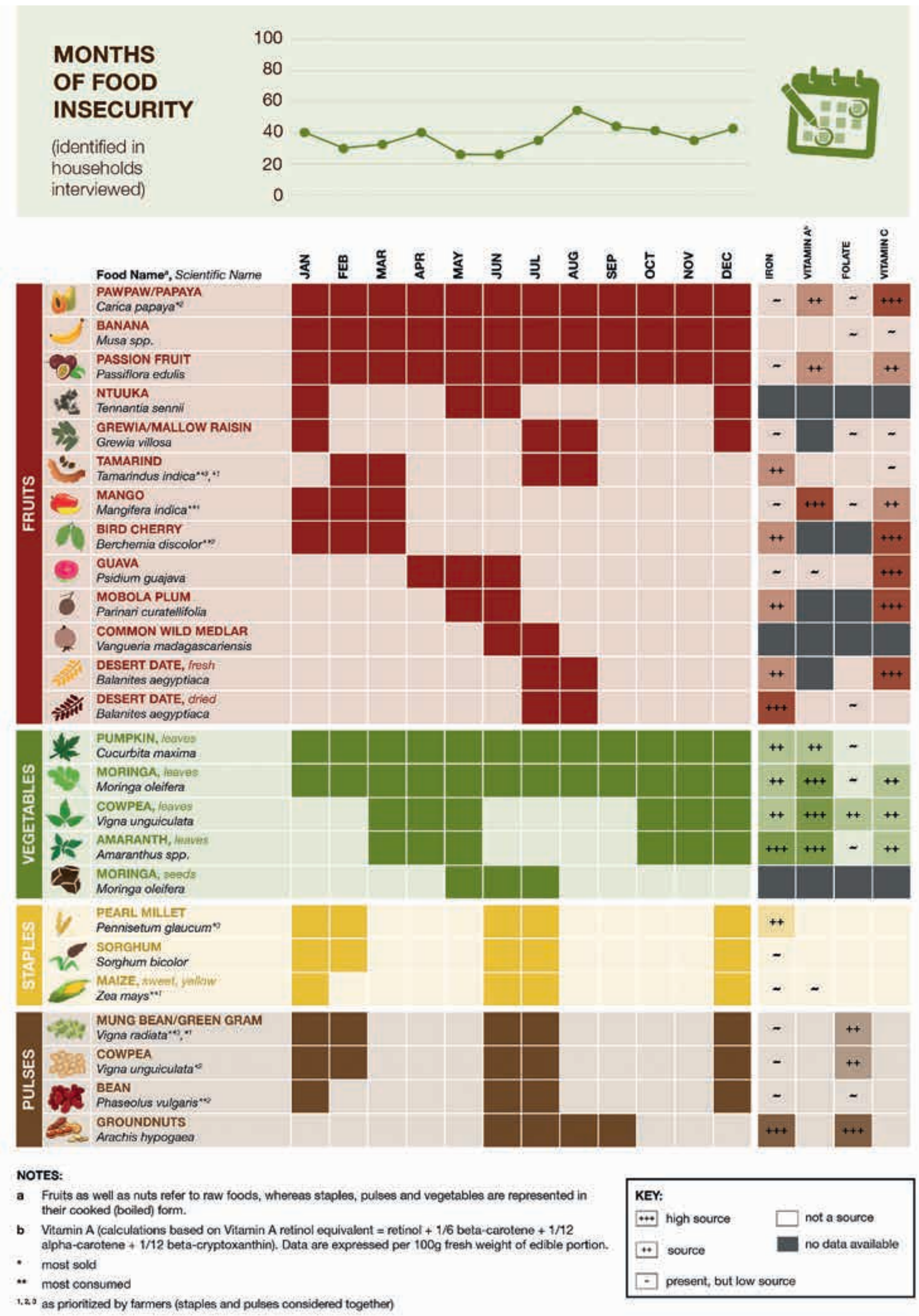

▲ ***Customized food tree portfolio for Igambe Ngombe, Tharaka Nithi County, Kenya.***
A diversity of food tree species, along with complementary vegetable, pulse and staple crops are prioritized with local communities, and mapped for their months of seasonal availability, and micronutrient values to address seasonal food harvest and micronutrient gaps in local diets. © ICRAF

Key micronutrients, vitamins A and C, iron and folate are prioritized to address public health concerns on the basis of their supportive functions and natural high quantity in tree foods. To simplify nutrition information, a scoring system accompanies the customized portfolios to support the species selection. However, this data is limited with regard to underutilized species —a knowledge gap due to inadequate investment and hence research is hampering a full contribution of these species in local food systems. Portfolios are promoted to communities through innovation hubs and school programmes in which agronomic and nutrition information is shared and access to quality planting material is facilitated. Quality seed and seedlings are essential for successful production, with attention focused on delivery systems for planting material being a key success factor for mainstreaming underutilized or 'orphan crops'[2]. **The customized portfolios enhance seasonal food resilience and diversified diets in local food systems.**

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For further information

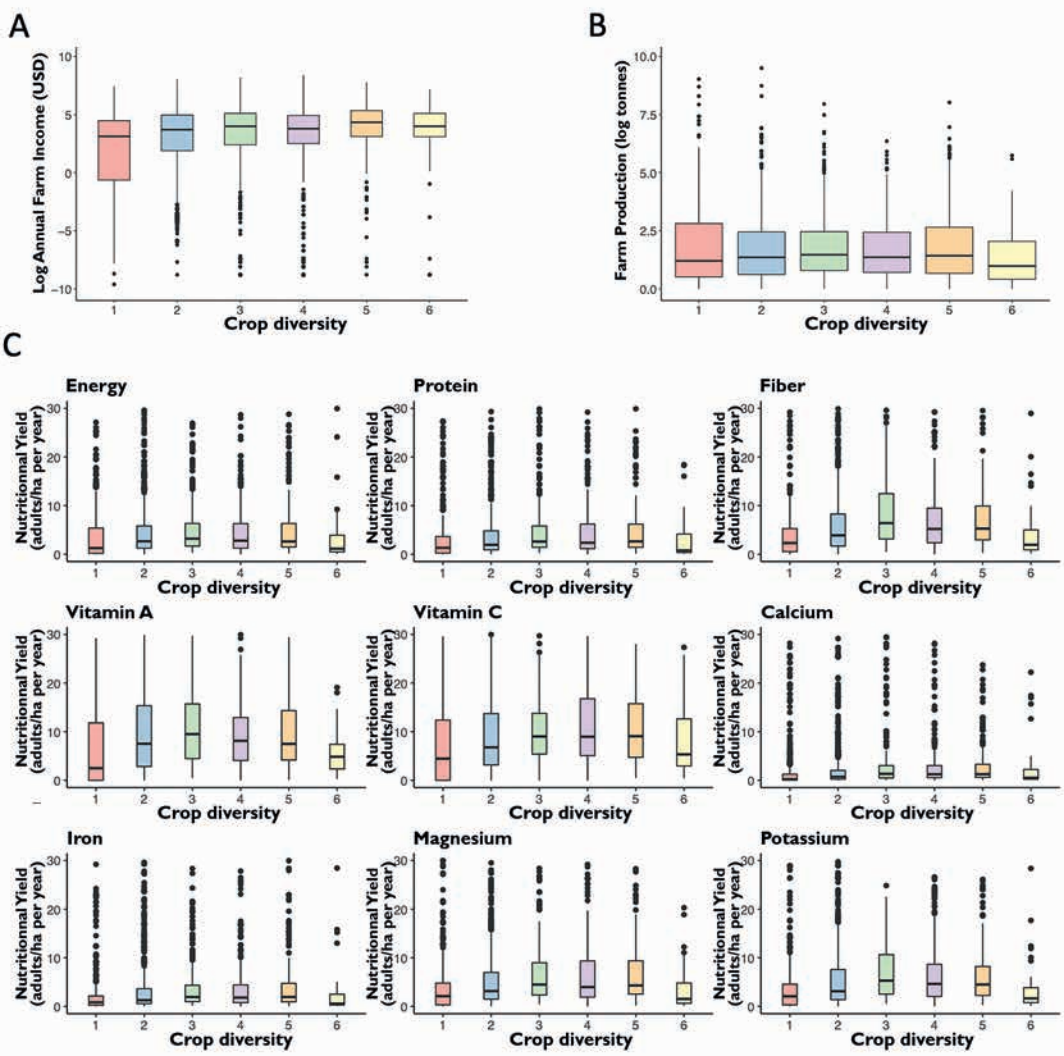
(1) McMullin S., Njogu, Wekesa B., Gachuiri A., Ngethe E., Stadlmayr B., Jamnadass R., Kehlenbeck K., 2019. Developing fruit tree portfolios that link agriculture more effectively with nutrition and health: a new approach for providing year-round micronutrients to smallholder farmers. *Food Security*, 11: 1355-1372. https://doi.org/10.1007/s12571-019-00970-7

(2) McMullin S., Stadlmayr B., Mausch K., Revoredo-Giha C., Burnett F., Guarino L., Brouwer I.D, Jamnadass R., Graudal L., Powell W., Dawson I., 2021. Determining appropriate interventions to mainstream nutritious orphan crops into African food systems. *Global Food Security*, 28. https://doi.org/10.1016/j.gfs.2020.100465

Synergies and tradeoffs between crop diversity, nutritional yield and farm income in the Central Africa Great Lakes Region

Managing biodiversity and economic diversification are two key principles of agroecology[1]. Diversified farming systems aim to integrate ecological and economic benefits for sustainable agriculture[2]. However, it is sometimes hypothesized that there might be a tradeoff between crop diversity and productivity or income[2,3]. Ecological-economic performance of farming diversification practices are highly context dependent[2]. Using data from the CIALCA-Base[4], we assessed this hypothesis for the African Great Lakes context. The CIALCA-Base is a dataset developed over 10 years of research in Rwanda, Burundi and the Democratic Republic of Congo as part of the Consortium for Improving Agricultural Livelihoods in Central Africa (CIALCA)* which contains **household and agricultural information from more than 4,000 agricultural households in Rwanda, Burundi and DRC[4]**. When analyzing the CIALCA-Base at the farm scale, **no tradeoffs between crop diversity and income or between crop diversity and total productivity were identified** (Figures A and B). To complement this, we also analyzed the relationship between farm-scale crop diversity and nutritional yield, for nine macro- and micronutrients. Here we found an 'n' trend of farm-scale crop diversity and nutrient yields, with nutritional yields being highest on farms cultivating three to four crops and lowest on those cultivating one or six crops (Figure C). **The outputs of this work suggest that managing farm-scale crop diversity could be beneficial for nutritional yields without a tradeoff on total yield or income.**

* CIALCA: www.cialca.org



◀ ***The relationships in the CIALCA Great Lakes context between: income log USD (international 2019) (fig. A) and crop diversity, total farm production log ton and crop diversity (fig. B), nutritional yields (number of adults who obtain 100% of their RDA/ha/year) and crop diversity (fig. C).***
The figure was designed by the authors based on data from the CIALCA-base, containing >4,000 smallholder farms in the Great Lakes Region in DR Congo, Rwanda and Burundi.

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(1) HLPE, 2019. *Agroecological and other innovative approaches for sustainable agriculture and food systems that enhance food security and nutrition.* A report by the High Level Panel of Experts on Food Security and Nutrition of the Committee on World Food Security, Rome.

(2) Rosa-Schleich J., Loos J., Mußhoff O., Tscharntke T., 2019. Ecological-economic trade-offs of diversified farming systems – A review. *Ecological Economics*, 160: 251-263. https://doi.org/10.1016/j.ecolecon.2019.03.002

(3) Mugwanya N., 2019. Why agroecology is a dead end for Africa. *Outlook on Agriculture*, 48(2): 113-116. doi:10.1177/0030727019854761

(4) CIALCA-Base indicators: https://cialca.shinyapps.io/cialca_base_2files

Reconnecting consumers and producers through information on alternative food networks

Reconnecting consumers and producers through alternative food networks is a key stage in the transition towards sustainable food systems based on localness, equity and justice[2]. Interventions which: strengthen the evidence-base on the nutritional value of diverse foods; establish supportive enabling policies and markets that incentivize family farmers and their agroecological products; and creatively use and celebrate food diversity that is nutritious, tasty and culturally relevant, help bring this reconnection closer. The Biodiversity for Food and Nutrition (BFN) project*, using a stakeholder-inclusive and cross-sectoral approach in Brazil, Kenya, Sri Lanka and Turkey, demonstrates how countries can fast track this transition through recent achievements and lessons learned[1,3]. **Collectively, the four countries have determined the nutritional value of almost 200 native food plant species, while making this data available through national databases and the global FAO/INFOODS database. This knowledge has been used in many novel ways.** The first official Brazilian Native Food Species of Nutritional Value list was recently compiled—this ordinance officially defines and recognizes over 100 native food species. This has helped target already existing supportive policies for agroecology and procurement markets (e.g. the National School Feeding Programme), which provide incentives for family farmers and agroecological products. The ordinance also supports the development of quality labels recognizing family farming and *Quilombos do Brasil* food products, while recognizing culturally relevant foods in national food-based dietary guidelines. In Kenya, schools were identified as new emerging markets for smallholder farmers using agroecological practices to supply biodiverse foods for school meals. Collaboration with celebrity chefs, education, school gardens and public awareness and food fairs, such as the *Alaçatı* Festival in Turkey and *Helabojun* food outlets in Sri Lanka that enhance women's livelihoods, have all helped raise the profile of food diversity, reconnect producers and consumers and promote healthy sustainable diets.

▲ ***Working with nutritionists and celebrity chefs to develop novel recipes using traditional foods has renewed interest in forgotten foods.*** *© S. Landersz/BFN Project/Alliance of Bioversity International and CIAT*

* BFN project: www.cgiar.org/innovations/biodiversity-for-food-and-nutrition/

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(1) Gee E., Borelli T., Beltrame D.M.O., Oliveira C.N.S., Coradin L., Wasike V., Manjella A., Samarasinghe G., Güner B., Tan A., *et al.*, 2020. The ABC of mainstreaming biodiversity for food and nutrition. Concepts, theory and practice. *In* Hunter D., *et al.* (eds): *Biodiversity food and nutrition. A new agenda for sustainable food systems.* Routledge: Abingdon, UK.

(2) Gliessman S.R., 2007. *The ecology of sustainable food systems.* CRC Press, Taylor & Francis New York, US.

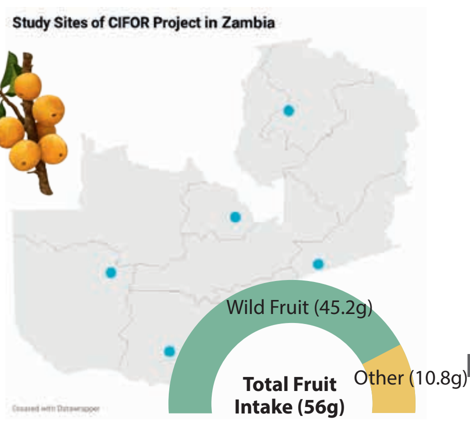
(3) Hunter D., Borelli T., Beltrame D., Oliveira C., Coradin L., Wasike V., Mwai J., Manjella A., Samarasinghe G., Madhujith T., Nadeeshani H., Tan A., Tugrul Ay S., Güzelsoy N., Lauridsen N., Gee E., Tartanac F., 2019. The potential of neglected and underutilized species for improving diets and nutrition. *Planta,* 250(3): 709-729.

(4) Hunter D., Borelli T., Gee E., 2020. *Biodiversity, food and nutrition: a new agenda for sustainable food systems.* Routledge, UK. https://cgspace.cgiar.org/handle/10568/108172

Wild fruit from forests in Zambia

Many people collect and consume wild foods from forests all over the world. Collection of wild foods can be seen as part of a continuum with agroecology as many wild food sources are managed by communities in their natural habitats (especially forests), while agroecology-oriented farmers manage natural processes in their cultivated fields. In addition, many wild food sources can be domesticated, and form part of agroecology's on-farm portfolio. However, quantitative data on wild foods, including variations in collection patterns within countries, are seldom accounted for in national or international statistics. The sustainable management of the forest and agricultural land resources that supply these foods is key, and agroecology can contribute to this objective. Quantifying the degree to which wild foods are harvested, managed and consumed can inform both agroecological policies and national food security and nutrition programs.

In 2019, CIFOR in collaboration with the Food and Agriculture Organization of the United Nations (FAO), carried out a research project to measure the collection and consumption of wild foods across Zambia. The study used a 1-year recall period to capture the seasonal nature of most wild foods, and an innovative method to ensure that household collecting units were quantified correctly. The project was carried out in five areas encompassing all agroecological zones of the country. We found that, in a sample of 209 households, **wild fruits from forests contributed approximately 80% to total fruit intake and to about 25% of recommended fruit intake,** i.e. Zambians are very far from meeting nutritional recommendations on fruit consumption (see figure). **This highlights the importance of conserving and sustainably managing forests and agroecosystems that can produce these foods.**



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• Bélanger J., Pilling D. (eds.), 2019. *The state of the World's biodiversity for food and agriculture.* FAO Commission on Genetic Resources for Food and Agriculture Assessments. FAO, Rome, 572 p. www.fao.org/3/CA3129EN/CA3129EN.pdf

• Rowland D., Ickowitz A., Powell B., Nasi R., Sunderland T., 2017. Forest foods and healthy diets: quantifying the contributions. *Environmental Conservation,* 44(2): 102-114.

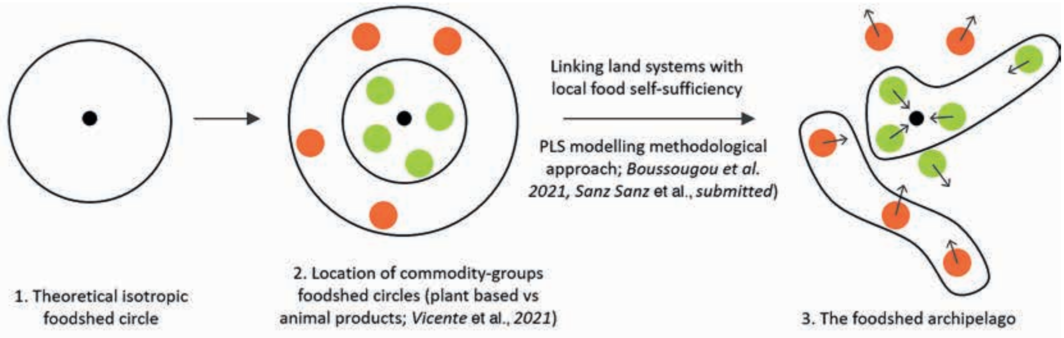
Agroecological transitions and local food self-sufficiency assessment

From the isotropic circle to the archipelago foodshed

Regionalization of food systems for shortening supply chains and developing local agriculture to feed city regions raises specific food planning and policy challenges. Existing foodshed approaches assess the theoretical capacity of food self-sufficiency of a given region, but they fall short in taking the diversity of existing crops and food chains into account. This results in the target area being mapped as an isotropic circle around the city without regard for the site-specific pedoclimatic, geographical and socioeconomic conditions. Furthermore, the multilevel aspect of food systems remains a remarkable scientific challenge to integrate stakeholders' local vision and global statistical data and thus tailor regional food security-oriented policies. To help fill this gap, we have developed **a comprehensive methodology using mixed methods in a participatory modelling approach linking different spatial levels (Mediterranean, regional, local)***. Significantly, our findings revealed that the analysis must be shifted from foodshed size assessment to a commodity-group specific spatial configuration based on biophysical and socioeconomic features—the foodshed assessment thereby becomes a complex of complementary components, i.e. the so-called foodshed archipelago (Figure). **This methodology is particularly promising in the context of agroecological transitions towards sustainable food systems because it highlights mechanisms that connect global to local aspects.** It can then be used in a participatory approach to build a collective shared vision of the transformation based on local stakeholder and expert knowledge connecting the environment, economy and society.

In this perspective, in the living labs framework**, we specifically analyze the role of public school food procurement as a driver to improve the capacity of cities to green their food system, and notably local farming. We highlight its crucial role to boost strategic alliances among territorial actors and analyze the conditions required to extend the farm-to-fork transition from school catering to the territorial food system (scale up) to benefit all consumers[2]. Beyond the methodological contribution (e.g. modelling approach[1]), findings are used to support urban food strategies (e.g. the implementation of green home-grown school feeding programs) and inform public decisions on land-use planning (e.g. periurban agricultural diagnostic tool developed in collaboration with land development and rural settlement public societies (SAFER).

* DIVERCROP project (2017/21, Arimnet2), Land system dynamics in the Mediterranean Basin across scales as relevant indicator for species diversity and local food systems: https://divercropblog.wordpress.com
** Aliville research-action project (2016/19, Fondation de France), Participative foresight for the re-location of urban agri-food system and supply of Avignon public canteens with local products; H2020 FoodSHIFT 2030 project (2020-24, H2020-SFS-2018-2020), Food system hubs innovating towards fast transition by 2030: https://foodshift2030.eu



▲ *Three-step methodological approach used to shift the focus of a foodshed analysis from an assessment of its size (isotropic circle) to its assessment as a complex of complementary pieces (foodshed archipelago).*

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For further information

(1) Boussougou G., Sanz Sanz E., Napoléone C., Martinetti D., 2021. Identifying agricultural areas with potential for city connections: a regional-scale methodology for urban planning. *Land Use Policy*, 103: 105321. https://doi.org/10.1016/j.landusepol.2021.105321

(2) Sanz Sanz E. (*in press*), Public procurement as a booster of medium-scale food supply chains. The case of Avignon, France. *In* Swensson L., *et al.* (eds): *Public food procurement for sustainable food systems and healthy diets.* FAO, UFRGS and Bioversity International.

(3) Vicente-Vicente J.L., Sanz-Sanz E., Napoléone C., Moulery M., Piorr A., 2021. Foodshed, agricultural diversification and self-sufficiency assessment: beyond the isotropic circle foodshed. A case study from Avignon (France). *Agriculture*, 11: 143. https://doi.org/10.3390/agriculture11020143

Urban agriculture and nutritional, health and environmental impacts in Bamako (Mali)

Large African metropolitan cities like Bamako (Mali) are facing high population growth and environmental changes that are prompting changes in people's lifestyles, particularly in their food consumption patterns, in addition to uncontrolled urban and periurban agriculture development. Given these food and environmental challenges, it is essential to accurately assess the food and health situation in Bamako. The AGRISAN* project, funded by the French Embassy in Mali, aims to characterize household food consumption patterns and their impacts in terms of public health, sanitary and environmental risks, as well as urban and periurban agricultural practices.

...cont'd

▲ *A kiosk-type food shop.* © *Y. Kameli/IRD/MOISA*

▲ ***An unprotected farmer conducting a herbicide treatment in his field.*** © M. Le Bars/IRD/SENS

Recommendations will then be drawn up regarding the implementation of suitable prevention policies on the basis of the findings. Specific emphasis is placed on the food consumption patterns of urban communities and their impact on health, particularly with regard to non-communicable diseases, and the nutritional status of women and children.

Agricultural practices have been monitored in terms of pesticide use in market gardening and the impacts on water quality. An analysis of pesticide residue levels in irrigation water for market gardening is underway using ultra-performance liquid chromatography (UPLC) at the Laboratory of Applied Molecular Biology (LBMA) in Bamako. We have selected 14 active ingredients from pesticide products used in market gardening that present environmental risks (e.g. acetochlor, paraquat and profenofos). The direct beneficiaries of this project are the District of Bamako, the Ministries of Health and Environment, NGOs, the higher education and research sector, the Institute of Rural Economy (IER), as well as the urban population. Farmers are also key beneficiaries as they could benefit from better productivity and improved quality of the products marketed, as well as consumers who will thus have access to healthy foods from short food supply chains.

*AGRISAN project (Urban agriculture, food and nutritional security) in Mali (video):
www.youtube.com/watch?v=4hB7gqQi5Yk&pbjreload=101

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Kameli Y., Meunier J., Besancon S., Savy M., Martin-Prevel Y., 2020. Alarming rates of obesity and diabetes in urban Africa: a case study in Bamako, Mali. *Current Developments in Nutrition,* 4(2): 215. https://doi. org/10.1093/cdn/nzaa043_066

Transition to healthy, sustainable local food in rural areas

TEASER-lab in Mirecourt (France)

The French rural area around Mirecourt (Vosges plain) is experiencing the harsh reality of social decline due to the current ongoing urbanization trend: negative population growth, the 'job drain', increased unemployment and poverty, highly specialized agriculture producing raw materials for the food industry (milk, beef and cereals), in conventional farming systems, but also often in certified organic farms. In 2016, a mutual desire for change prompted meetings and exchanges between associative and institutional organizations (including INRAE Mirecourt[1]) in the area, in turn leading to the emergence of a common project aimed at jointly contributing to a territorial transition towards job-friendly, healthy, sustainable local food. The transition under way in the Mirecourt area is based on the premise that societal transition requires high involvement of diverse people commited to jointly defining a future in a process facilitated by a range of different modalities of engagement[2]. Actors are thus cooperating in this project via different actions (growing produce in community gardens and vegetable plots, providing market outlets for organic and local commodities[3], and offering meals at recreational sites that are prepared with local and organic ingredients, etc.), and shared values (cooperation, trust, education, mutual respect for others and the environment). **Different forms of project participation are pivotal to this action-based approach: reflection, management and implementation of actions.** This collective project has triggered a territorial agroecological transition around Mirecourt in various ways[4]: collective action and the creation of common goods contributes to the political empowerment of those involved; agricultural and culinary choices giving rise to organic farming products, thereby enhancing ecological production; the inclusion of disadvantaged people (migrants, disabled people, people requiring food aid) are involved in the project and thus socially reintegrated in the area.

▲ ***Collective work in a vegetable crop plot involving association members and technical staff.*** © R. Fèche

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(1) Coquil X., Anglade J., Barataud F., Brunet L., Durpoix A., Godfroy M., 2019. TEASER-lab : concevoir un territoire pour une alimentation saine, localisée et créatrice d'emplois à partir de la polyculture-polyélevage autonome et économe. La diversification des productions sur le dispositif expérimental Aster-Mirecourt. *Innovations Agronomiques*, 72: 61-75.

(2) Gamache G., Anglade J., Fèche R., Barataud F., Mignolet C., Coquil X., 2020. Can living labs offer a pathway to support local agri-food sustainability transitions? *Environmental Innovation and Societal Transitions*, 37: 93-107.

(3) Fèche R., Barataud F., 2019. *Agroecological farmers' cooperation for shared commercialisation and rural population access to healthy food: is living-lab a support?* Presented at European Society of Rural Sociology (ESRS) in Trondheim (Norway) in June 2019.

(4) Coquil X., Barataud F., Fèche R., 2021. *À Mirecourt, l'autre façon de vivre la transition.* Publication on the Visionscarto website (January 25, 2021): https://visionscarto.net/mirecourt

Wasteborne nutrient recycling

A missing link in territorial food systems

Although recycling of organic waste products (OWPs) in agriculture is an age-old practice on a plot scale, this strategy is largely overlooked today despite the large volumes of OWPs of multiple origins (manure, slurry, compost, sewage plant sludge, industrial effluents) accumulating in congested areas. The current agroecological trend calls for its reintroduction, but implementing this strategy in highly complex territories and agroecosystems requires the organization of real recycling chains underpinned by concerted efforts between multiple stakeholders. **Our studies—based on applied analytical territory-specific research—are geared towards the design of tailored recycling scenarios endorsed by all.**

An original and generic approach has been applied in western Réunion*. In addition to increased OWP volumes and limited spreading possibilities, difficulties in organizing and managing OWP recycling networks on a territorial scale are due to inadequate interactions between OWP producers and end-users, and not to structural constraints. The implementation of a participatory approach with three coordination levels (Figure) covering several years has given rise to several scenarios, including: a 'minimal' scenario whereby co-compost based on livestock manure and green waste is produced; and an 'optimal' scenario that expands on the first scenario with the emergence of a second sector involving organic and organomineral fertilizer production. Yet the use of concentrated fertilizers dictated by the numerous territorial constraints would limit the potential *in situ* agroecological benefits. Implementation of the optimal scenario would nevertheless eventually reduce the reliance on imported fertilizers in the study area by at least half, if not more. Research is ongoing to enhance this approach. It is being tailored for implementation in several food systems and urban-rural focal areas in sub-Saharan Africa and South America. The systems targeted for the study areas will be defined on the basis of a functional rather than geographical spatial concept (as is the case in the island situation of Réunion).

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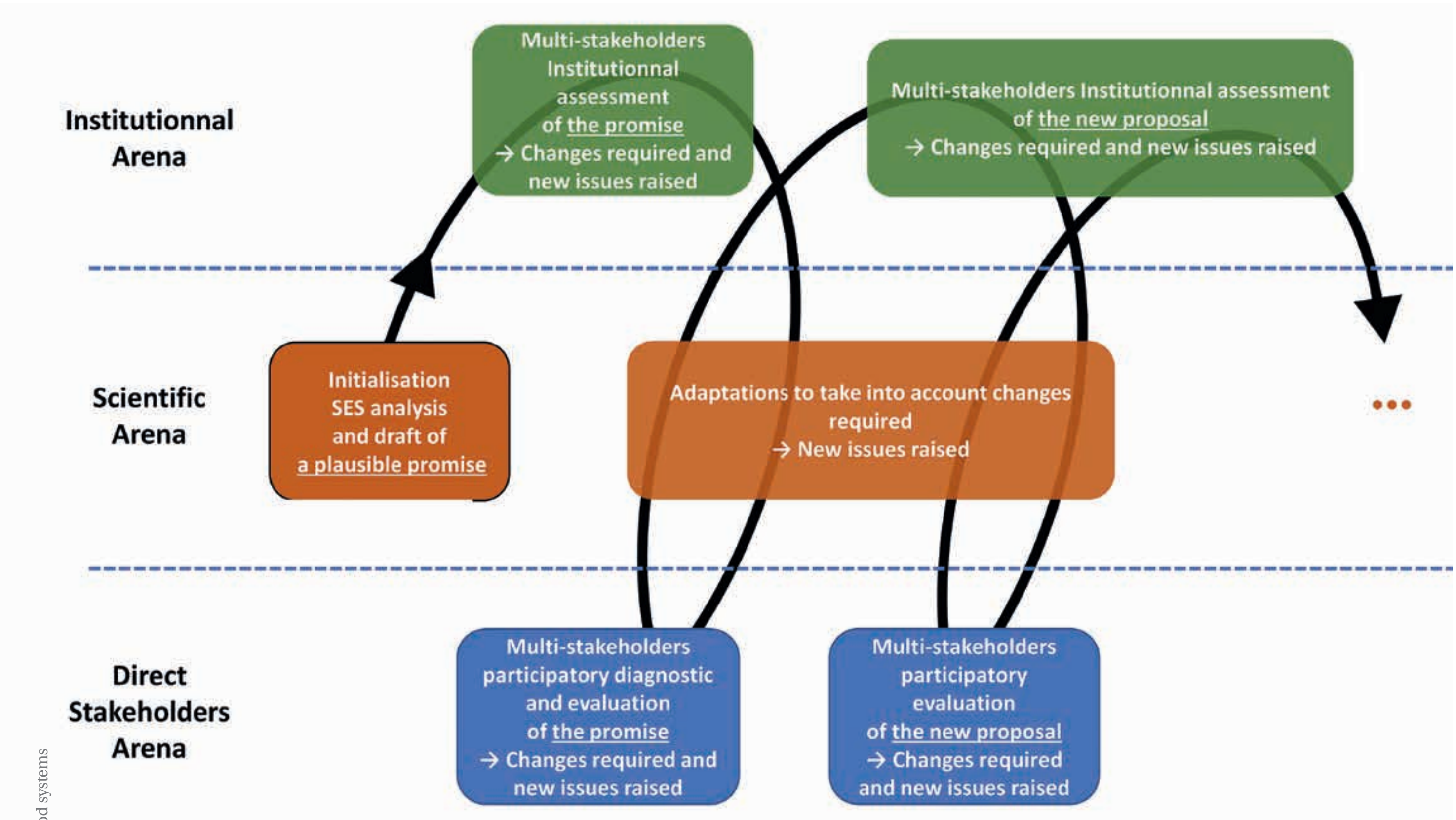
• Queste, J., Wassenaar, T., 2019. A practical dialogue protocol for sustainability science to contribute to regional resources management: its implementation in Réunion. *Natural Resources Forum*, 43(1): 3-16.

• Wassenaar T., Queste, J., Paillat, J.-M., 2016. Le recyclage agricole des résidus organiques : une ressource naturelle pour en préserver d'autres. *Agronomie, Environnement & Société*, 6(1): e12.

* GIROVAR Project: Integrated management of organic resides by agricultural recycling in Réunion.

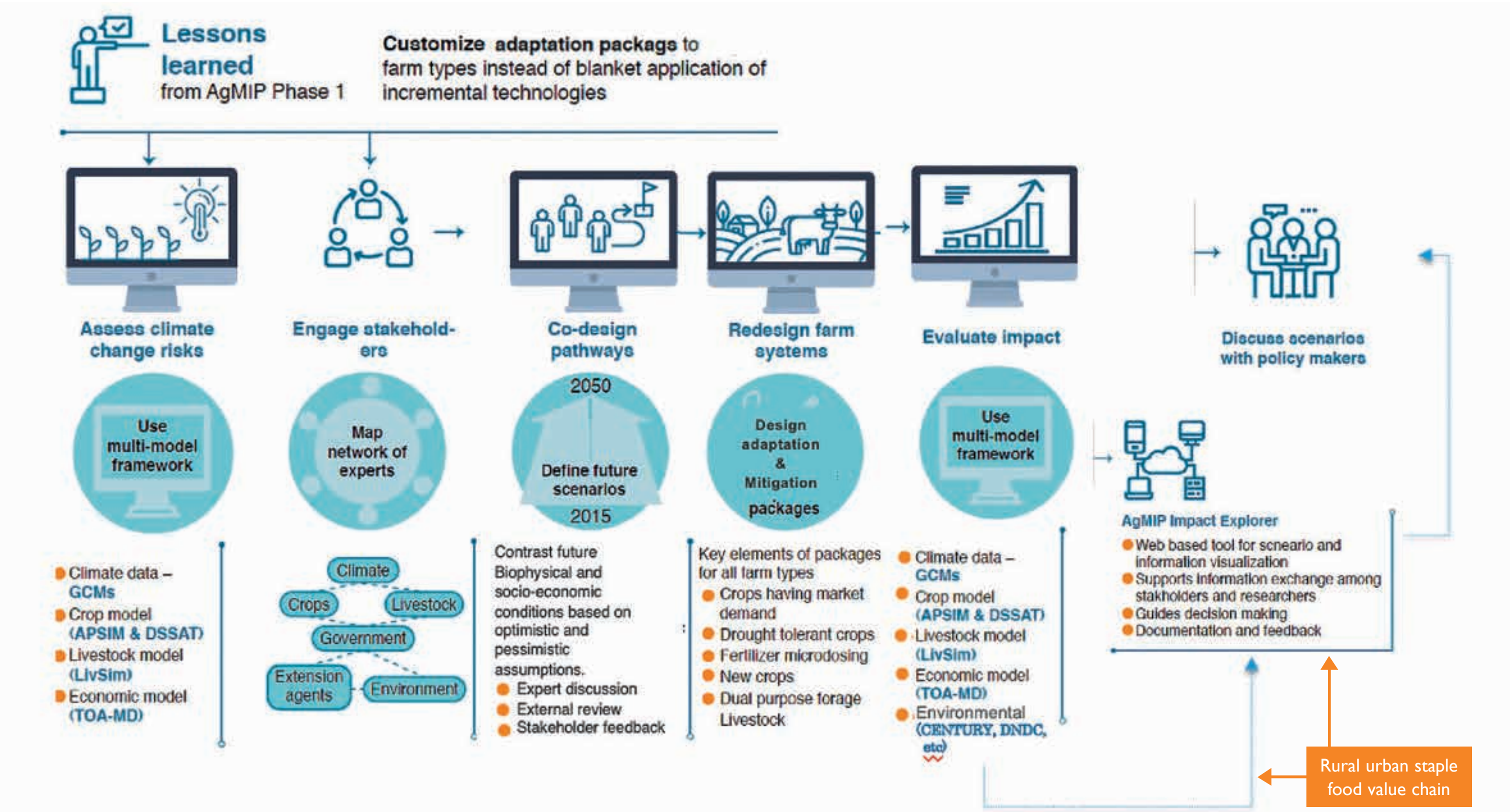


▲ ***Iterative codesign process.*** *Adapted from Queste & Wassenaar (2019)*

Strengthening research-policy links for agrifood system transformation in Zimbabwe

In Zimbabwe[1], agrifood system vulnerabilities reflect multiple overlapping crises that threaten food security. They also offer an opportunity to strengthen and transform local food systems so as to improve economic conditions, environmental sustainability and resilience to future shocks. To identify equitable and sustainable development pathways, our analysis combined an integrated modelling approach[2] with agricultural strategies codesigned with national experts from various sectors. We investigated how specific crop-livestock farming systems could be tailored to address food system disruptions caused by climate change and the COVID-19 shock. **We identified economic vulnerabilities and consequences faced by farmers, innovative coping mechanisms of other food system actors and value chain responses. In particular, we identified entry points to support a transition towards a more diverse range of locally produced foods to strengthen food and nutrition security of the most vulnerable populations**.

Climate change threatens farming systems, particularly farms with large cattle herds due to feed shortages. Mobility restrictions under COVID-19 lockdown has further worsened the long-term impacts, causing a loss of livelihoods, food, nutrition/income security, human safety and wellbeing, especially for women and girls. Strategic approaches[3] to sustainable agricultural development include a switch to growing substantially more food and feed legumes in farming systems, supporting organic soil fertility improvement and increased livestock ownership, especially among resource-poor farmers. However, in order to achieve sustainable farm income growth, livelihood improvement and farming system resilience, **these approaches need to be accompanied by investments in input and output market infrastructure, environmentally sound and productivity-enhancing technologies and inclusive development interventions.** Our analyses have enhanced the understanding of how concerted efforts by various food system actors, including decision makers, help more effectively increase the availability and affordability of nutritious foods by incentivizing food production diversification. The outcomes inform stakeholder engagements and national-level policy decision makers[4] on equitable and sustainable food systems, providing a knowledge base on blockages, inefficiencies and opportunities in current food value chains. The results will feed into the ongoing codesign of mid-term strategies for the Government of Zimbabwe and humanitarian organizations, while supporting sustainable and climate resilient agrifood systems through nuanced agricultural, food security and nutrition interventions and food procurement.



▲ *Customizing sustainable development pathways for agrifood systems to reduce vulnerability to climate change and other shocks.*
Source: Valdivia et al. *(2019).*

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(1) Hambloch C., Homann-Kee Tui S., Ojewo C.O., 2020. *Stronger local food value chains can leave eastern and southern Africa more resilient post COVID-19.* www.preventionweb.net/news/view/71602

(2) Homann-Kee Tui S., Masikati P., Descheemaeker K., Sisito G., Francis B., Senda T., Crespo O., Moyo E.N., Valdivia R., 2021. Transforming smallholder crop–livestock systems in the face of climate change: stakeholder-driven multi-model research in semi-arid Zimbabwe. *In* Rosenzweig C., *et al.* (eds.): *Handbook of climate change and agroecosystems: climate change and farming system planning in Africa and South Asia: AgMIP stakeholder-driven research* (in 2 parts) (vol. 5). World Scientific Publishing. https://www.worldscientific.com/worldscibooks/10.1142/Q0259

(3) Homann-Kee Tui S., Valdivia R.O., Descheemaeker K., Senda T., Masikati P., Makumbe M.T., Van Rooyen A., 2020. Crop-livestock integration to enhance ecosystem services in sustainable food systems, *In* Rusinamhodzi L. (ed.): *The role of ecosystem services in sustainable food systems.* Elsevier, chapter 8: 141-163.

(4) Valdivia R., Antle J., Homann-Kee Tui S., Mutter C., Evengaard A., Ruane A., Witkowski K., 2019. *Enhancing agricultural production and food security amid a changing climate: a new approach to inform decision-making.* The Inter-American Institute for cooperation on agriculture-climate change, natural resources and management of production risks and the agricultural model intercomparison and improvement project. A policy brief presented at the Joint Inter-American Agricultural Ministers Exchange. Pre-COP 25, San José.

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Foresight agroecology in India by 2050

The AgroEco2050 study (2019-2021) aims to explore the implications of contrasted scenarios—conventional industrial agriculture vs agroecology—for the future of agriculture, food and welfare in Andhra Pradesh, a southern Indian state. The study also aims to contribute to national and international debates and research on agroecology and future of food and agriculture. Since 2016, the Government of Andhra Pradesh (GoAP) has been committed to scaling up climate-resilient and community-managed 'natural farming'—an approach based on regenerative agriculture principles. Natural farming, which emphasizes healthy soils and landscape regeneration, highly diversified and synergistic crop/livestock production, no pesticide or synthetic fertilizer usage, involvement of self-help groups and farmer-centered learning, is seen as part of the science, movement and practice of agroecology. As of April 2020, natural farming was already being practiced by around 700,000 farmers in Andhra Pradesh, with the hope that this would increase to 6 million farmers and 8 Mha by 2027. It attracted the attention of a few other states in India, the central government, national and international institutions[1]. In this context, it is important to explore the implications of such an option based on rigorous evidence and a multi-stakeholder process.

The AgroEco2050 foresight study intends to explore what impacts on farmers' livelihood, land use, productivity, nutrition, public finance and other aspects could be expected by 2050 if Andhra Pradesh were to move to a 'natural farming at scale' scenario, compared to the impacts of a 'deepening conventional agriculture' scenario. The methodology is based on the CIRAD-INRAE 'Agrimonde: 'Scenario and Challenges for Feeding the World in 2050' global foresight initiative (2006-2010). It will be carried out using collective expertise and the quantitative 'Agribiom' tool/model[2]. Substantial time-consuming data collection and modelling since the 1970s are currently being carried out by the research team on many parameters (human and animal populations, GDP, land use, land and labor productivity, diets, etc.). An interactive interface is being built to screen and discuss past developments and future scenarios with an expert group of stakeholders (policymakers, scientists, civil society, farmers) at workshops throughout 2020 and 2021. **The study —co-constructed with policymakers of Andhra Pradesh—will support evidence-based policy decisions in the State. The findings will also be of prime interest for other Indian states and worldwide.**

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(1) Dorin B., 2021. Theory, Practice and Challenges of Agroecology in India, *International Journal of Agricultural Sustainability*. doi: 10.1080/14735903.2021.1920760

(2) Dorin B., Joly P.-B., 2020. Modelling world agriculture as a learning machine? From mainstream models to Agribiom 1.0. *Land Use Policy*, 96(July). doi: 10.1016/j.landusepol.2018.09.028

Chapter 5

Building a new global food system based on equity, participation, democracy and justice

This chapter addresses an essential issue of the agroecological transition, which is much more than simply a set of innovative agricultural practices and techniques. An agroecological transition gives rise to alternative ways of managing agricultural production, as outlined in the first three chapters of this *Dossier* but go beyond this and incorporate aspects of equity, democracy, and justice at the food system level, from the farm to the fork. Beyond the aspects developed and illustrated in Chapter 4 (page 80), the focus here is on the far-reaching transformations in value chains, business models and funding sources, and in the socioeconomic dynamics in territories, as a result of agroecological approaches applied in a diverse range of specific situations with a diversity of food system actors. These transformations result in changes in the terms of interaction between agricultural and food system actors conducive to more environment-friendly and equitable, to the mutual benefit of producers and consumers.

In keeping with our initial choice of structuring according to the levels outlined by Stephen Gliessman, as he outlines in the following terms: "By thinking beyond Levels 1-4, Level 5 involves change that is global in scope and reaches beyond the food system to the nature of human culture, civilization, progress and development. The depth of change is more than mere conversion or transition, and enters into the realm of full reform or transformation. With Level 5 thinking and action, agroecology provides ways to build upon farm-scale and farmer-driven change processes to a full re-thinking of how we all relate to each other and to the earth that supports us. Basic beliefs, values, and ethical systems change. The expanding awareness that is part of this process then extends to other facets of environmental and social relationships beyond food, bringing about a paradigm shift focused on how the agriculture and food systems of the future can help reduce our ecological footprint, recognize that there are limits to growth, and what it really means to live sustainably. The important role that food systems can and must play in mitigating and adapting to climate change as a global issue is one example of the value of Level 5 thinking. The growing food justice movement, where everyone in the food system enjoys the benefits of equity, justice, security, and sustainability, is another." He then wraps up by: "**Building a new global food system, based on equity, participation, democracy, and justice, that is not only sustainable but helps restore and protects earth's life support systems upon which we all depend**".

This is of course not self-evident and is particularly demanding for those who pursue this pathway. For the scientific community, it implies a realignment of the research agenda that adopts a systemic perspective on agriculture, advances research on circularity of agricultural and food systems, and on social equity on farms, territories, value chains, and in policies and institutions affecting food systems. This realignment of the research agenda goes hand in hand with the awareness that availability and access to healthy and nutritious food is the result of political economy dynamics within food systems. Any research aimed at supporting agroecological transitions at scale must therefore encompass three strategic moves: developing theories of change based on strengthened systems research, focusing on process research to inform impact pathways of development partners, and engaging in an open dialogue about fundamental questions related to agricultural development and food systems models, strategies and finance.

The following contributions illustrate the current state of research geared towards the development of a new global food system based on examples drawn from real-life situations. They are organized in three groups: **Improving value chains by agroecology,** i.e. how agroecological approaches create and enhance the value of agricultural products beyond their mere commodity status and the social issues in supply chains; **Collective action, knowledge co-generation, linking products and territory**, underlining that one of the issues agroecology has put back on the

▼ *Buvuma Island cassava plantation, Uganda.*
© HansVellema/TBI

agenda concerns collective entities and heterogenous conditions—building the future is a joint venture that fosters the diversity and complementarity of agricultural contexts and knowledge, i.e. it is not merely a question of pooling the technical and economic efficiency of separate individuals and interventions but of bringing together the diversity of actors interplaying in those agricultural contexts to achieve a common goal; and finally **Innovative business models and finance,** which looks at the resources, markets, and business alliances required to facilitate agroecological transition processes via innovative financing methods.

In the first part, **Improving value chains via agroecology**, the first three contributions illustrate how a revision of usual marketing patterns gives meaning and value to products, while contributing to the recognition of women's essential role in these processes with regard to the production of palm oil (Ihalainen *et al.*), coffee (Gallagher *et al.*) and shea butter (Wardell *et al.*). In the following contribution, Hugo de Vries shows how—with the help of innovative technologies—by-products can be transformed into co-products, thereby generating diversity in monoculture conditions. Hostiou *et al.* stress that agricultural work must be taken into account in its various dimensions so as to highlight the values it contributes to the production system, and in turn to the derived products, whose value is not based exclusively on their intrinsic quality but also on all factors that contribute to their production process.

The second part, **Collective action, knowledge generation, linking products and territory**, pools contributions that showcase the collective dimension of the agroecological transition. Indeed, the values discussed in the previous section can be formally recognized via collective action. These collective dynamics may then highlight qualities specific to such shared assets and lead to various forms of designation such as fair trade, as outlined by Thierry Winkel; or participatory mechanisms to certify that food has been produced sustainably, such as participatory guarantee systems (PGS), as illustrated by Nadia Bergamini with regard to on original initiatives in Cuba, and by Estelle Biénabe and Claire Cerdan through specific examples from three continents. Moreover, Allison Loconto points out that PGSs have now widespread in 76 countries in the Global South, which do not have the conventional certification and control instruments that are available to certify organic farming practices in the Global North. Moreover, any kind of collective action may only take place if essential learning and knowledge exchange processes are under way within these organized spaces and collectives, not only between peers but also between stakeholders in these territories, as illustrated by the contributions of François Affholder and Aurélie Toillier. The next two contributions of Marc Piraux and Carmen Gervet *et al.* showcase the importance of the relationships within a collective to manage common goods within their space of action, i.e. a territory. Finally, the last contribution by Éric Sabourin and Jean-François Le Coq argues in favor of territorialized public policies that support agroecological development.

Four texts contribute to the **innovative business models and finance research**: Nelson and Sander's study stresses that agroecological rice systems are beneficial from the carbon emissions perspective and should be given greater recognition and benefit from the carbon credit market. Stoian *et al.* assess the relevance of inclusive forms of business models for small-scale oil palm, cocoa and coffee farmers to enable them to benefit more fully from the allocation of added value in industrialized value chains. The next two papers of Mockshell *et al.* and Louman *et al.* call for a greater private sector contribution to support agroecological production systems whose multidimensional performance benefits the entire food system.

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Improving value chains via agroecology

Towards sustainable palm oil

Social footprinting of informal and formal market value chains

Ghana is a major producer and consumer of palm oil, yet it is unable to meet domestic demand[1]. Notwithstanding the emergence of large-scale plantations and industrial millers, smallholder farms account for approximately 80% of the land under oil palm cultivation, and 76% of crude palm oil (CPO) is processed by small-scale artisanal mills[3]. The growth and expansion of smallholder and estate oil palm plantations in Kwaebibirem District has prompted a concurrent boom in informal mills operated by 'oil palm mamas' driving land-use transitions in favor of oil palm, to the detriment of other tree crops. Palm oil processing in Ghana has traditionally been perceived as a 'kitchen activity' in the domain of women, who have also historically dominated midstream value chain nodes as farmgate buyers, artisanal millers and processors, and market traders[2].

Despite the importance of the informal oil-palm sector for women's employment, artisanal mills face serious challenges in terms of poor extraction rates, impurities in the oil, deleterious working conditions, and negative environmental impacts associated with fuelwood consumption, carbon emissions, air and water pollution. While registered companies must comply with environmental, labor and health regulations, informal mills operate outside of such standards. Moreover, the formal sector maintains a critical value chain niche in terms of smallholder service provision and achieving sustainabilities at scale, yet competition with the informal sector has threatened the viability of medium-scale enterprises and undercut large-scale service-delivery models. Through a mixed-methods gendered value chain analysis, we examine opportunities and challenges for upgrading palm oil processing and decent employment at different points within the chain, thereby providing a gendered perspective on women and men's participation and benefits across different value chain segments. We also develop and explore innovative participatory methodologies to measure and visually map the gender footprint in terms of livelihood impacts for the men and women within informal and formal oil palm value chains. Our results will feed into **an ongoing integrated landscape development process with the aim of informing more inclusive and gender-responsive landscape governance and value-chain development**.

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(1) Rhebergen T., Fairhurst T., Whitbread A., Giller K.E., Zingore S., 2018. Yield gap analysis and entry points for improving productivity on large oil palm plantations and smallholder farms in Ghana. *Agricultural Systems*, 165: 14-25.

(2) Sarku R., 2016. Analyses of gender roles in the oil palm industry in Kwaebibirem District, Ghana. *International Journal of Humanities and Social Sciences*, 6(3): 187-198.

(3) MoFA, 2010. MASDAR: master plan study on the oil palm industry in Ghana. https://mofa.gov.gh/site/images/pdf/GHANA%27S%20OIL%20PALM%20MASTER%20PLAN.pdf

▼ *'Kramer' or artisanal oil palm mill in Eastern Region, Ghana.* © A. Gonzalez/CIFOR

Mapping gendered impact pathways of Fairtrade coffee

Case studies from Guatemala, Indonesia and Kenya

▲ *Interviewing coffee farmers in Indonesia.* © CIFOR

This research analyzes the contribution of Fairtrade to gendered value chain development through targeted interventions to improve women's participation, social and economic empowerment, and transformation of gender norms which reproduce inequalities between male and female producers. Gender specialists* have adopted a contribution analysis approach to systematically examine gender impact pathways embedded in the Fairtrade Theories of Change against gendered outputs, outcomes and impacts. The study examines: how Fairtrade—through its standards, strategies, programs, and capacity-building workstreams—contributes to gendered outcomes; and whether Fairtrade further generates benefits for Fairtrade farmers, workers and their communities regarding non-discrimination and empowerment of women and girls.

Key findings show that Fairtrade standards and gender programs have improved the proportion of female members and female representation in leadership positions through affirmative action, the inception of women's committees, and gender-specific interventions to address structural barriers to participation (lack of secure land tenure, poor access to childcare, household labor burden). The Growing Women in Coffee program in Kenya took proactive steps to negotiate women's tenure barriers to cooperative membership by lobbying men to transfer coffee bushes into their wives' names and registering women as full members with associated benefits. Empowerment indicators to measure the close relationship between social and economic empowerment demonstrated the positive impact of gender awareness training coupled with steps to increase women's market participation and access to working capital. In Guatemala, the Women's Leadership School has set the standard for building women's agronomic and entrepreneurial skills and sense of self efficacy, with the support of male allies to champion their leadership roles within producer organizations. Recommendations to address more deeply embedded sociocultural gender norms challenge Fairtrade to identify levers for action within the scope of Fairtrade business model, while providing more specific guidance regarding Fairtrade's position on casual labor and the labor of women who actively participate in commodity production but are not themselves full members. Women participating in leadership training in Indonesia, for example, must still navigate sociocultural norms about women's participation in the public sphere and the invisiblization of women's labor in value chains to more fully contribute to cooperative decision-making and business activities. **These case studies represent progress at the level of Fairtrade regional Producer Networks and smallholder producer organizations, as well localized innovations to address deeply embedded gender norms which constrain women's full participation.**

* Gender specialists from CIFOR, commissioned by Fairtrade system partners, with support from the CGIAR Research Program on Forests, Trees and Agroforestry (CRP-FTA).

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• Gallagher E.J., Monterroso I., Sanjaya M., 2020. *Women's access, equity and empowerment: Progress and uptake of the Fairtrade Gender Strategy 2016-2020*. Fairtrade International, Bonn.

• www.fairtrade.net/news/new-fairtrade-study-highlights-successes-and-ways-forward-towards-gender-equality

• Fairtrade Foundation, 2015. *Equal harvest: removing the barriers to women's participation in smallholder agriculture*. Fairtrade Foundation, London, 50 p.

• Malapit H., Quisumbing A., Meinzen-Dick R., Seymour G., Martinez E.M., Heckert J., Phase, G.A.A.P. (2019). Development of the project-level Women's Empowerment in Agriculture Index (pro-WEAI). *World development.* 122: 675-692.

Continuity and change in shea supply chain governance in Burkina Faso (1890-2019)

Shea fruits, nuts and butter are non-timber forest products of the shea tree (*Vitellaria paradoxa*), the most widespread tree species in West African parklands. The fruits and butter extracted from its kernels are essential ingredients in the diet of rural communities, and sales of surplus nuts and butter generate crucial income for women[1,2]. The parklands are also important sources of other subsistence foods and provide critical ecosystem services. Historical evidence indicates a widespread centuries-old exchange of shea kernels and butter by women in periodic local markets and, regionally, in markets serving communities along the densely-populated West African coastline[4]. Such exchanges were not only between producing and non-producing areas but also within producing areas due to seasonal variations in supply. In the early 20th century, French (and British) colonial administrations considered the possibility of exporting shea kernels to Europe on a large scale.

...cont'd

▶ ***Shea nut processing.*** *Once roasted, Rabo Nafissatou (left) and Bassia Mariam (right) ground shea nuts into a paste, which is then mixed with water and beaten (Burkina Faso).* © O. Girard/CIFOR

Multiple initiatives to tax, extract (mechanically and chemically) and plant shea were unsuccessful. In the post-independence era, several state-led efforts to regulate and control the shea trade through stabilization funds and parastatal marketing boards were abandoned after 1984 when shea markets were liberalized. Increasingly since 2003, an oligopolistic global supply chain, dominated by three foreign firms that manufacture cocoa butter equivalents (CBEs), is sourcing shea to meet the growing demand of multi-billion dollar confectionary and cosmetics industries[(3)]. Burkina Faso is one of the main exporters. The first '*Stratégie national de développement durable de la filière karité du Burkina Faso 2015-2019*' was adopted by the Government with the aim of expanding the shea nut trade as part of its 'major non-traditional agricultural export commodities' portfolio. This is embedded within the (now) dominant neoliberal orthodoxy, which privileges private over public rights, and monetized production systems. We suggest that **the historical continuity, resilience and sovereignty of womens' shea production and trade are now confronted with several disintegration risks associated with the contemporary forces of globalization.**

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(1) Rousseau K., Gautier D., Wardell D.A., 2017. Socio-economic differentiation and shea globalization in western Burkina Faso: integrating gender politics and agrarian change. *The Journal of Peasant Studies,* 46(4): 747-766. http://dx.doi.org/10.1080/03066150.2017.1401612

(2) Elias M., 2015. Gender, knowledge-sharing and management of shea (*Vitellaria paradoxa*) parklands in central-west Burkina Faso. *Journal of Rural Studies,* 38: 27-38. www.sciencedirect.com/science/article/abs/pii/S0743016715000157?via%3Dihub

(3) Rousseau J., Gautier D., Wardell D.A., 2015. Coping with the upheavals of globalization in the value chain of shea: the maintenance and relevance of upstream shea nut supply chain organization in western Burkina Faso. *World Development,* 66: 413-427. http://dx.doi.org/10.1016/j.worlddev.2014.09.004

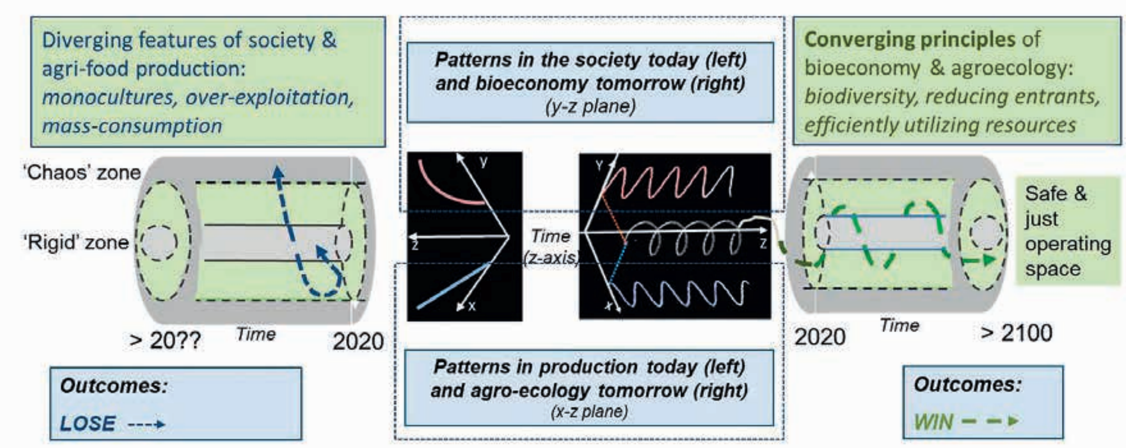
(4) Wardell D.A., Fold N., 2013. Globalizations in a nutshell: historical perspectives on the changing governance of the shea commodity chain in northern Ghana. *International Journal of the Commons,* 7(2): 367-405. www.thecommonsjournal.org/articles/10.18352/ijc.361/

Converging agroecology and bioeconomy principles define new processing pathways

Agroecological practices combine three sustainability dimensions, namely economic, environmental and social performance. Practices favor biodiversity, input reduction and efficient resource use, while reconsidering production from ecological standpoints. The bioeconomy concept was first focused on biotechnology and then on efficient resource usage, while today it is hinged on socioecological orientations in which agrifood systems have a major share. Hence, agroecology and bioeconomy have converged towards one sustainability framework, thereby setting the stage for production, manufacturing, distribution, consumption and recycling. This poses the following questions with regard to agroresource processing pathways:

1. How would it be possible to progress from large volume, high-throughput processing of monocultures towards processing of biodiversified resources?
2. How could main products and by-products be processed in an integral manner to enhance efficient resource use?
3. How could all subsequent recycling steps be designed to guarantee minimum nutrient loss?
4. How could the above three processing pathways be sustainably innovated in three dimensions?

A bioeconomy prospective analysis report[(1)] offers suggestions, such as downscaled food technologies, cascading processes for multiple resources, closed cycle approaches for biomass and combined technological, organizational and social innovations[(2)]. The above questions could be addressed by considering that globally sustainable bioeconomy systems should be built on interconnected territorial bioeconomy subsystems instead of linear bioeconomy systems, including food value chains[(3)]. In subsystems, actors, products, transformations, playing fields, rules and (un)sustainable outcomes should be jointly considered to determine whether agroecology and bioeconomy principles have been respected. This can be experimentally verified in so-called 'living labs'. The latter—as currently explored in agroecology—can then become 'bioeconomy systems labs' to assess cases with a wide range of public-private partners. Moreover, the scope of existing bioeconomy research and innovation clusters (including food systems) could also be broadened to encompass agroecological production practices. An existing wine research station, like INRAE Pech Rouge, could possibly serve as an example by combining wine produced via agroecological practices, and the utilization of coproducts and waste, with the three processing pathways—biodiversified resources processing, integral processing, multiple recycling—mentioned above. In addition, the research station could address both environment-friendly technological, as well as organizational and social innovations to strive to come up with sustainable solutions in their three dimensions.



▲ *Converging features of agroecology and bioeconomy result in sustainable outcomes in safe and just operating spaces, in contrast with current societal and production patterns leading to chaos or rigidity.*
Modified image of www.radartutorial.eu/06.antennas/pic/zirku lanim.gif is included. Adapted from De Vries et al. *(2021)*

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(1) Axelos M. *et al.*, 2020. *Réflexion prospective interdisciplinaire bioéconomie.* Rapport de synthèse. INRAE, France. (hal-02866076)

(2) Donner M., de Vries H., 2021. How to innovate business models for a circular bio-economy? *Business Strategy and the Environment.* doi: 10.1002/bse.2725

(3) De Vries, H., Donner M., Axelos M., 2021. A new conceptual cylinder framework for sustainable bioeconomy systems and their actors. *J Agric. Environ. Ethics.,* 34: 11. https://doi.org/10.1007/s10806-021-09850-7

Work and agroecology

The agroecological transition changes farmers' work by increasing the diversity and range of tasks to manage (e.g. crops and livestock) and the uncertainty (natural processes are hard to predict), while also requiring new skills and know-how. Agroecology hypothetically offers better working conditions, but with heavier work and mental loads. The agroecological transition also implies a change of professional model involving different norms, values, practices and objectives (e.g. autonomy). This transition does not solely concern practices! It requires creativity, peer dialogue and learning. The process gradually reconciles the ideal and the possible (PraiFacE project, 2008-2013, ruminant livestock farms, western France).

Work times depend on many factors, primarily the size (area, herd) and workforce composition. Drawing conclusions on the direct effects of agroecological practices using precise techniques such as the Quaework method is difficult. Moreover, the mental workload is hard to assess (apart from biological measures regarding stress). The sense of drudgery has a strong individual and subjective dimension, while complexity is not regarded as a hardship. Work is not just impacted by change—at the farm scale, the tasks and who will carry them out, the equipment used and the role of non-agricultural activities are renegotiated (LIFT 2020-2023 project, cash crops and ruminant livestock farming, 12 European countries). **The significance of work, the feeling of usefulness, the wealth of relationships (with others and with animals), decision-making autonomy, consistency and the meaningful relationship with nature are all accentuated by agroecology. Research findings jointly underline the fact that the agroecological transition is experienced as an empowerment process while fostering a sense of involvement in rewarding work** (Transaé project, 2016-2019, ruminant livestock farming, France).

▲ *Collective work in a vegetable crop plot involving association members and technical staff.* © R. Fèche

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• International association 'Work in Agriculture': www.workinagriculture.com

Projects

• LIFT project, Low-input farming and territories. Integrating knowledge for improving ecosystem-based farming (project H2020 n°770747, INRAE coordination).

• PraiFacE project, *Faciliter les transitions vers des systèmes plus autonomes* (Casdar, France, INRAE-FNCIVAM coordination).

• Transaé project, *Transition vers l'agroécologie* (Casdar, France, INRAE-FNCIVAM coordination).

For further information

• Coquil X., Dedieu B., Beguin P. 2017. Professional transitions toward sustainable farming systems. The development of farmers' professional worlds. *Work*, 57(3): 325-337. doi: 10.3233/WOR-172565

• Hostiou N., Dedieu B., 2011. A method for assessing work productivity and flexibility in livestock farms. *Animal*, 6(5): 852-862. doi:10.1017/S1751731111002084

• Duval J., Cournut S., Hostiou N., 2021. Livestock farmers' working conditions in agroecological farming systems. A review. *Agronomy for Sustainable Development*, 41(22). https://doi.org/10.1007/s13593-021-00679-y

Collective action, knowledge generation, linking products and territory

Panarchy: a conceptual framework to support the inclusive sustainability of peasant agrosystems

Fair and sustainable marketing of peasant agriculture products remains problematic. In addition to difficulties inherent to any agricultural activity, farmers have little bargaining power in value chains and they face technical barriers to processing and distributing their products. Yet consumers value the quality of these products to an increasing extent, not to mention their environmental and social benefits. Making value chains more inclusive for peasant agriculture, while ensuring sustainability and equity, is therefore a complex challenge. It mobilizes a variety of actors—producers, experts, policymakers—while dealing with a diverse range of information and concepts on the environment and society at several spatiotemporal scales, with various growth, reduction and stability objectives.

Sustainability science prioritizes this heterogeneous knowledge and information, thereby making it possible to analyze the vulnerabilities and prospects for changing complex systems. Among its tools, panarchy[1] offers a heuristic approach that links the target systems (e.g. families, territories and societies), before tracking their trajectories through four generic phases, i.e. initiation, maturation, release and reorganization (Figure). Interactions between these systems underpin the more or less adaptive and sustainable transformation scenarios. **Panarchy fosters dialogue between experts and social actors on the basis of graphic models, thereby facilitating exchange on issues, perspectives and decision making.**

Several action-research projects* have successfully used this approach by tailoring it to issues of inclusive peasant production sustainability in both local short circuits and globalized markets[2]. In Bolivia, for example, agroecological transition to meet renewed territorial management standards was planned locally and then recognized and mainstreamed via the international FairTrade/ MaxHavelaar certification system (Photo). These results highlight that the community territory provides an ideal space for debate and collective action in favor of sustainable and equitable governance of natural resources.

* ANR-06-PADD-011-EQUECO Project, Emergence of quinoa in world trade
CONICYT-BAQUIANA Project, Socio-ecological bases of participatory management of quinoa genetic resources in family farming communities
ANID-PABIOCA Project, Mobilizing biocultural heritage for peasant agriculture
MSH-SUD-PANARCHI Project, Mobilizing natural and cultural heritage for inclusive agriculture
ECOS-SUD-ARCHIPA Project, Patrimonialization of biocultural resources for peasant family agriculture in Argentina and Chile

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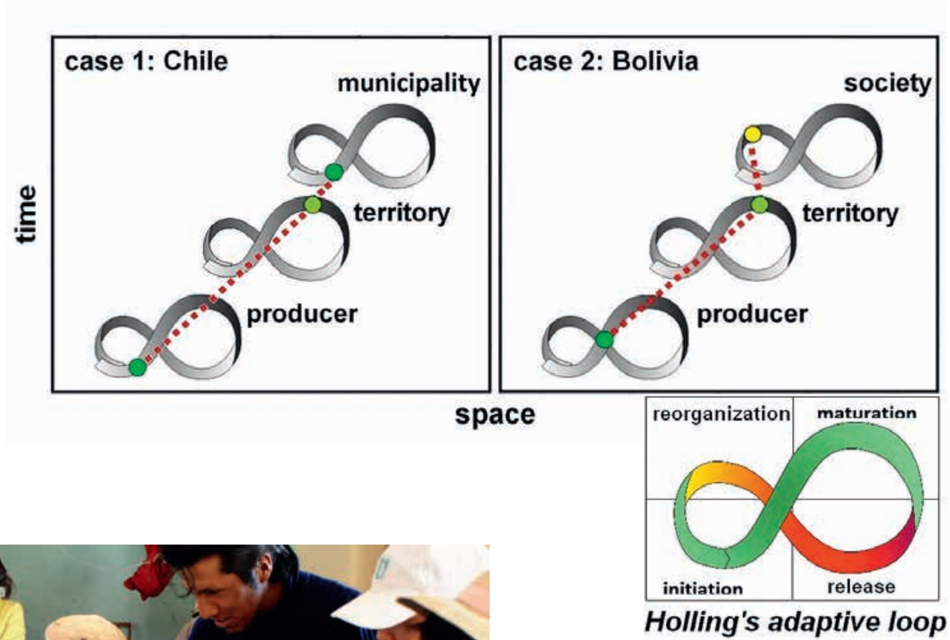
(1) Winkel T., Bommel P., Chevarría-Lazo M., Cortes G., Del Castillo C., Gasselin P., Léger F., Nina-Laura J.P., Rambal S., Tichit M., *et al.* 2016. Panarchy of an indigenous agroecosystem in the globalized market: the quinoa production in the Bolivian Altiplano. *Global Environmental Change.* 39: 195-204.
https://doi.org/10.1016/j.gloenvcha.2016.05.007

(2) Winkel T., Núñez-Carrasco L., Cruz P.J., Egan N., Sáez-Tonacca L., Cubillos-Celis P.E., Poblete-Olivera C.J., Zavalla-Nanco N.O., Miño-Baes B., Viedma-Araya M.P., 2020. Mobilising common biocultural heritage for the socioeconomic inclusion of small farmers: panarchy of two case studies on quinoa in Chile and Bolivia. *Agriculture and Human Values.* 37: 433-447.
https://doi.org/10.1007/s10460-019-09996-1



▲ ***Panarchies of quinoa producers in Chile and Bolivia.***
In each case, three nested subsystems are hierarchized and their respective positions in Holling's adaptive loops are symbolized according to the right-hand insert. © Th. Winkel/IRD, 2020

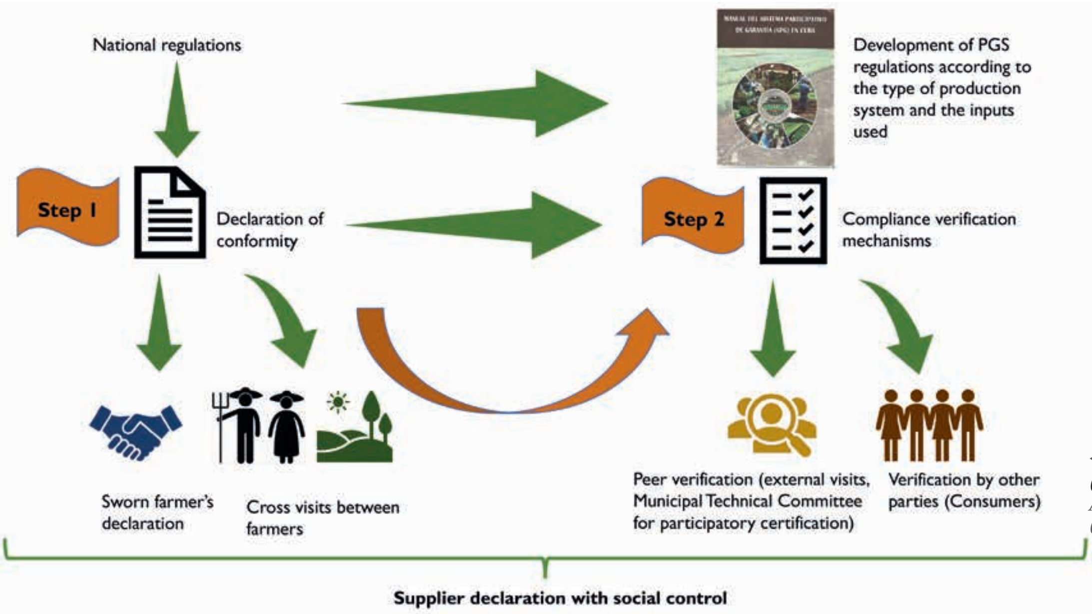
◀ ***In participatory research, role-playing reveals the logic of the different actors, thereby fostering debate and concertation with a view to collective action.***
© M. Vieira-Pak/CIRAD, 2007

Participatory guarantee systems

A cheap and fair way to reward farmers for their efforts and agroecology adoption

Participatory guarantee systems (PGS) provide an alternative to third-party certification. They are cheap and easy to implement and represent locally relevant quality assurance initiatives that emphasize stakeholder participation, including producers and consumers, and are ideal for smallholder farmers worldwide. We explore how the PGS scheme can work in a country like Cuba* where agroecology and low input agriculture have been strongly supported by the government over last 30 years. Agroecology is pivotal to agricultural production in the country but, unless food is purchased directly from farmers or local markets, consumers have no way of knowing whether their produce purchases are from uniform intensive high-input farms or diversified low-input agroecological farms. We worked together with the Institute for Fundamental Research in Tropical Agriculture (INIFAT) of the Cuban Ministry of Agriculture. INIFAT is also leading the Cuba's Urban, Suburban and Family Agriculture Program' where most agroecological production is happening. The idea was to support farmers living and working in buffer and transition zones of two UNESCO Man and the Biosphere Reserves (MAB) in Cuba by adding value (through certification) to their high-quality products for the local and tourist markets. MAB farm produce supplying organic markets included mango, coconut, avocado, guava, sweet and sour orange, lemon, banana, sweet potato, tomato, cucumber, pineapple, cowpea, common beans and cassava. During the testing phase, six farmers from one MAB were trained for PGS application. Previous research demonstrated that farmers in the reserves play an important role in agrobiodiversity and traditional knowledge conservation, while also providing ecosystem services. All of this information is lost once the products leave the farm on a state truck that collects from both organic and conventional farms, and everything is mixed to serve the state food distributions system. **PGS development in Cuba is an attempt to empower smallholder farmers by recognizing and promoting their efforts in the use of agroecological practices, as well as their role as biodiversity custodians and providing a guarantee to consumers**.

* In the framework of a UNEP-GEF-funded project.



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• Vega León M., Gavilanes Díaz P., 2016. Los sistemas participativos de garantía (SPG), una alternativa para la valorización de los productos de las Reservas de la Biosfera. *Agrotecnia de Cuba*, 40(2): 87-93.

• Pérez Lamas J., Gomez Molldón J., Vega León M., Gavilanes Dias P., 2016. *Manual del sistema participativo de garantía (SPG) en Cuba*. Playa, Cuba: Asociación Cubana de Técnicos Agrícolas y Forestales

◀ ***The participatory guarantee system (PGS) developed in Cuba.***
Adapted from Vega León & Gavilanes Díaz (2016)

Scaling agroecological transitions

Supporting institutional market innovations

A diverse range of market innovations link agroecological farmers and consumers in the Global South. Supporting the underlying institutional innovations and collective knowledge building are necessary for scaling agroecological transitions and intervening at the food system level[3]. Our research documents and supports the ways by which agricultural and food system actors rethink and organize their involvement in different markets, bolster agroecological changes, and modify the rules that structure market interactions*. It is a matter of qualifying and developing the quality attributes promoted in market exchanges and the institutions that underwrite them (standards, certifications, accreditations).

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▶ ***Clean vegetable producers from Moc Châu (Vietnam) preparing their orders, 2018.***
© E. Biénabe

The recognition and dissemination of agroecological practices occurs through the institutionalization of new standards via the socialization and promotion of links between product quality and production systems[1]. Successful scaling combines:

1. local experience involving actors from production areas in quality or origin labeling processes, e.g. geographical indications (Rooibos, South Africa[2]) or other territorial certifications (clean vegetables from Moc Châu, Vietnam) with the collective body playing a key role as guarantor in the distinction and quality building process[3]
2. networking between innovative areas and organizations via NGOs, projects and/or public actors, such as AGRECO** (Brazil), whose scaling occurred via a public family farming support program and the involvement of a network of qualified people
3. an increase in State policy support, with complementarity between research and NGOs in testing and explaining the mechanisms, such as the establishment and recognition of participatory guarantee systems (PGS) in Morocco, or the creation by Ecovida** of solidarity-based processing channels between three Brazilian States, whose political impact contributed to the institutionalization of PGS in the Brazilian Organic Law regarding organic agriculture[4].

* "Defining who has the right to participate in the market, what goods are included in the trading, how the trade should be conducted and the specific rights and obligations of each economic operator." (Niederle and Gelain, 2013)

** AGRECO: an agroecological farmers' association of Encostas da Serra Geral (Brazil).

Ecovida: a network of men and women agroecological farmers and NGOs.

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(1) Biénabe E., 2013. Towards biodiverse agricultural systems: reflecting on the technological, social and institutional changes at stake *In* E. Hainzelin (eds): *Cultivating Biodiversity to Transform Agriculture*. Springer, Heidelberg: 221-261.

(2) Biénabe E., Marie-Vivien D., 2017. Institutionalizing geographical indications in Southern countries: lessons learned from Basmati and Rooibos. *World Development*, 98: 58-67.

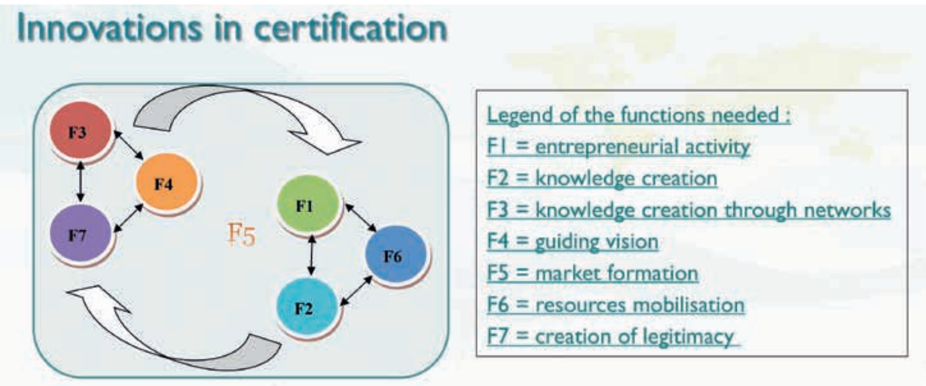
(3) Cerdan C., Biénabe E., Benz H., Lemeilleur S., Marie-Vivien D., Vagneron I., Moustier P., 2019. What market dynamics for promoting an agroecological transition? Chapter 15. *In* Côte F.X., *et al.* (eds): *The agroecological transition of agricultural systems in the Global South*. Collection Cirad-AFD Agricultures et défis du monde. Éditions Quae, Versailles: 271-291.

(4) Lemeilleur S., Allaire G., 2018. Système participatif de garantie dans les labels du mouvement de l'agriculture biologique. Une réappropriation des communs intellectuels. *Économie Rurale*, 365: 7-27. https://doi.org/10.4000/economierurale.5813

Participatory guarantee systems that reconnect consumers and producers

Participatory guarantee systems (PGS) are increasingly important institutional innovations that link agroecological production with responsible consumption. While today's dominant models of assurance for sustainable agriculture allocate oversight authority to third-party certifiers or standard-setters, PGS "certify producers based on active participation of stakeholders and are built on a foundation of trust, social networks and knowledge exchange."[1] PGS focus on the democratization of knowledge whereby oversight systems for compliance with standards are created by producers, public-sector officials, food service actors, experts and consumers. Together they ensure that the techniques are adopted and that the audit is a learning process for all actors involved.[2] PGS provide a direct guarantee—through the formation of local markets—for sustainably produced food. PGS thus ensure the scaling-out of agroecological innovations as they typically emerge from farmer-led initiatives to co-create knowledge, and through alliances with consumer-led diverse economies.

The purpose of PGS is to assure actors' responsibility for producing food sustainably. This method dates back to organic agriculture experiments conducted in USA, France, Japan and Brazil in the 1960s. Participatory audits were one of the original ways of controlling organic agriculture techniques before the third-party certification model became dominant in policy and practice.[3] These pioneers felt that—to be in line with the environmental ethics of organic farming—farmers' expertise had to be trusted when verifying their practices. This certification approach eroded in the 1980s as organic farming was gradually mainstreamed into national legislation and international trade systems. However, PGS re-emerged in the 2000s, reaching 76 countries worldwide by 2019. Most of these countries were located in the Global South, where PGS arose to offset the dominant standard-setting paradigm adopted by non-governmental and corporate actors in the Global North via third-party certification. The latter was considered too costly for many small-scale producers and not applicable to local agroecological and socio-technical conditions. **As of 2021, 11 countries and one regional intergovernmental organization have included PGS as a legitimate form of certification for agroecological or organic products in domestic markets, i.e., Bolivia, Brazil, Chile, Costa Rica, French Polynesia, India, Madagascar, Mexico, New Caledonia, New Zealand, Philippines and the East African Community (Kilimo Hai standard).**



▲ *PGS innovation mechanism.* © A. Loconto

▼ *Quezon PGS Certification Committee Meeting, Lucena, Philippines. 7 March 2019.* © A. Loconto

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(1) Loconto A., 2017. Models of assurance: diversity and standardization of modes of intermediation. *The Annals of the American Academy of Political and Social Science*, 670(1): 1-21.

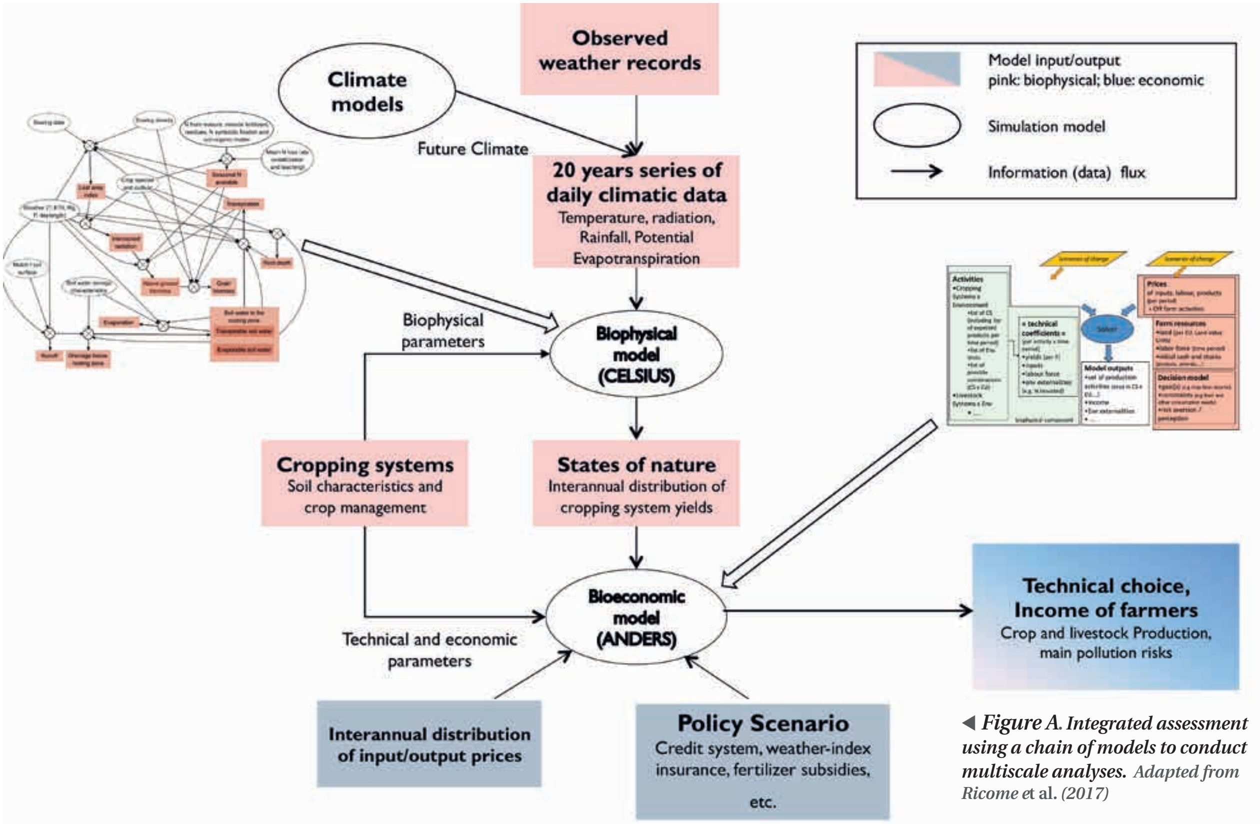
(2) Loconto A., Hatanaka M., 2018. Participatory guarantee systems: alternative ways of defining, measuring, and assessing 'sustainability'. *Sociologia Ruralis*, 58(2): 412-432.

(3) Niederle P., Loconto A., Lemeilleur S., Dorville C., 2020. Social movements and institutional change in organic food markets: evidence from participatory guarantee systems in Brazil and France. *Journal of Rural Studies*, 78: 282-29.

Assessing trade-offs between environmental and socioeconomic issues in agroecological systems

To be able to achieve the agroecological transition, it is necessary to resolve trade-offs between social, economic and environmental dimensions of sustainability that farmers have to cope with when changing their farming practices. For instance, replenishing the soil organic matter content will increase the soil carbon stock, thereby contributing to climate change mitigation, while also enhancing soil fertility. Consequently, household incomes may increase through the higher crop yields achieved without mineral fertilizer applications, i.e. with reduced emissions from the industrial sector. However, when this *a priori* 'win-win' situation is achieved at the expense of crop residue grazing by livestock, farmers may be obliged to purchase supplementary feed whose carbon footprint could be greater than that 'saved' by restoring crop residues to the soil. Moreover, improving soil fertility—and thus agricultural production—takes several years, and the return on this investment is therefore not immediate and is highly dependent on the prevailing soil-climate conditions. This example demonstrates: **(i) the complexity of comparing different production systems in terms of their sustainability, and (ii) the need to contextualize the analysis**. In addition to farmers, other actors have a key influence on agricultural practices, including agricultural policymakers and consumers.

Sustainability assessment is geared towards informing various actors on the expected impacts of changing practices. Standard assessment methods—such as life cycle or ecological footprint analysis—focus on the environmental dimension of sustainability. This is particularly problematic with regard to family farming in the Global South, where socioeconomic sustainability is paramount owing to farmers' poor livelihoods. When combined in integrated assessments, models focused on cropping, farm household decision making, territorial resource flows and their collective management could generate indicators covering all sustainability aspects (Fig. A). Given that these models have been developed in a conventional intensive farming framework, further research is needed to tailor them to the needs of agroecological systems. Moreover, it would be pointless to attempt to address complex systems in a perfectly objective manner. **Research should also focus on ways to take the aims and viewpoints of the different stakeholders into account (Fig. B), while dovetailing them with the available models and scientific knowledge. This could be achieved by clarifying the associated assumptions, simplifications, uncertainties and trade-offs between contradictory indicators. One challenge is to embed these assessments in approaches that reflect a dynamic view of the systems studied and their context so as to avoid reliance on innovations that might quickly turn out to be obsolete due to global changes. Agroecological systems assessments should be multidisciplinary, multiactor, multiscale and prospective in scope.**



◀ ***Figure A.** Integrated assessment using a chain of models to conduct multiscale analyses.* *Adapted from Ricome* et al. *(2017)*

◀ ***Figure B.** A between-actor discussion on ecological intensification support policies.*
The debate is prepared via a board game (here © TerriStories), staging the responses of a given production system to potential policies and climate hazards. This type of approach complements model-based assessments and helps integrate actors' viewpoints. www.terristories.org/fr/jeu.html.
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• Affholder, F., Bessou, C., Lairez, J., Feschet, P., 2019. Assessment of trade-offs between environmental and socio-economic issues in agroecological systems. *In* Côte F.-X., *et al.* (ed.): *The agroecological transition of agricultural systems in the Global South*. Éditions Quae, Versailles, France: 219-238.

• Ricome A., Affholder F., Gérard F., Muller B., Poeydebat C., Quirion P., Sall M., 2017. Are subsidies to weather-index insurance the best use of public funds? A bio-economic farm model applied to the Senegalese groundnut basin. *Agric. Syst.* 156: 149-176.

Supporting the ecologization of agriculture in the light of open innovation challenges

Interorganizational collaboration between public, private and civil society organizations is key for boosting social innovations that address core problems related to ecological intensification implementation in local contexts. The main challenges concern the 'openness' of organizations, i.e. the essential trade-off between competitiveness, control, ownership and short-term achievements and, on the other hand, knowledge and value sharing, creativity, uncertainties and broader achievements[1]. CIRAD seeks to meet these challenges by supporting institutionalized multiactor innovation platforms, project innovation partnerships or loose innovation networks, that propose coordination mechanisms and a learning environment for open innovation. In Burkina Faso, three of these different coordination mechanisms were supported in order to solve different types of problems: a research-led innovation platform that was developed to test a conservation agriculture model at the village scale[2]; a facilitated network of membership-based organizations promoting agroecology that has developed the first organic label at the country level; and an end-user-led innovation partnership for the development of agroecology advisory services by farmer organizations[3].

The outcomes highlighted that interaction protocols were strongly needed to help the diverse range of organizations share a common vision on aspects requiring change while aligning their objectives and activities to achieve viable solutions. The most immediate outcomes were increased collaboration capacities through mutual trust and a joint innovation agenda. Longer-term outcomes, especially new technology-related ones, were hinged on the quality of the facilitation process by third parties—when external facilitators were able to manage joint knowledge production and material resource availability in a timely manner, this boosted the pace of the design and scaling of innovative viable solutions[4]. Based on these new insight regarding success factors for open innovation, CIRAD developed an R&D agenda at the crossroads of innovation management and organizational studies to promote the coproduction of knowledge with practitioners on third-party mediated open innovation to accelerate agroecological transitions in the Global South.

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For further information

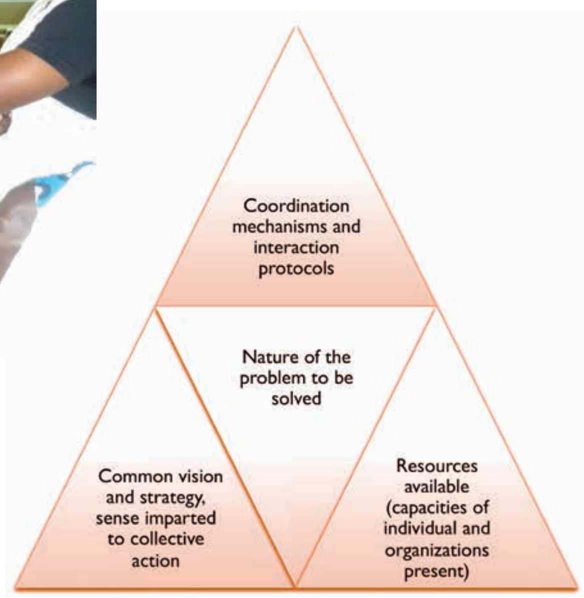
(1) McGahan A.M., Bogers M.L., Chesbrough H., Holgersson M., 2020. Tackling societal challenges with open innovation. *California Management Review*, 0008125620973713.

(2) Dabire D., Andrieu N., Djamen P., Coulibaly K., Posthumus H., Diallo A., Karambiri M., Douzet J.-M., Triomphe B., 2017. Operationalizing an innovation platform approach for community-based participatory research on conservation agriculture in Burkina Faso. *Experimental Agriculture*, 53(3): 460-479.

(3) Toillier A., Kola Nomandé P., Mathe S., Tsafack S., Dabire D., Triomphe B., 2019. The ecologisation of agriculture through the prism of collaborative innovation. *In*: Côte F.-X. *et al.* (eds), *The agroecological transition of agricultural systems in the Global South*. Ed. Quae, Versailles: 251-270. www.quae-open.com/produit/114/9782759230570/the-agroecological-transition-of-agricultural-systems-in-the-global-south

(4) Toillier A., Kola P., 2020. Le rôle des pratiques de gestion interorganisationnelles dans le renforcement de communautés d'innovation inexpérimentées : étude exploratoire au Burkina Faso. *Innovations*, 2: 191-220.

◀ ***Facilitation techniques to support open innovation.***
Top: Facilitating bridging events between innovators and policymakers (CDAIS project)© CIRAD
Bottom: Facilitating social network analysis (CDAIS project). © CIRAD



▼ ***Factors of success of interorganizational collaboration for open social innovation.***
Adapted from Toillier et al. *(2019)*

Territorial mechanisms as common goods to achieve the agroecological transition

Agroecology must be viewed beyond: (i) technical changes alone; (ii) the field and farm; and (iii) sectoral and value chain spheres. Defining new resource usage rules, implementing adapted public policies, creating new public markets for agroecological products, producing ecosystem services and bringing together actors in associations or cooperatives are necessary steps in the agroecological transition. These processes require multifaceted, collective and institutional action coordinated at all scales. The territorial mechanism thereby seeks to shape collective action by establishing new institutional arrangements between actors, i.e. playing rules and their uses within territories. This is an explicit assembly of material (organizational structure, platform, instruments, tools, etc.) and immaterial (ideas, knowledge, attitude, etc.) elements, often of political scope.

Each system implements norms that it tailors to its needs at its own pace using specific instruments. In Brazil[1], many organizations have been created in the semiarid region to provide policy support for local agroecological proposals; local production arrangements, set up within the framework of the rural territorial policy, while seeking to consolidate family farmer integration in production systems and to bolster the agroecological dimension; territorial charters and certifications (e.g. Paragominas in the eastern Amazon) are defined to promote more ecological agricultural practices, linked to new land and resource usage rules and to a change in the power relations. **Applying common goods* management methods to the territorial system ensures greater efficiency because the rules co-constructed by the actors are more tailored to the specific situation.** These rules must be subject to dispute management and self-control so as to be able to adjust them. These processes encourage learning and contribute to the legitimacy of territorial mechanisms. They modify relationships with territories by providing a common vision of problems and solutions, by participating in the governance of the agroecological transition and by dovetailing individual, collective and governmental actions. **The territorial mechanism is a key element in the institutionalization of agroecology in territories.**

* A shared and collectively managed resource by a community.

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For further information

(1) Piraux M., Tonneau J.P., Poccard-Chapuis R., 2019. Territorial mechanisms: common goods for undertaking the agroecological transition. *In* Côte F.-X. *et al.* (eds): *The agroecological transition of agricultural systems in the Global South*. Éditions Quae, Versailles: 293-312. (Agricultures et défis du monde).

◀ ***Building natural resource management rules in the Brazilian Amazon.*** *© M. Piraux*

Modeling and the systems paradigm

Agroecological transition as a focus of interdisciplinary research

Agroecological challenges must be addressed by interdisciplinary approaches, firstly based on knowledge acquired through modeling to enable the development of adaptation solutions and monitoring tools, and secondly geared towards defining and implementing a new paradigm to reconnect mankind to the biosphere (including the legal implications). Three exemplary models have been developed by the ESPACE-DEV research unit through a socioecological coviability approach:

- An oasis agrosystem (palm groves in Djibouti) that fosters sustainable agricultural development in drylands, but it is being undermined by climate change. A method based on GIS, *in situ* and remote sensing data has shed light on the adaptive capacity of palm trees under water and salt stress. Knowledge regarding this agrosystem in the medium and long term (datasets in semantic web formats) may be tapped to set up and implement a system for its monitoring.

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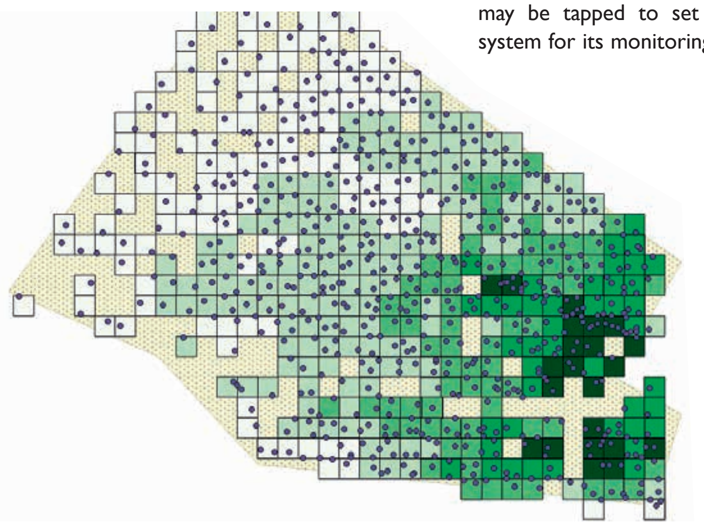
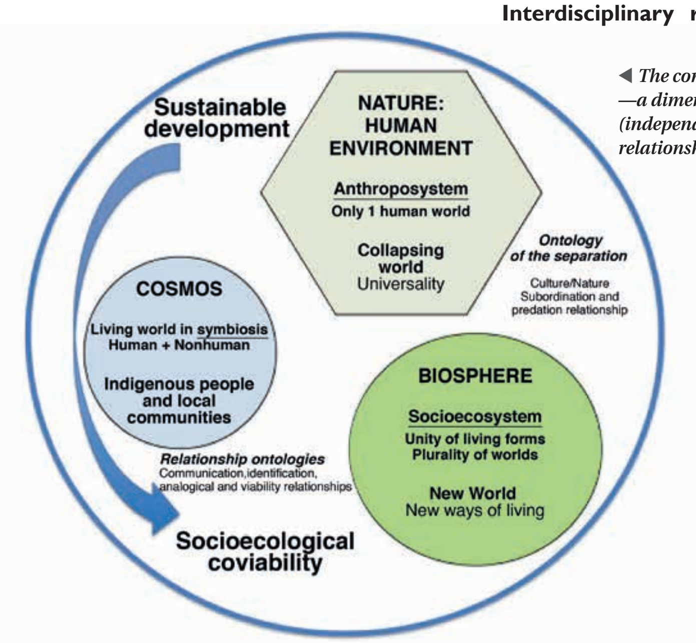


▲ ***Mohamed Djama plot near Ali Sabieh, Djibouti: Google Maps aerial view (left) and laboratory analysis (right).*** *© M. Djama*

- A climate change simulation database focused on studies of future impacts and risks for agriculture in West Africa. The aim here is to design potential scenarios, such as adaptation strategies, that could enable implementation of transition solutions through a web portal* cobuilt with African actors and partners.
- An innovative process cobuilt by local actors (Cévennes, France) and researchers has given rise to an intercommunal pastoral pact** formalizing an agroecological territorial regulation.

Ecological imperatives must be addressed via the transformation of modern societies in both the Global North and South. The relationship between mankind and the biosphere must be rebooted to achieve this change. The socioecological coviability concept-paradigm refers to the joint viability between living beings. This systemic interdependence underpins a new pathway regarding the relationship between human societies and the environment and agriculture in the Anthropocene. **Agroecology is a socioecological coviability model. Interdisciplinary research is focused on interactions starting from practices, regulations and the diversity of interlinked life forms constituting socioecosystems.** Our research is geared towards developing methods for their evaluation, defining indicators regarding the appropriation of this paradigm by stakeholders at pilot sites and testing legal regulations on a territorial scale.

*Climate scenario portal: https://retd1.teledetection.fr/climap/proj
** *Pacte pastoral*: https://caussesaigoualcevennes.fr/competences/pacte-pastoral



◄ *The contribution of agroecology —a dimension that goes beyond nature (independent of societies) for a coviable relationship with the biosphere.*

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- Barrière O. *et al.* (éd.), 2019. *Coviability of social and ecological systems: reconnecting mankind to the biosphere in an era of global change.* Vol.1 et 2. Springer.
- Barrière O., 2017. Human relationship to the land from a legal perspective as a human and environmental security challenge. *In* Behnassi M., McGlade K. (eds.), *Environmental change and human security in Africa and the Middle East.* Springer: 259-304.

What public policies to support agroecology in Latin America and the Caribbean?

Latin American agroecology proposes the transformation of conventional agrifood systems. It is driven by social movements that have succeeded in forming coalitions that have promoted its public policy integration. These policies involve a range of instruments that are often embedded in programs that also support organic and sustainable agricultural systems. However, while these two types of agriculture propose more ecological practices, they do not question the basis of the conventional agrifood system. The implementation of instruments to support agroecology therefore depends on the power relations established within each country. These policies remain fragile due to the continued support for conventional agriculture. The challenge is therefore to convince farmers, consumers and policymakers to a greater extent on the importance of issues regarding public health, food security and sovereignty. Three elements underpin these policies: (i) pressure exerted by social movements; (ii) the search for solutions to economic and environmental crises caused by specialized agroindustrial models and extreme climatic events, or geopolitical and financial crises; and (iii) partial responses by public authorities to environmental issues (the sustainable rural development act in Mexico, recognition of the environmental benefits applied to agriculture in Costa Rica, and the sustainable agriculture plan in Chile). Despite this progress, agroecological production is still scattered and limited, except in Cuba where it accounts for 65% of agrifood products.

▼ *Agroecological farmers' market in Buenos Aires, Argentina.* © C. Moyano

The implementation and monitoring of agroecology-oriented policies are dependent on coordination between different actors and levels, i.e. between social movements supporting alternative models and public organizations, between standards institutions and between national and territorial governments. Policy instruments supporting agroecology must be flexible and designed at several levels to be able to convince both producers and decision makers, as is the case regarding the Ecoforte program* in Brazil which supports the structuring of territorial agroecological knowledge management networks, and the ProHuerta program* in Argentina which promotes local agroecological farmers' markets. The territorial level approach is essential to enable producers, consumers and their organizations to tailor these instruments to their specific setting.

* Ecoforte, Program to develop and consolidate agroecology and organic agriculture networks
ProHuerta program, Argentina: http://prohuerta.inta.gov.ar

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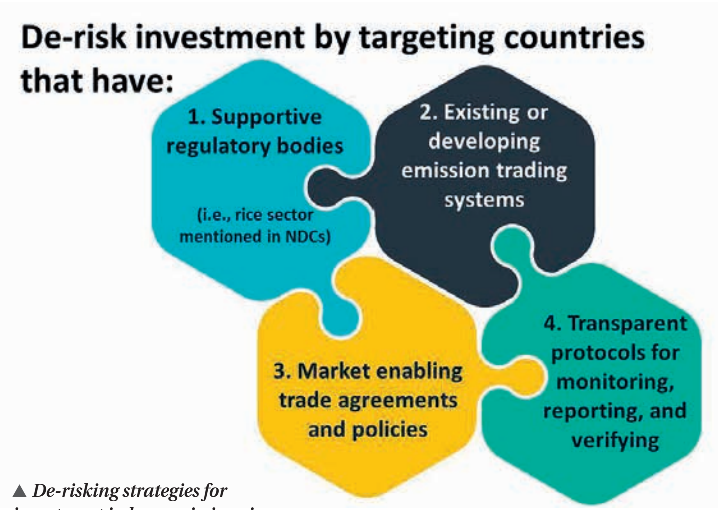
For further information

Sabourin E., Le Coq J.-F., Fréguin-Gresh S., Marzin J., Bonin M., Patrouilleau M.M., Vázquez L., Niederle P., 2018. Public policies to support agroecology in Latin America and the Caribbean. *Perspective*, 45. CIRAD, Montpellier. https://doi.org/10.19182/agritrop/00020

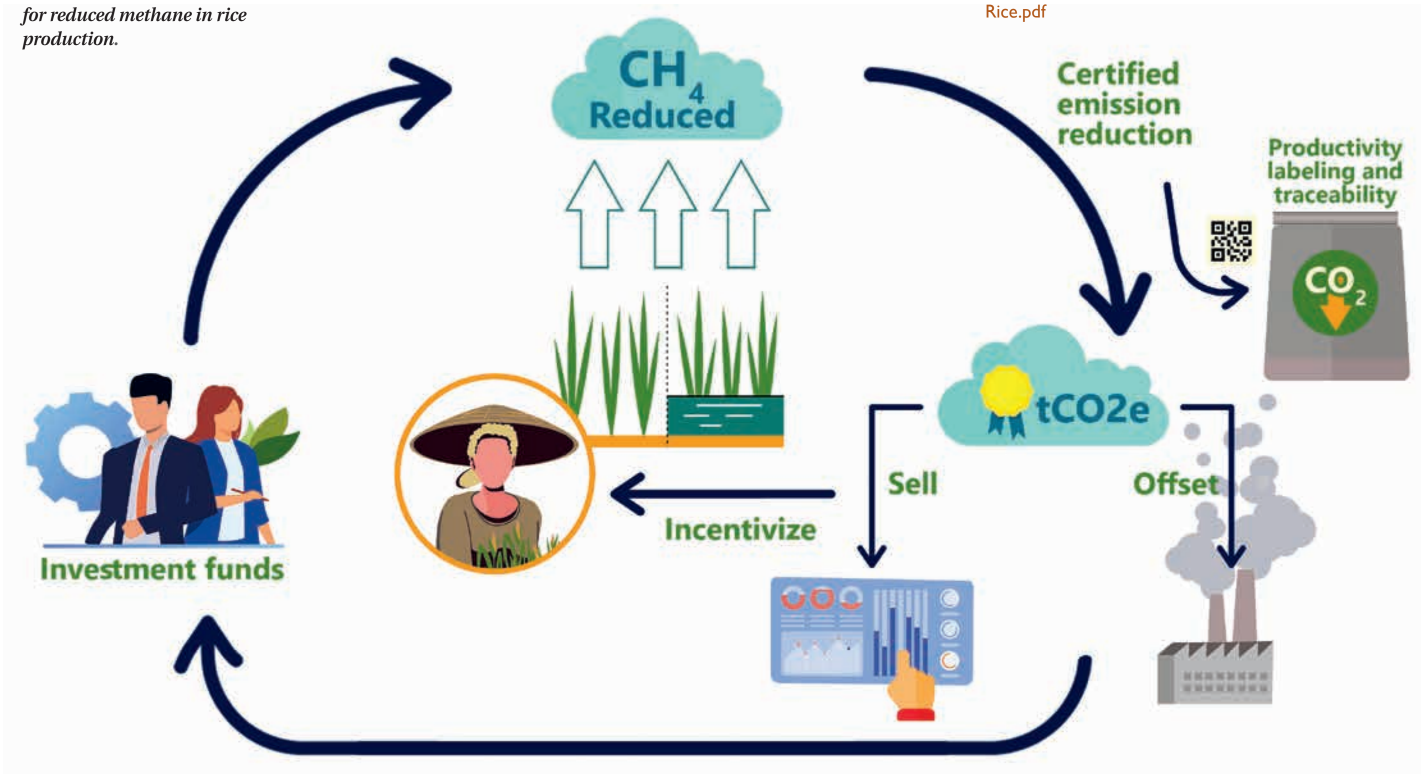
Tapping the carbon market as a sustainable finance source for low-emission rice

The lack of financial incentives for environmental benefits is a major constraint to scaling agroecological production practices in rice landscapes. This barrier applies to both producers who are required to change their practices to meet sustainability standards and to investments that hinge on financial return. Carbon credits for rice can be generated by eligible farmers that follow standardized protocols for emission reduction and reporting guidelines. The proof-of-concept for the efficiency of carbon credits in smallholder contexts, though, has yet to be achieved. Paddy rice provides one of the most promising options for reducing emissions in the crop agriculture sector due to high baseline emissions, available mitigation technologies, and globally established accreditation protocols[1]. The main activities to reduce on-farm emissions from rice include controlling irrigation through alternate wetting and drying, and improving fertilizer and residue management[2]. However, the uncertainty and risk due to complex and costly validation/verification systems that are largely unconducive in smallholder contexts currently hinders success. **Given that the majority of rice is grown by smallholders in low- to middle-income countries, the strategies outlined to de-risk investment include targeting countries that have supportive regulatory bodies, emission trading systems, enabling trade agreements, and transparent protocols for monitoring/reporting/verification (MRV).** Launching appeals to multilateral climate funds and blended finance mechanisms is recommended to support sovereign green bonds and diversify investment[3]. At smaller scales, carbon credits allow private investors to offset their own emissions or monetize emission reduction. Alongside other environmental co-benefits such as water saving, new possibilities for stacking benefits with aligned accreditation protocols are emerging, although this trend has yet to be substantiated. The next steps to advance the carbon credit market for low-emission rice are to adapt the carbon registry protocols for MRV to ensure the economic viability of the process in a smallholder context in low- and middle-income countries.



▲ *De-risking strategies for investment in low-emission rice production.*

▼ *Investment in carbon credits for reduced methane in rice production.*



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(1) United Nations Framework Convention on Climate Change. 2020. Clean Development Mechanism Methodology booklet. https://cdm.unfccc.int/methodologies/documentation/meth_booklet.pdf#AMS_III_AU

(2) Tran V.T., Mai V.T., Nguyen T.D.T., Le H.A., Richards M.B., Sebastian L., Wollenberg E., Vu D.Q., Sander B.O., 2019. An investment plan for low-emission rice production in the Mekong River Delta region in support of Vietnam's Nationally Determined Contribution to the Paris Agreement. *CCAFS Working Paper,* 263. Wageningen, Netherlands: CGIAR Research Program on Climate Change, Agriculture and Food Security (CCAFS). www.ccafs.cgiar.org

(3) Earth Security Group, 2019. *Financing sustainable rice for a secure future: innovative finance partnerships for climate mitigation and adaptation.* https://earthsecuritygroup.com/wp-content/uploads/2019/11/ESG-Financing-Sustainable-Rice.pdf

Progress and persistent challenges of inclusive business models in cocoa and oil palm sectors in Ghana and Peru

Inclusive business models (IBM) connect smallholders and other low-income people with buyers, processors and traders in agricultural and forest product value chains. Value chain actors engage with each other through diverse institutional arrangements, including international (e.g. UN Global Compact, zero deforestation) and industry standards (e.g. Roundtable on Sustainable Palm Oil, Cocoa and Forests Initiative), certifications (e.g. fair trade, organic), and contract farming. With the aim of gaining a better understanding of how IBM perform both from a smallholder and company perspective, we studied IBM in Ghana and Peru in two phases: (i) a scoping study on IBM in three value chains in Ghana (cocoa, oil palm, rubber) and Peru (cocoa, coffee, oil palm): analysis of secondary information, key informant interviews (n = 39) among aggregators and service providers, and focus group discussions (FGD, n = 3) for feedback and validation with value chain stakeholders; and (ii) an in-depth study based on a household survey among randomly selected households participating in IBM (n = 948) in two prioritized value chains per country (cocoa, oil palm), with two IBM per chain, and an FGD (one per IBM) for feedback and validation by smallholder representatives. Our analysis focused on household assets (human, social, natural, physical and financial capital) for assessing the socioeconomic performance of IBM, and on landscape-level indicators for their environmental performance.

Across the eight IBM and the five capitals, we found significant asset building among smallholder households. However, the results varied widely across IBM cases and households. We also found broad variation in terms of environmental performance, particularly as regards the contribution of each IBM to forest conservation and deforestation, respectively. Our analysis showed the extent to which **given institutional arrangements contribute to measured or observed outcomes, along with other drivers of change. We conclude by showcasing opportunities for designing and implementing IBM in ways that enhance smallholder asset building, commercial viability and environmental performance of IBM.**

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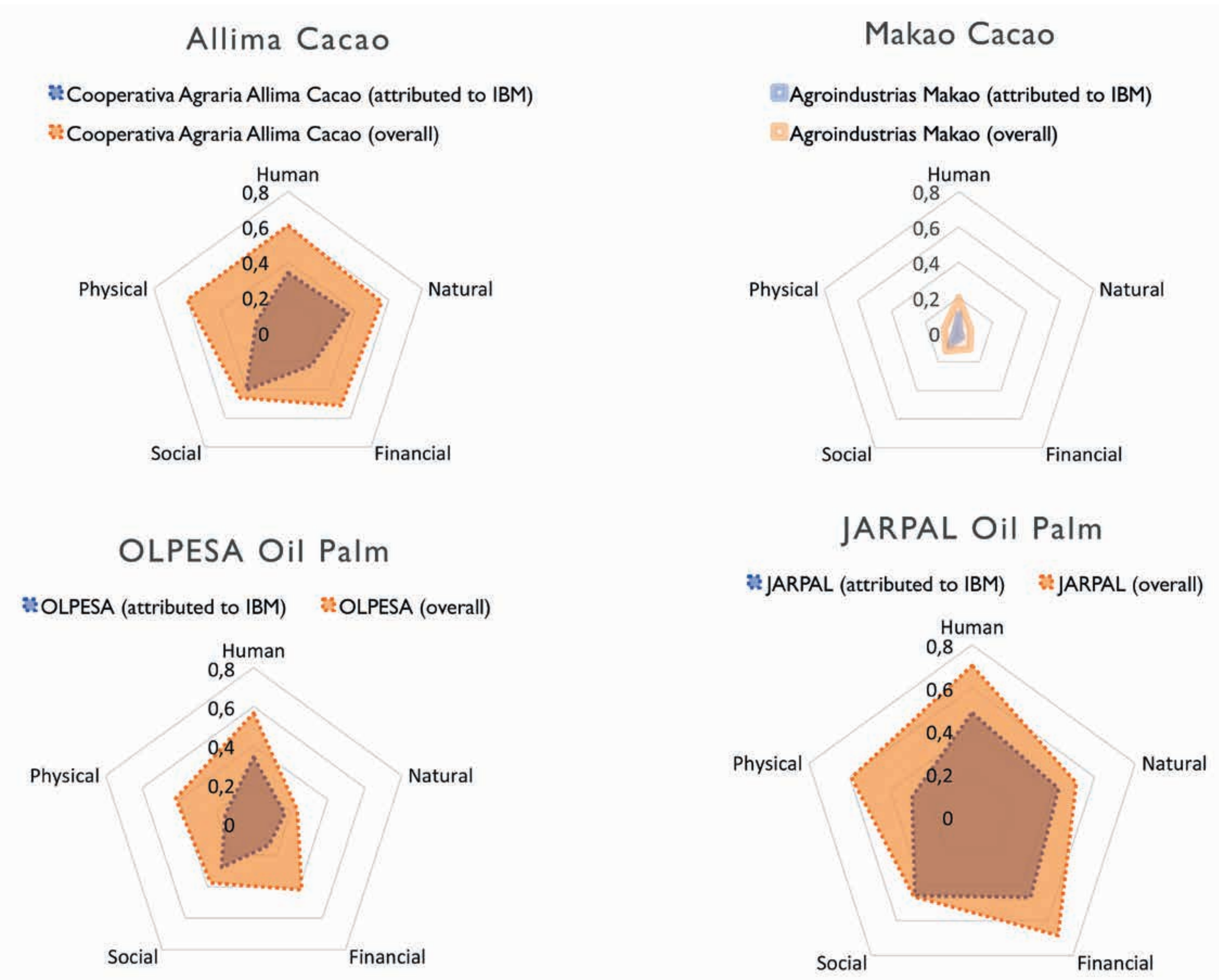
• Schoneveld G.C., 2020. Sustainable business models for inclusive growth: towards a conceptual foundation of inclusive business. *Journal of Cleaner Production*, 124062.

• Stoian D., Foundjem D., Kikulwe E., Blare T., Menza G., Van der Haar S., 2021. *Progress and persistent challenges of inclusive business models: insights from the cocoa and oil palm value chains in Ghana and Peru*. ICRAF, CIFOR and Alliance of Bioversity International and CIAT, Nairobi, Kenya *(forthcoming)*.



▲ ***Asset building and attribution in four inclusive business models in Peru.*** *Source: Stoian* et al. *(2021)*

Accelerating agroecological transitions

The hidden private-public ecosystem

The goal of achieving global food and nutrition security, while simultaneously reducing impacts on the natural environment and improving welfare is complex, and characterized by several trade-offs[1]. Simultaneous transitions are required at multiple levels—economic, socio-ecological and politico-institutional—to change the 'business as usual' situation. Sustainable agricultural practices through agroecology principles are promoted as a paradigm shift to transition food systems at multiple scales while ensuring regenerative use of natural resources. However, the existing sustainability and agroecological transition frameworks informing decision-making are dominated by social-ecological and social-innovation system concepts[2], while the private-public ecosystem is often neglected and its role in accelerating food systems transformation has generally remained concealed. To contribute to filling this knowledge gap, new initiatives such as the "Agroecological transitions" project aims at innovating pathways for long-term incentives, and private and public investments for agroecological transitions. In this context, we apply a horizon-scanning literature review approach to design a private-public ecosystem transition framework. This framework unpacks a hidden private-public ecosystem into: (i) incentives and investment; (ii) bridging institutions; (iii) research and development; and (iv) start-ups and businesses. **The blend of interactions within the private-public ecosystem (e.g. regulation, investment and incentive mix) influence food systems from pre-production to post-consumption and achieving agrotecological transition outcomes** (Figure).

With the increasing demand for food system transparency, incentivizing businesses to integrate holistic agroecological metrics in traceability tools is fundamental for transforming food systems. This requires optimal collaboration within the private-public ecosystem to leverage investments (e.g. blended finance, impact bonds, etc.) while incentivizing the private sector through intellectual property rights, tax breaks, and ecological subsidies at multiple food system levels. A more visible private-public ecosystem provides new opportunities to accelerate simultaneous agroecological transitions via de-risking, mobilizing investments, and balancing trade-offs to contribute to more socially equitable, economically efficient, and environmentally friendly food systems.

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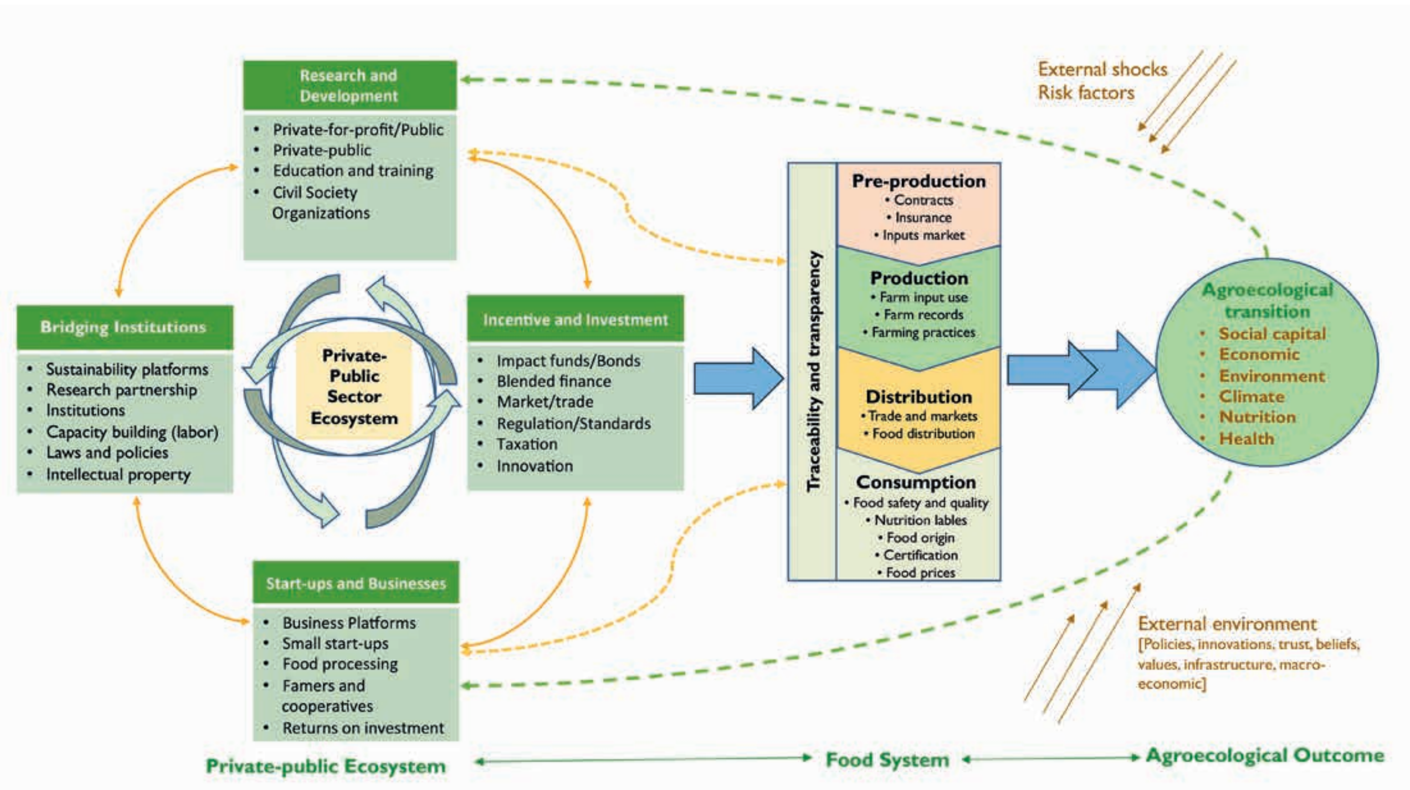
For further information

(1) Mockshell J., Kamanda J., 2018. Beyond the agroecological and sustainable agricultural intensification debate: is blended sustainability the way forward? *International Journal of Agricultural Sustainability*, 16(2): 127-149.

(2) Ollivier G., Magda D., Mazé A., Plumecocq G., Lamine C., 2018. Agroecological transitions: what can sustainability transition frameworks teach us? An ontological and empirical analysis. *Ecology and Society*, 23(2): 5.



▲ *Private-public ecosystem transition framework.*

Unlocking finance for agroecology at scale

Private investors seek a return that offsets the risk they run when investing, while also seeking the benefits of scale (low transaction costs per invested currency unit). Public finance, on the other hand, is less concerned with financial return and more with contributing to sustainable development. However, public funds are limited and insufficient to meet the needs to achieve the SDGs of zero hunger, good water for all, sustainable consumption and production, climate action and life on land[3]. Agroecology is well positioned to contribute to these SDGs but several challenges must be overcome for its upscaling[2], including accessing private money to finance the agroecological transition from conventional agriculture. In agroecology, co-creation of local and scientific knowledge and equitable stakeholder involvement can lead to locally adapted practices[4], which may vary according to social, economic and ecological settings, and for which the range of potential outcomes is still insufficiently documented. This contrasts with investors' needs for scale and predictability of outcomes.

Innovative finance structures, especially those blending public and private finance, are able to direct more money into sustainable agriculture initiatives but have been more successful for larger initiatives. Besides scale and risk, several additional barriers exist for smaller scale initiatives to access finance[3]. **Lessons learned from local initiatives that have been able to overcome those barriers could well apply to agroecology financing. A common denominator of these initiatives is the building of local financial infrastructure,** such as bank branches, credit unions, savings and loans associations, cooperatives or mobile banking systems. Combining these with technical assistance for agroecological production and farm administration can generate successful business initiatives. For example, in Uganda, ECOTRUST blends public funds that are used to help farmers increase their financial literacy and start-up their agri-related businesses, along with private funds received from carbon credit buyers[1]. Carbon purchase contracts were used as income guarantee for farmers' loan applications with local financial institutions. Whereas actual income (carbon and non-carbon) was used to pay back loans, as well as to create a revolving fund that replaces public funds in supporting new start-ups that contribute to generating new carbon credits while also producing non-carbon products and services.

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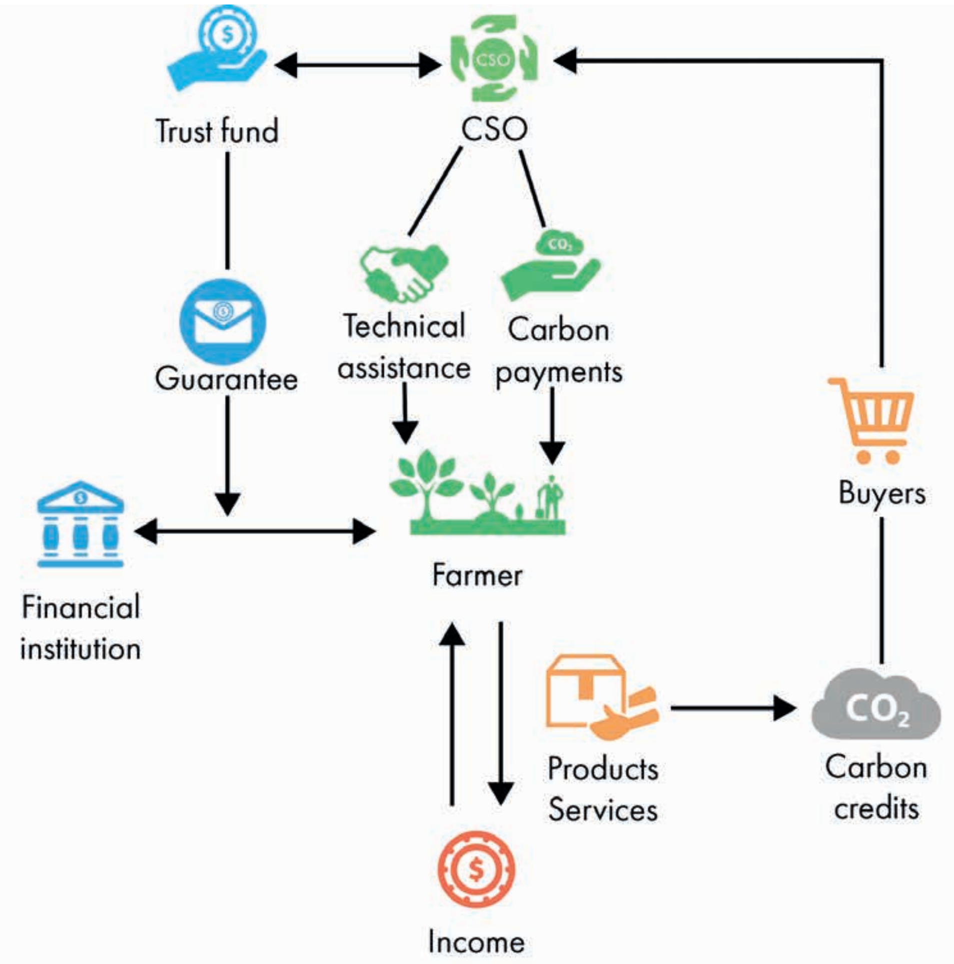
(1) Byakagaba *et al*., forthcoming. *The trees for global benefit financial system*. Report. Ecotrust/Tropenbos, Uganda/ Netherlands.

(2) FAO, 2018. *Scaling up agroecology initiative: transforming food and agricultural systems in support of the SDGs*. Food and Agriculture Organization of the United Nations, Rome, Italy.

(3) Louman B., Meybeck A., Mulder G., Brady M., Fremy L., Savenije H., Gitz V., Trines E., 2020. *Innovative finance for sustainable landscapes*. Working Paper 7. Bogor, Indonesia: The CGIAR Research Program on Forests, Trees and Agroforestry (FTA).

(4) Wezel A., Herren B.G., Kerr R.B., Barrios E., Gonçalves A.L.R., Sinclair F., 2020. Agroecological principles and elements and their implications for transitioning to sustainable food systems. A review. *Agronomy for Sustainable Development*, 40(6): 1-13.



▲ ***Simplified diagram of how a local financial mechanism could look like if carbon sequestration were to be one of the services provided by an ecoagricultural farm.*** *Modified from Byakagaba (forthcoming).*

▲ ***Agroforestry plot in Juaboso, Ghana.*** *© Hans Vellema/TBI*

PART 3

Key processes, methods and tools for agroecology

This part complements the previous chapters which were structured according to an agrifood system transition gradient. It is crosscutting to these chapters and shows how France and CGIAR are working to provide essential agricultural and ecological knowledge, as well as research methods and tools for initiating the transformation of current schemes into agroecology-oriented systems, agrifood value chains and territories. It spans across different spatial scales, human and social sciences as well as ecology and biotechnology. This part covers research carried out within institutions and research infrastructures (national or international), but also in transdisciplinary way, working with stakeholders, local or national social initiatives that foster the transition of agrifood systems.

Mobilizing knowledge on ecological processes for agroecology: Incorporating more biodiversity in agroecosystems is a key way to enhance their resilience to climate change, overcome barriers to access to resources such as water and nutrients, and curb the spread of diseases. Agroecology can benefit from better identification, knowledge and use of intra- and inter-specific genetic resources, crop associations and the role of this diversification. A few examples presented here illustrate some scientific and technological approaches used to explore the role of this diversification, through: contributions of plant genomics and phenotyping and plant associations to agroecology (Hippolyte & Mia; Tardieu *et al.*), the development of seed banks (Fadda *et al.*) and crop associations (Tchamitchian *et al.*).

Soils and their associated biodiversity influence the functioning of agroecosystems, particularly with regard to their structure, and thus their moisture and biogeochemical conditions, access to water and nutrient resources, and soil food webs. Two examples illustrate this role, i.e. one on macrofauna (Jouquet *et al.*) and the other on soil microarthropods (Beggi & Menta).

Methods and tools for better agricultural practices and landscape management: Agricultural practices such as fertilization and irrigation need to specifically address agroecosystem needs. The aim here is not at achieving maximum yield but rather at stabilizing production over time to meet food and nutrition objectives, and at minimizing inputs such as water and nutrients so as to safeguard these resources along with the health of terrestrial and aquatic ecosystems. Careful management is essential as resources decline. This is especially important in the most vulnerable and resource scarce contexts. Two examples illustrate this, i.e. one on fertilization in Sahelian conditions (Vanlauwe *et al.*) and the other on irrigation (Van Rooyen). At the territorial level, the restoration of landscapes and the ecosystem services provided by trees calls for renewed consideration of tree species choices both in forests (Fremout *et al.*) and agricultural landscapes (Coudel *et al.*).

Methods and tools for assessment and learning to support agroecosystem transitions: Knowledge—especially ways of acquiring it—and learning methods are a lever for building solutions step-by-step and locally adapted, which is essential for the design of agroecological systems. Farmers and stakeholders in the sector need to conceive specific benchmark systems tailored to the prevailing socioeconomic and environmental contexts and conditions rather than applying generic reference systems. This needs to rely on experience sharing and stakeholder networks (Labeyrie *et al.*), guides

▼ *Co-building of environmental service payment scenarios in a territorial planning setting in Yunnan, China.*
© J.C. Castella/I-REDD+ project, 2012

(Coe & Sinclair), multicriteria assessment methods for agricultural systems, such as life cycle analysis, which is particularly relevant for the analysis of recycling solutions or complementarities between systems (animal-plant) (Aubin & Paillat; Van der Werf *et al.*), crop system modeling platforms (Raynal & Casellas), agroecosystem analysis and management tools, such as decision support and ecosystem status analysis tools, including soil analysis tools (Brauman & Thoumazeau). This part is illustrated by several examples dealing with these different aspects. Multicriteria assessment or modeling approaches focused on systems that are already in place or under development, through individual or collective scenario building, are often hampered by datasets that are not sufficiently comprehensive to describe the complexity of agroecological systems. New data acquisition methods and tools along the transition processes are complementary to these approaches.

Living labs, as facilitators of agrifood chain transformation: Living labs are open innovation mechanisms that promote transdisciplinary research with an array of stakeholders from agricultural and food sectors, environmental and food NGOs, public authorities and the private sector. They are useful for designing transitions throughout the entire value chain—from producers to consumers—by associating suitable governance methods, economic instruments and public policies. These initiatives are often tailored to territorial scales, while being facilitators and incubators for innovation (Neyra *et al.*). The solutions can be highly robust because from the outset they take key actors and the environmental and socioeconomic contexts into account. Although living lab initiatives have been developing for several years, it is still too early and there are not enough of them to be able to draw full conclusions on their effectiveness. Yet they may have a ripple effect in terms of stimulating innovation dynamics for agroecology, exchanging values, building visions and setting transformations in motion. A few examples of living labs are presented in this part (Mambrini-Doudet *et al.*; Andrieu; Gardeazabal *et al.*).

Contribution of digital technology to agroecology: Digital technology is being rolled out throughout the agricultural sector. For agroecology, this technology can be applied to monitor biological dynamics (in soil, plant cover, etc.) using soil sensors, proxies and remote sensing, or even—which is the ultimate goal—to better manage agroecosystems (Biradar). Digital technology also concerns the overall information domain, decision support tools, and information management and exchange between actors from production to consumption. However to foster agroecological transitions, digital technology needs to respond to the needs of actors along the value chains, and not the reverse as is often the case. Adapted tools, training and information need to be provided and tailored to the use and users, the variety of agroecological systems and related transitions. Digital technology substantially contributes to agroecology and to its scaling up, as clearly illustrated here with two concrete examples (Reboud & Gée; Reboud & Crauser).

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Mobilizing knowledge on ecological processes for agroecology

Contribution of genomics to agroecology

To what extent could scientific advances achieved through projects funded by the French National Research Agency (ANR) in animal, plant and microbial genomics contribute to agroecology research? The development of new technologies for studying the genome and its expression, alongside the genomics research carried out over the last two decades, have led to cognitive and methodological breakthroughs on the functional features of living organisms. These advances could contribute to agroecology research, which aims to better characterize, understand and enhance functional biodiversity in order to optimize biological regulation within agroecosystems, improve their functionality and design sustainable farming practices.

ANR published a thematic report in 2020 that presents an analysis of the funding of genomics projects since 2005—projects of substantial interest for agroecology—and priority avenues for genomics research to support agroecology research. **The results revealed that genomics could help overcome cognitive and methodological barriers to issues of importance for agroecology.** Across several issues, genomics can help optimize agroecosystem performance and the services expected via biodiversity promotion, such as pest control, better expression of root microbiota functionalities, greater insight into interactions within associated crops, etc. Genomics can also contribute to the characterization of crops and the development of new technologies. It may also help to characterize the functions performed by living organisms in agroecosystems, to define early events allowing prediction and promotion of adult phenotypes, or to determine interactions between organisms favorable to agroecosystem functioning and sustainability. These analyses also highlighted that agroecology requires multi-year time steps—which is incompatible with the programming of research through projects funded for only 3 years—as well as multi- and interdisciplinary approaches. The objectives (favoring interactions and relationships, moving between organizational levels, treating diversity as an asset, etc.) and especially a common vision will attract a diverse range of disciplines to contribute to the agroecological transition.

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- ANR, 2020. Les apports de la génomique à l'agroécologie. Bilan des projets financés sur la période 2005-2019 et perspectives pour la recherche. *Les cahiers de l'ANR*, 12, France.
- https://anr.fr/fr/actualites-de-lanr/details/news/publication-du-cahier-n12-de-lanr-les-apports-de-la-genomique-a-lagroecologie/
- Seminar on the contribution of genomics to agroecology organized by ANR on 27 March 2018, Montpellier, France: http://ptolemee.com/genomique-agro/index.html

Identification of species and genotypes to meet agroecology challenges

Agroecology represents a major challenge for plant breeding which is currently focused on the selection of genotypes for single species/variety canopies, and on genetic resistance to plant diseases. Novel phenotyping approaches are essential to generate multispecies/multigenotype canopies and integrated methods for exploiting biotic interactions. To this end, **Phenome EMPHASIS deploys new tools for: (i) imaging and artificial intelligence to determine the structure and size of respective components (species/varieties) in a canopy; (ii) modelling interactions between components to optimize photosynthesis and plant-to-plant competition and limit spore diffusion; and (iii) data organization to tailor existing information systems to complex canopies.** This provides a basis for training new genomic models for *in silico* selection of genotypes able to optimize canopy photosynthesis, yield, plant health and the viability of plant mixtures.

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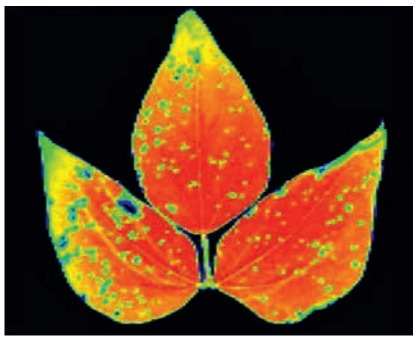

▲ ***False-color image of photosynthesis based on fluorescence imaging in a plant subjected to a pathogen.*** © D. Rousseau/Université d'Angers/IRHS

Phenome-EMPHASIS* organizes and coordinates nine local infrastructures and two methodological projects at French level, by developing: (i) novel imaging approaches combined with artificial intelligence; and (ii) an information system able to organize phenomic data, at different plant scales, with relevant environmental data and metadata. A few examples of applications include: (i) 3D modelling of canopies, with explicit simulation of spore diffusion and light interception as a function of leaf area and plant architecture in wheat(1); (ii) genomic prediction of maize yield in a diverse range of environmental conditions across Europe, based on the responses to environmental conditions(3); and (iii) canopy imaging with recognition of individual plants in monogenotype canopies(2), which has currently been extended to complex canopies.

* Phenome-EMPHASIS:
www.phenome-emphasis.fr/phenome_eng/Installations

▲ ***Field imaging with a Phenomobile.*** © Ph. Burger/INRAE Toulouse/AGIR

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For further information

(1) Garin G., Pradal C., Fournier C., Claessen D., Houlès V., Robert C., 2018. Modelling interaction dynamics between two foliar pathogens in wheat: a multi-scale approach. *Annals of Botany*, 121: 927-940.

(2) Li W., Fang H., Wei S., Weiss M., Baret F., 2021. Critical analysis of methods to estimate the fraction of absorbed or intercepted photosynthetically active radiation from ground measurements: application to rice crops. *Agriculture and Forest Meteorology*, 297: 108273.

(3) Millet E.J., Kruijer W., Coupel-Ledru A., Prado S.A., Cabrera-Bosquet L., Lacube S., Charcosset A., Welcker C., van Eeuwijk F., Tardieu F., 2019. Genomic prediction of maize yield across European environmental conditions. *Nature Genetics*, 51: 952-956.

The experience of community seed banks: a global analysis

Agrobiodiversity is an essential part of agroecological transition and at the heart of the design of nature-based solutions that enhance production (e.g. in crop rotation schemes) and integrate useful biodiversity in production systems (e.g. pollinators). However, knowledge about effective pathways for the use of agrobiodiversity that can lead to improved food and nutrition, adaptation and resilience, is scarce. One challenge is to identify sources and channels to access appropriate reproductive material and related knowledge from formal and informal seed systems, while addressing potential knowledge gaps through participatory and formal research. Another is to determine how to maintain and improve seed quality, which is often poor.

Community seed banks offer an efficient way to address these challenges via information access and quality seed provision, thereby contributing to better agrobiodiversity management. Apart from these functions, community seed banks now serve as a platform for community development, which in turn contributes to local food security and improved livelihoods. They are also no longer just conservation centers but also seed cooperatives capable (after selection and participatory plant breeding) of marketing good quality local seed. Moreover, they have become an agent for the promotion of farmers' rights, including engagement in policy processes, while meeting the need for improved nutrition and fulfilling a broad range of community goals. In Uganda and Kenya, new community seed banks are emerging that provide an opportunity to improve livelihoods in addition to their usual seed conservation role. Farmers are involved as citizen scientists in the selection of crops and varieties which are subsequently distributed through the banks. These crops and varieties are easy to exchange or sell as they are already approved by farmers. In addition, farmers who are community seed bank members receive training on management practices, nutrition and seed production to ensure high seed quality. While originally being the focus of initiatives by NGOs, now governments and multinational bodies such as Global Crop Trust, FAO and the International Treaty on Plant Genetic Resources for Food and Agriculture (ITPGRFA) have shown interest in supporting community seed banks, in recognition of the important role they play in local development. **Community seed banks—by providing improved planting material and capacity-building potential—offer a major opportunity to promote agroecological transitions.**

▼ ***A community seed bank in Ethiopia.*** © C. Fadda

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• Vernooy R., Shrestha P., Sthapit B. (eds), 2015. *Community seed banks: origins, evolution and prospects. Issues in agricultural biodiversity*. Routledge, London, 270 p. www.bioversityinternational.org/fileadmin/user_upload/Community_Seed_Banks.pdf

• Vernooy R., Sthapit B., Otieno G., Shrestha P., Gupta A., 2017. The roles of community seed banks in climate change adaption. *Development in Practice*, 27(3): 316-327. DOI: 10.1080/09614524.2017.129465

Crop diversification and association to enhance the agroecological transition

The greening of agriculture—whereby agricultural production dynamics are hinged on ecological processes—has led to a profound paradigm shift. This implies reaching beyond the prior management and control rationale, which sought to overcome environmental variability, so as to develop forms of agriculture adapted to local soil-climate conditions. Variability in environmental conditions is thus a key element to be promoted. In this setting a growing number of highly diversified systems are emerging, where fruit trees are combined with vegetables in so-called 'orchard-market gardening' agroforestry systems. It is essential to analyze the impacts of this diversification.

To this end, our research team is collaborating with extension and support structures (ADAF*, GRAB**, CIVAM***) to gain further insight into the functioning of these systems. The research carried out proposes analytical frameworks to measure and distinguish between the effects of mosaic diversification (without interactions between crops) and association (with interactions between crops) in mixed systems. This research is conducted on the basis of the portfolio theory to quantify the effects of diversification on risk, and the land equivalent ratio concept to measure the effects of association on yield. **Application of these theoretical precepts to a body of scientific literature revealed that associated horticultural crop systems outperformed systems under a mosaic approach in terms of yield and risk.** This research could be applied to design innovative cropping systems, in particular to sustainably boost their diversity. The findings could also have broader implications for other agricultural systems (cereal crops, livestock, etc.). Finally, in addition to the agronomic benefits of these systems, close attention must be paid to the impact of such diversification on the complexity of labor organization and management practices.

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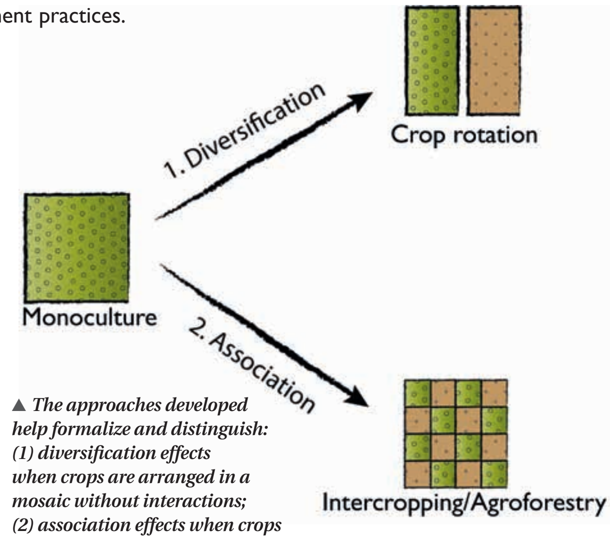
• Paut R., Sabatier R., Tchamitchian M., 2020. Modelling crop diversification and association effects in agricultural systems. *Agric. Ecosyst. Environ*. 288: 106711. https://doi.org/10.1016/j.agee.2019.106711

• Paut R., Sabatier R., Tchamitchian M., 2019. Reducing risk through crop diversification: an application of portfolio theory to diversified horticultural systems. *Agric. Syst.*, 168: 123-130. https://doi.org/10.1016/j.agsy.2018.11.002

▲ *An example of a mixed fruit tree–vegetable crop system, in southern France. © R. Paut*



▲ *The approaches developed help formalize and distinguish: (1) diversification effects when crops are arranged in a mosaic without interactions; (2) association effects when crops are spatially associated.*

Bioturbation and ecosystem services in agroecosystems

Progress in scientific knowledge on soil ecological functioning has revealed that earthworms are emblematic of soil health and quality, and consequently of agroecology. While this aura of earthworms is fully justified due to their importance in nutrient cycling, soil organic matter protection, water cycling and soil erosion resistance, the role of termites—their tropical counterparts—has received surprisingly little attention(1). **Like earthworms, termites influence soil functioning at different overlapping spatiotemporal scales and are hence discrete but major actors in tropical soils.** They boost soil fertility by enriching soils with clay and sometimes organic matter or bioavailable silicon for plants(2). Termites live mainly in the soil and play the same role as earthworms by digging networks of galleries and cavities that increase the soil hydraulic conductivity and water retention capacity(3). Yet their key feature is their ability to produce termite mounds that structure agricultural landscapes in Southeast Asia. By hosting specific flora and fauna(4), these mounds represent islands of fertility and biodiversity in agrosystems. They thereby provide a variety of ecosystem services, such as serving as refuges for biodiversity, improving plant productivity and contributing to the dietary diversity and health of local communities.

▲ *Termite mounds covered by specific vegetation that represent fertile biodiversity refuges in paddy fields. Cambodia, 2007. © P. Jouquet*

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For further information

(1) Jouquet P., Traoré S., Harit A., Choosai C., Cheik S., Bottinelli N., 2020. Moving beyond the distinction between the bright and dark sides of termites to achieve sustainable development goals. *Current Opinion in Insect Science, special issue Insects and Sustainable Development Goals*, 40: 71-76. https://doi.org/10.1016/j.cois.2020.05.010

(2) Jouquet P., Jamoteau F., Majumdar S., Podwokewski P., Nagabovanalli P., Caner L., Bardoni D., Meunier J.-D., 2020. The distribution of Silicon in soil is influenced by termite bioturbation in South Indian forest soils. *Geoderma*, 372: 114362. https://doi.org/10.1016/j.geoderma.2020.114362

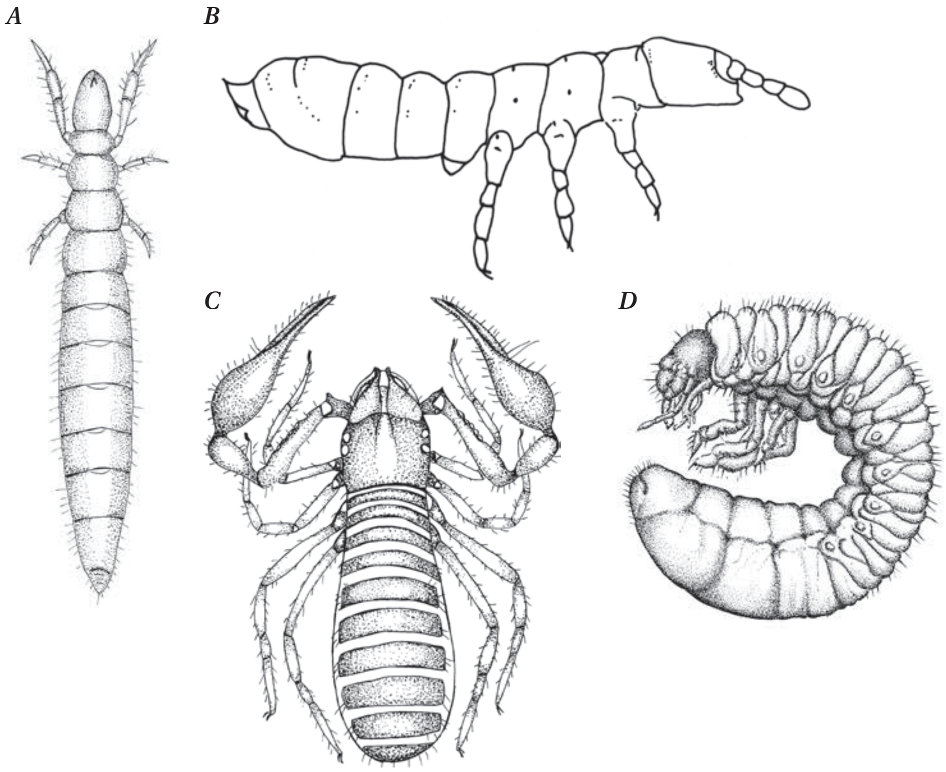
(3) Cheik, S., Bottinelli, N., Tran M.T., Doan, T.T., Jouquet P. 2019. Quantification of three dimensional characteristics of macrofauna macropores and their effects on soil hydraulic conductivity in northern Vietnam. *Frontiers in Environmental Science*, 7(31). https://doi.org/10.3389/fenvs.2019.00031

(4) Choosai C., Mathieu J., Hanboonsong Y., Jouquet P., 2009. Termite mounds and dykes are biodiversity refuges in paddy fields in north-eastern Thailand. *Environmental Conservation*, 36(1): 71-79. https://doi.org/10.1017/S0376892909005475

The role of soil arthropods in soil health monitoring studies

Soil health quantification is still dominated by chemical indicators despite growing appreciation of the importance of soil biodiversity, as further emphasized by the European Commission's recent recommendations to include soil biodiversity as a soil health indicator). Soil arthropods—being involved in organic matter decomposition and translocation, nutrient cycling, soil structure improvement and water regulation—play a key role in agroecosystem soil health maintenance. Conventional agricultural practices increase soil erosion, compaction and pollution, whereas agroecological practices, such as minimum- or no-tillage, organic fertilization and cropping system diversification (i.e. rotation), have proven to enhance soil organic matter aggregate stabilization, nutrient retention and water infiltration, while also having positive effects on soil microbial biomass and arthropod communities[1].

Several soil arthropod groups can serve to monitor soil health, given their extreme level of adaptation to specific soil conditions. They feature reduced (or no) pigmentation and visual apparatus, a streamlined body form with reduced and more compact appendages (hairs, antennae, legs), reduced flying, jumping and running adaptations, a thinner cuticle, etc. **The presence of these ecomorphological features is used to calculate the synthetic QBS-ar index, i.e. an arthropod community-based soil biological quality index[2,4].** This cost-effective edaphic trait-based index is a useful tool for quantifying the impacts of extreme climatic events[1], land-use changes[2] and management practices, such as no-tillage and the use of cover crops[3]. The index is representative of the whole soil arthropod community and is efficient for highlighting poor soil health conditions.



▲ ***Examples of soil arthropods used in QBS-ar index.*** *© C. Menta*

***A.** Proturans are small soilborne primitive hexapods (0.5-2.5 mm) with no antennae, wings or eyes. They are usually part of the decomposer community and feed mainly on fungal hyphae. They are also important prey for small predators, such as spiders, mites and pseudoscorpions.*

***B.** Collembola are small (0.12-17 mm) wingless hexapods commonly known as 'springtails'. They mostly feed on fungi, bacteria and decaying plant material. However, some species are predators, feeding on nematodes or on other Collembola. They are responsible for up to 30% of total soil invertebrate respiration, depending on the habitat.*

***C.** Pseudoscorpions are tiny (< 5 mm long) arachnids that are known as 'false scorpions' because they look like scorpions but do not have an elongated postabdomen with a venomous stinger at the end. Pseudoscorpions live under bark and stones, in leaf litter, caves and soil, while preying on different pest species.*

***D.** Beetle larvae, like many other insect larvae, have undergone numerous adaptations to live in the soil. In contrast to adult forms, the trophic niche of these larvae is completely dependent on the soil habitat.*

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(1) Lakshmi G., Beggi F., Menta C., Kumar N.K., Jayesh P., 2021. Dynamics of soil microarthropod populations affected by a combination of extreme climatic events in tropical home gardens of Kerala, India. *Pedobiologia*, https://doi.org/10.1016/j.pedobi.2021.150719

(2) Menta C., Conti F.D., Pinto S., Bodini A., 2018. Soil Biological Quality index (QBS-ar): 15 years of application at global scale. *Ecol. Indic.*, 85: 773-780. https://doi.org/10.1016/j.ecolind.2017.11.030

(3) Menta C., Conti F.D., Lozano Fondón C., Staffilani F., Remelli S., 2020. Soil arthropod responses in agroecosystem: implications of different management and cropping systems. *Agronomy,* 10: 982. https://doi.org/10.3390/agronomy10070982

(4) Parisi V., Menta C., Gardi C., Jacomini C., Mozzanica E., 2005. Microarthropod communities as a tool to assess soil quality and biodiversity: a new approach in Italy. *Agric. Ecosyst. Environ.,* 105: 323-333. https://doi.org/10.1016/j.agee.2004.02.002

Methods and tools for better agricultural practices and landscape management

Integrated soil fertility management

Maximizing the fertilizer use efficiency towards sustainable intensification of smallholder agriculture in sub-Saharan Africa

Intensification of smallholder agriculture in sub-Saharan Africa is necessary to address rural poverty and natural resource degradation. Sustainable intensification denotes farming systems with increased and less variable crop yields and enhanced soil health. Integrated soil fertility management (ISFM) aims at increasing crop yields while maximizing the agronomic efficiency (AE) of applied inputs. **ISFM consists of a set of best practices, including the use of adapted germplasm, targeted use of fertilizer and organic resources, and good agronomic practices** (Figure). At the plot level, 'local adaptation' (Figure) refers to the need for additional soil amendments or management to address secondary limitations to maximizing AE, including soil acidity, micronutrient deficiency or hardpan formation. At the farm scale, tailoring fertilizer applications to within-farm soil fertility gradients could potentially boost AE as compared to blanket recommendations, particularly in settings where fertility gradients are strong.

Recent review papers have confirmed that the combined application of fertilizer and organic inputs commonly results in higher and more stable yields and increased agronomic efficiency, yet the impact on soil organic carbon stocks is less clear. Some exemplary interventions include dual purpose legume-cereal rotations with targeted crop-specific fertilizer applications, fertilizer micro-dosing systems combined with water harvesting and manure application, and alternative cassava-legume intercrop configurations with site-specific fertilizer inputs. While ISFM does not aim at eliminating external nutrient sources—an unrealistic goal if yield gaps are to be narrowed in African farming systems—it is fully aligned to levels 1 (input use efficiency) and 2 (substitute conventional inputs) regarding early transition to sustainable food systems, and partly to level 3 (redesign agroecosystems) through its focus on nitrogen-fixing legume integration in farming systems. The paper also explores how ISFM is aligned to the 10 agroecology elements, as recently defined by FAO.

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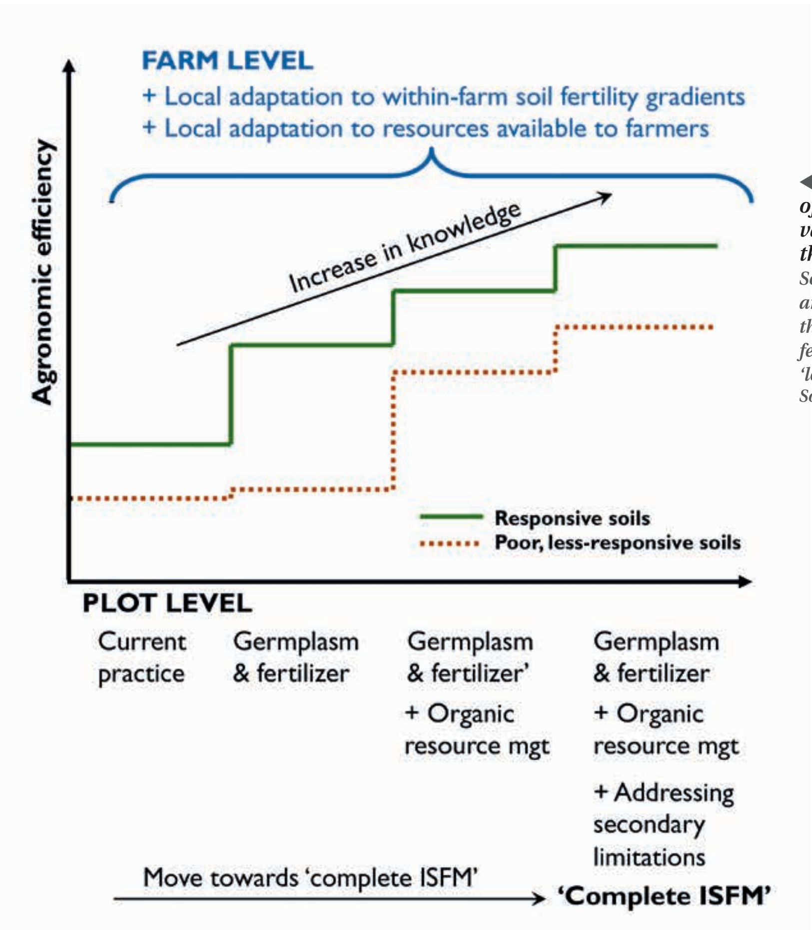
For further information

• Vanlauwe B., Bationo A., Chianu J., Giller K.E., Merckx R., Mokwunye U., Ohiokpehai O., Pypers P., Tabo R., Shepherd K., Smaling E., Woomer P.L., Sanginga N., 2010. Integrated soil fertility management: operational definition and consequences for implementation and dissemination. *Outlook on Agriculture*, 39: 17-24.

• Vanlauwe B., Descheemaeker K., Giller K.E., Huising J., Merckx R., Nziguheba G., Wendt J., Zingore S., 2015. Integrated soil fertility management in sub-Saharan Africa: Unravelling local adaptation. *SOIL*, 1: 491-508.

• Vanlauwe B., Hungria M., Kanampiu F., Giller K.E., 2019. The role of legumes in the sustainable intensification of African smallholder agriculture: myths, lessons, and challenges for the future. *Agriculture, Ecosystems and Environment, In Press.*



◀ ***Conceptual relationship between the agronomic efficiency (AE) of fertilizers and organic resources and the implementation of various ISFM components, culminating in complete ISFM towards the right side of the graph.***

Soils that are responsive to NPK-based fertilizer and those that are poor and less responsive are distinguished. The 'current practice' step assumes the use of the current average fertilizer application rate in SSA of 8 kg fertilizer nutrients ha^{-1}. The figure also distinguishes plot from farm-level 'local adaptation' interventions.

Source: Vanlauwe et al. *(2015)*

Learning as a first step towards agroecology

Efficient irrigation strategies reduce nutrient losses and increase yields

In complex agricultural systems, like irrigated agriculture, interventions applied in one place may have adverse and unexpected outcomes elsewhere. Agroecology principles are based on an understanding of ecology and minimizing the impacts of management strategies. Many farmers do not have access to formal training, so learning can be a key factor when measuring feedback from specific management actions. Successful irrigated agriculture is underpinned by knowing when and how much to irrigate. The TISA project introduced tools to create a learning system to answer these questions. **The Chameleon is a handheld instrument that measures soil moisture at three different depths.** The tool's value lies in the simple user interface. Three LEDs—one per depth, emitting red, green or blue—provide immediate information on whether the soil is dry, moist or wet. A pair of wetting front detectors set up within and beyond the root zone indicates the wetting front depth during irrigation. A flag pops up when water reaches and fills the funnel at the bottom of the instrument and it can be extracted to determine nitrate and salinity levels. The goal is to achieve high nitrate levels within the root zone, while increased nitrate levels beyond this zone indicate nutrient leaching. **Data from these instruments enhance soil water and nutrient management, while also providing a learning opportunity.** TISA project staff never guided farmers on decision making and farmers actually experimented and strengthened their mental models with the aim of retaining nutrients in the root zone by managing the water application frequency and quantity. Consequently, water productivity increased by more than 100%, and farmer-to-farmer learning resulted in a wider impact than tool ownership. Finally, higher level learning resulted in extension and governance stakeholders facilitating profound institutional change.

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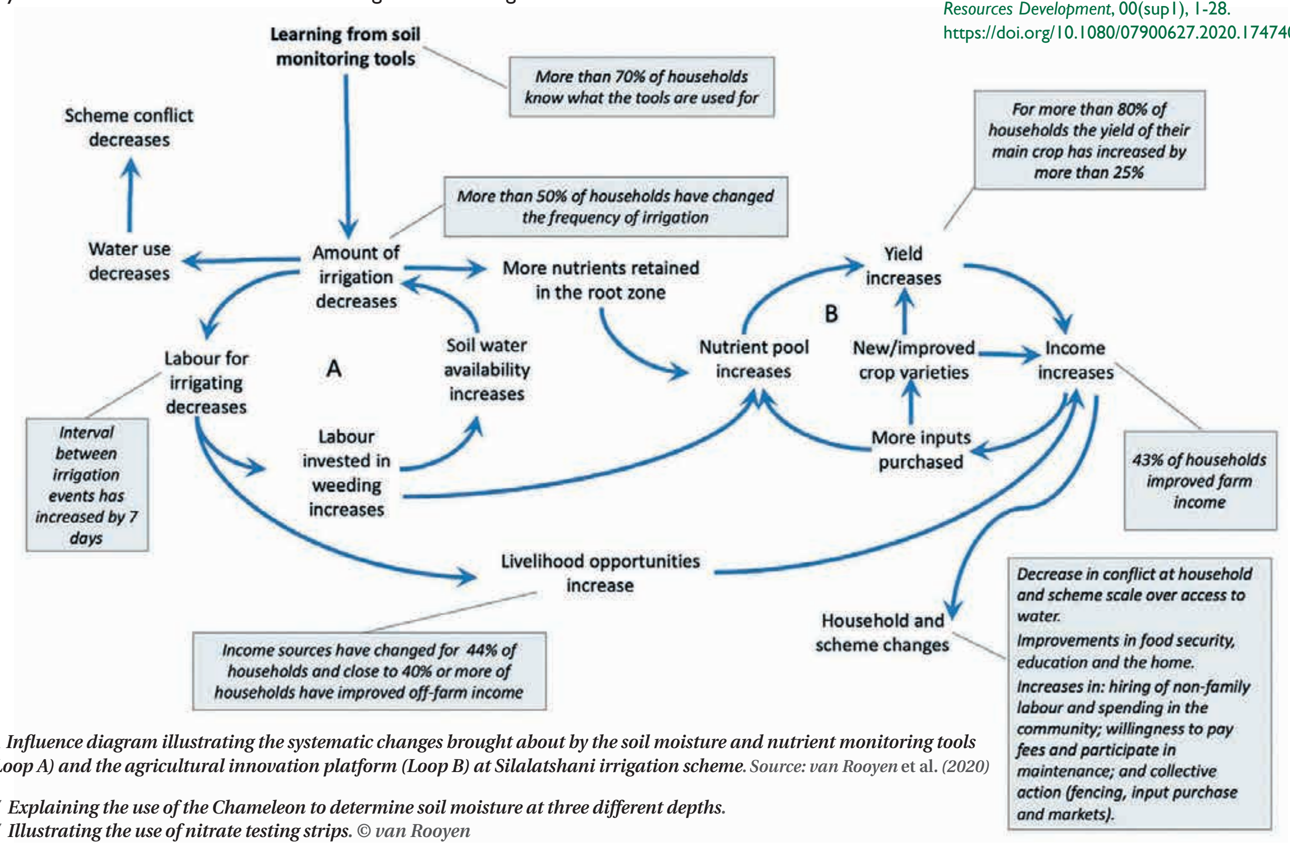
For further information

• Moyo M., Van Rooyen A., Bjornlund H., Parry K., Stirzaker R., Dube T., Maya M., 2020. The dynamics between irrigation frequency and soil nutrient management: transitioning smallholder irrigation towards more profitable and sustainable systems in Zimbabwe. *International Journal of Water Resources Development*, 36(sup1): S102–S126. https://doi.org/10.1080/07900627.2020.1739513

• Parry K., van Rooyen A.F., Bjornlund H., Kissoly L., Moyo M., de Sousa W., 2020. The importance of learning processes in transitioning small-scale irrigation schemes. *International Journal of Water Resources Development*, 36(sup1): S199–S223. https://doi.org/10.1080/07900627.2020.1767542

• Van Rooyen A.F., Moyo M., Bjornlund H., Dube T., Parry K., Stirzaker R., 2020. Identifying leverage points to transition dysfunctional irrigation schemes towards complex adaptive systems. *International Journal of Water Resources Development*, 00(sup1), 1-28. https://doi.org/10.1080/07900627.2020.1747409



▲ ***Influence diagram illustrating the systematic changes brought about by the soil moisture and nutrient monitoring tools (Loop A) and the agricultural innovation platform (Loop B) at Silalatshani irrigation scheme.*** *Source: van Rooyen* et al. *(2020)*

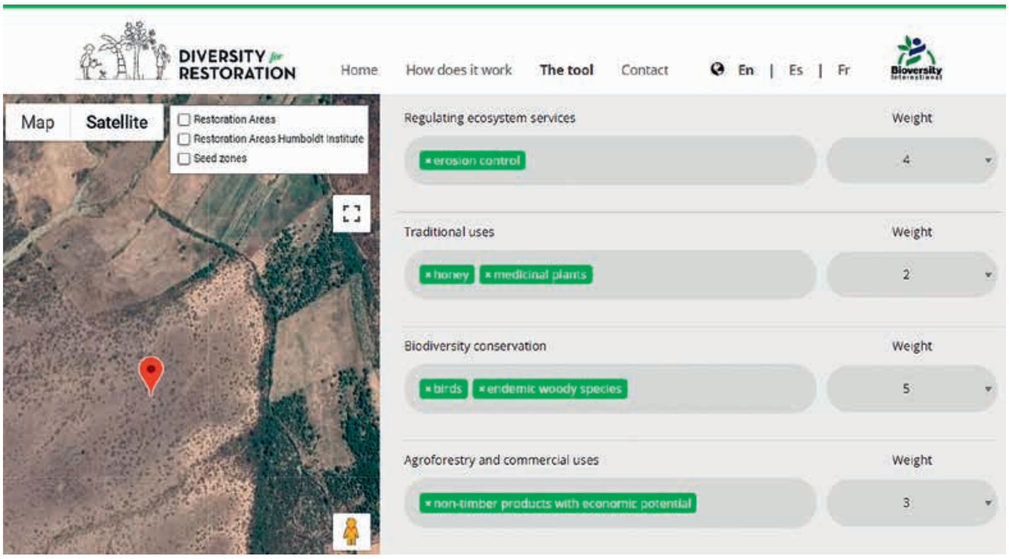
▼ ***Explaining the use of the Chameleon to determine soil moisture at three different depths.***
▼ ***Illustrating the use of nitrate testing strips.*** *© van Rooyen*

Diversity for restoration

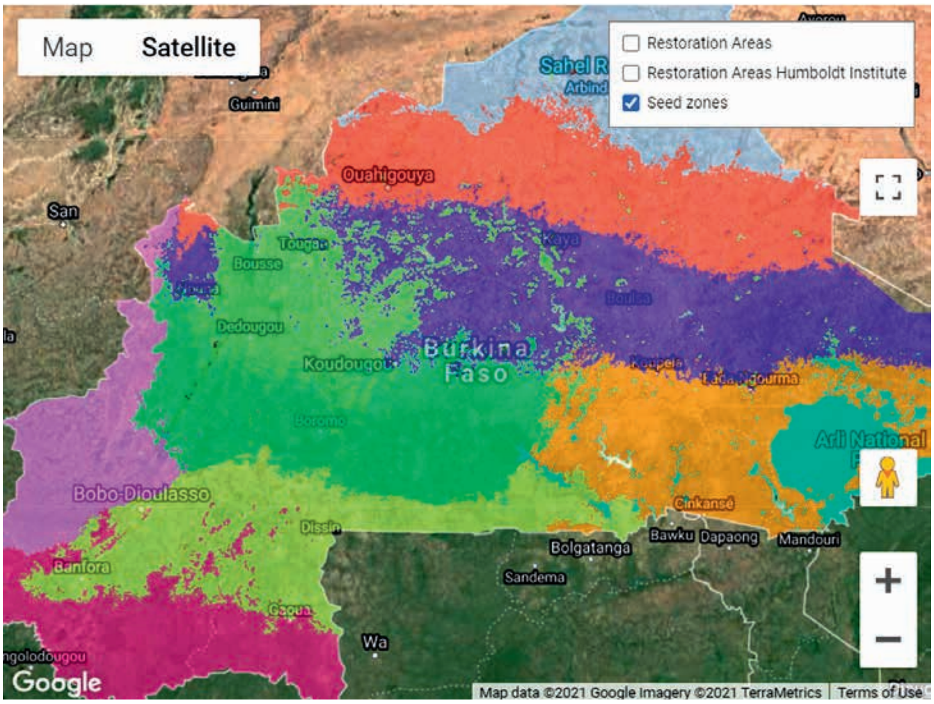
A tool for guiding tree species and seed source selection to restore tropical forest landscapes

In times of unprecedented human pressure on the Earth's ecosystems, tree-based restoration of degraded forest landscapes is seen as fundamental to overcome current global environmental and socioeconomic challenges, with many countries worldwide setting ambitious restoration targets. However, careful planning is required to turn these commitments into successfully restored landscapes. An important aspect of ensuring the long-term success of restoration initiatives involving tree planting is the selection of species and seed sources that are adapted to the restoration site conditions and meet the restoration objectives. Here we present the user-friendly Diversity for Restoration* online tool that is designed to assist decision makers and restoration practitioners with this selection. **Depending on the planting site location, restoration site conditions and restoration objectives (Fig. A), the user receives recommendations on combinations of species to plant, where to get the seeds, and how to propagate the species**. The tool was originally developed for the tropical dry forests of Colombia but has now been expanded to cover the tropical dry forests of northwestern Peru–southern Ecuador and Burkina Faso, and further expansion is underway. Drawing on published literature and traditional knowledge, the tool integrates: (i) species habitat suitability maps under current and future climatic conditions; (ii) analysis of functional trait data, local ecological knowledge and other relevant species characteristics, such as the species threat status, to score the species adaptations according to local site conditions and the ability of these species to contribute to restoration objectives; (iii) optimization of functional trait diversity or phylogenetic diversity to foster complementarity effects; and (iv) development of seed zone maps (Fig. B) to guide the sourcing of planting material adapted to present and expected future environmental conditions. While acknowledging that the meanings and goals of restoration are wide ranging, **the tool is intended to support decision making for anyone interested in tree-based restoration in tropical forest landscapes, regardless of the purpose, and it fosters the achievement of multiple objectives via optimal combinations of species traits.**

* D4R: www.diversityforrestoration.org



◀ *Figure A. User interface of the Diversity For Restoration tool, showing the map-based selection of the restoration site on the left and the selection of priority restoration objectives with their corresponding weight on the right. Other user inputs (not shown) include the restoration site conditions (e.g. compacted soils, steep slopes), the number of species to plant and the climate change scenario to take into account.*



▲ *Figure B. Map of seed zones in Burkina Faso in the user interface of the Diversity For Restoration tool. Seed zones are geographical areas within which seeds may be moved around while minimizing the risk of maladaptation and disruption of population genetic patterns. To increase the probability that the planting material is well adapted to both present and future climatic conditions, the tool generates seed zone projections based on expected future climatic conditions. It then recommends sourcing 50% of the seeds from the present seed zone (shown here) and 50% from future seed zones, as predicted by different global climate models.*

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- Thomas E., Alcazar C., Moscoso L G.H., Vasquez A., Osorio L.F., Salgado-Negret B., Gonzalez M., Bozzano M., Loo J., Jalonen R., Ramirez W., 2017. The importance of species selection and seed sourcing in forest restoration for enhancing adaptive potential to climate change: Colombian tropical dry forest as a model. *CBD Technical Series: Biodiversity and Climate Change*: 122-132.
- Fremout, T., Gutierrez-Miranda C.E., Briers S., Marcelo-Peña J.L., Cueva-Ortiz E., Linares-Palomino R., La Torre-Cuadros M. de los Á., Chang-Ruiz J.C., Villegas-Gómez T.L., Acosta-Florta A.H., Plouvier D., Atkinson R., Charcape-Ravelo M., Aguirre-Mendoza Z., Muys B., Thomas E., 2021. The value of local ecological knowledge to guide tree species selection in tropical dry forest restoration. *Restoration Ecology*: e13347.
- Fremout T., Thomas E., Bocanegra-González K., Aguirre-Morales C.A., Morillo-Paz A.T., Atkinson R., Kettle C., González-M R., Alcázar-Caicedo C., González M.A., Gil-Tobón C., Gutiérrez J.P., Moscoso-Higuita L.G., Becerrá Lopez-Lavalle L.A., de Carvalho D., Muys B., 2021. Dynamic seed zones to guide climate-smart seed sourcing for tropical dry forest restoration in Colombia. *Forest Ecology and Management*, 490:119127.

Accompanying rural actors in the agroecological transition

A role-playing game approach

Pathways to agroecological transition are winding, context-specific, and seldom consensual among actors. Beyond the adoption of individual agroecological practices, it is essential to find trade-offs between actors with divergent interests so as to build more sustainable landscapes. In this respect, accompanying approaches—including participatory ecosystem service (ES) assessment—facilitate constructive exchange between actors and help transcend mere confrontation of viewpoints[1]. In our research in different regions worldwide, we use Companion Modeling (ComMod) approaches that provide a forum for actors to discuss options and uncertainties related to the use, maintenance and trade-offs between ES (e.g. food production, biodiversity preservation, carbon storage; pollinating insects, etc.) in agroforestry landscapes. These approaches involve three key steps:

- *Which ES?* Actors define the situation to be considered and prioritize the ES attributed to different practices and land uses (e.g. slash-and-burn, cash crops, agroforestry systems, conservation), during individual interviews[2,4] or collective workshops[3,4].
- *What impacts do practices have on ES?* Indicators are co-built and used to develop role playing games that will enable actors to assess and compare (over a few years) the constraints and impacts of different practices at the farm, village or landscape scale[3,4].
- *What trade-offs between ES?* The pathways identified via the games are simulated over 10- or 20-year periods using a computer model to assess the long-term impacts of trade-offs between different ES in relation to wellbeing[3,4]. Actors' step-by-step participation in trade-off negotiations heightens their understanding of how their practices shape the simulated landscape dynamics.

Through these participatory approaches and the assessment of scenarios for transforming individual and collective practices, actors are involved in knowledge sharing and enhance their insight into the linkages between resource use and ES. In this way, they contribute, along with researchers, to defining initiatives required to establish sustainable and equitable agroecological socioecosystems.

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(1) Barnaud C., Corbera E., Muradian R., Salliou N., Sirami C., Vialatte A., Choisis J.-P., Dendoncker N., Mathevet R., Moreau C., Reyes-García V., Boada M., Deconchat M., Cibien C., Garnier S., Maneja R., Antona M., 2018. Ecosystem services, social interdependencies, and collective action: a conceptual framework. *Ecology and Society,* 23(1): 15. https://doi.org/10.5751/

(2) Blanco J., Sourdril A., Deconchat M., Barnaud C., San Cristobal M., Andrieu E., 2020. How farmers feel about trees: perceptions of ecosystem services and disservices associated with rural forests in southwestern France. *Ecosystem Services,* 42: 101066.

(3) Castella J.C., Lestrelin G., 2021. Explorer l'impact environnemental des transformations agraires en Asie du Sud-Est grâce à l'évaluation participative des services écosystémiques. *Cahiers Agricultures*, 200088. doi: 10.1051/cagri/2020042

(4) Resque G., Perrier E., Coudel E., Braga L. Fontes V., Carneiro R., Navegantes L., Le Page C., 2021. Discussing ecosystem services in management of agroecosystems: a role playing game in the eastern Brazilian Amazon. *Agroforestry systems.* doi:10.1007/s10457-021-00633-7

▲ ***Role-playing game on forest restoration in Amazonia, Brazil.*** *© K. Naudin/Refloramaz project, 2018*

Methods and tools for assessment and learning to support agroecosystem transitions

Co-designing new organizational strategies to promote biodiversity access

A key challenge for the agroecological transition

▲ *Presentation of the Adaptive Governance for the Coexistence of Crop Diversity Management Systems (CoEx) project at Niakhar, Senegal.* © V. Labeyrie/CIRAD

▲ *Bambara groundnut seeds, Ethiolo, Senegal.* © V. Labeyrie/CIRAD

Promoting farmers' access to diverse genetic resources and associated knowledge is a major challenge of the agroecological transition. Current agricultural models prioritize centralized production and circulation of these resources. Such models are, however, limited in their ability to deal with global changes because they do not foster agroecosystem resilience. It is thus urgent to characterize the plurality of ways farmers manage agrobiodiversity and to understand their impact on its availability so as to co-design new management methods that are tailored to each context and address changes underway.

To this end, the first challenge is to develop a unified conceptual and methodological framework to gain insight into: (i) how the diverse range of actors and the structuring of their interactions affect agrobiodiversity dynamics; and (ii) what implications they have with regard to farmers' ability to harness it. The theoretical framework of socioecological networks is relevant in this respect(1). **A second challenge is to develop appropriate co-design methods, and modeling is promising in this respect.** For instance, to support West African farmers in their reflection on the implementation of new agrobiodiversity management institutions, a combination of role-playing games with multi-agent systems helps them collectively discuss several scenarios to secure their seed supply and sustain dynamic conservation of local varieties(2).

Combining this type of approach with genetic models further broadens the perspectives. An ongoing collaboration with a group of about 20 French small-scale seed producers and two genetics laboratories* aims to co-design and assess the potential impacts of a change in organization with regard to the level of genetic diversity managed via different scenarios. These experiments with local networks open up interesting avenues for co-designing new agrobiodiversity management methods.

* Quantitative Genetics and Evolution-Le Moulon and Genetic Improvement and Adaptation of Mediterranean and Tropical Plants joint research units (France).

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(1) Labeyrie V., Antona M., Baudry J., Bazile D., Bodin Ö., Caillon S., Leclerc C., Le Page C., Louafi S., Mariel J., Massol F., Thomas M., 2021. Networking agrobiodiversity management to foster biodiversity-based agriculture. A review. *Agronomy for Sustainable Development*, 41(1): 1-15.

(2) Belem M., Bazile D., Coulibaly H., 2018. Simulating the impacts of climate variability and change on crop varietal diversity in Mali (West-Africa) using agent-based modeling approach. *Journal of Artificial Societies and Social Simulation*, 21(2): 8. https://doi.org/10.18564/jasss.3690

Agroecological principles as design guides

Agroecology ideas have a long history and have been gaining attention recently as they aim to simultaneously address productivity, nutritional, social and environmental concerns about the sustainability of agriculture and food systems. Agroecology manifests as science, practice and social movements and has been defined in multiple ways, thereby giving rise to the 'multiple agroecologies' concept. Principles, defined as 'statements that provide guidance on how to behave towards a desired result', are needed to navigate such a complex and adaptive space.

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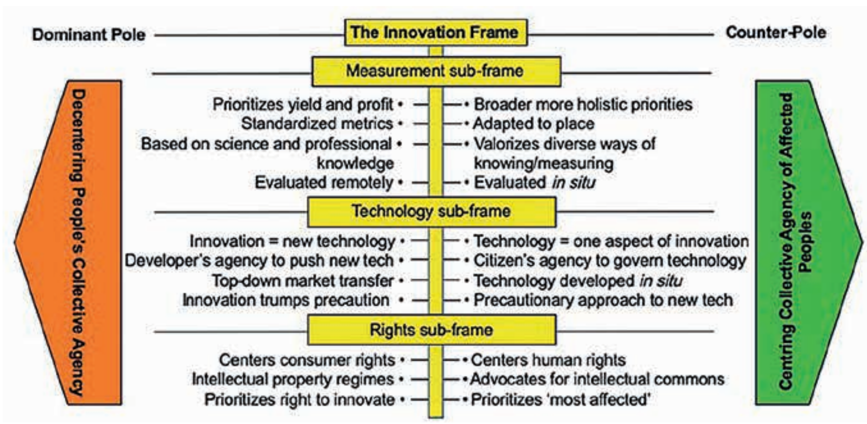

▲ *The subframes of the innovation frame have both a 'counter-pole' that centers the collective agency of people and a dominant pole that decenters people's collective agency.* © 2021 Anderson and Maughan

The evolution of agroecology principles has been mapped and a consolidated set of 13 proposed[1] but, as agroecology means many different things, it is rare to find them all followed with equal vigor. This raises questions: do they all need to be followed to claim that an initiative is 'agroecological'; does violating any of the principles render something not agroecological, or is it sufficient to work on the basis of being more or less agroecological, in line with agroecological transitions moving systems towards greater equity and sustainability? Strong statements of principles have counter principles that describe alternative actions or behaviors. Being explicit about these counter principles highlights the decisions that have to made on the basis of values or beliefs about what is important. The HLPE Agroecology report[2] distinguishes normative and causative elements of principles and presents counter principles as continua between two 'poles'. The positions on such continua of any stakeholder in an innovation platform influences their innovation frame and hence likely outcomes (Figure previous page)[3]. A recent framework for analyzing agroecological development projects proposes 21 principles —classified as ecological, socioecological, political and methodological—and highlights how they apply at different scales[4]. Within an innovation and development process at any particular scale, the principles that are being employed can be made explicit. **Where institutions and their innovation platforms or projects make such positions clear, this guides design and makes claims for being agroecologically transparent and accountable.**

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(1) Wezel A. *et al.*, 2020. Agroecological principles and elements and their implications for transitioning to sustainable food systems. A review. *Agron. Sustain. Dev.*, 40.

(2) HLPE, 2019. *Agroecological and other innovative approaches for sustainable agriculture and food systems that enhance food security and nutrition*. High Level Panel of Experts on Food Security and Nutrition of the Committee on World Food Security.

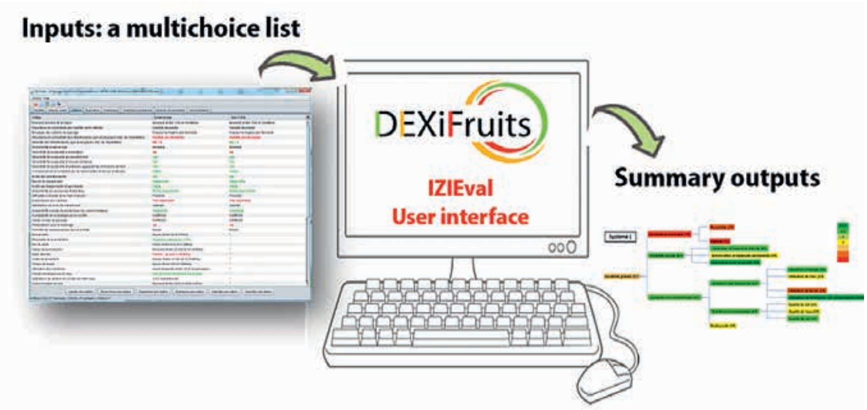
(3) Anderson C.R., Maughan C., 2021. 'The innovation imperative': the struggle over agroecology in the international food policy arena. *Front. Sustain. Food Syst.*, 5: 619185.

(4) Kapgen D., Roudart L., 2020. Proposal of a principle cum scale analytical framework for analysing agroecological development projects. *Agroecol. Sustain. Food Syst.*

MEANS platform

A conceptual framework and INRAE-CIRAD tool for multicriteria assessment of agrosystem sustainability

The agroecological transition encompasses a broad range of practices and system changes. It raises many questions regarding its influence on various functions and impacts of agriculture: productivity, profitability, environmental impacts, ecosystem services, work, product quality, etc. Multicriteria Decision Analysis aims to shed light on these different areas and helps guide choices on potential future directions. This is a vast field that includes many tools and methodological approaches. The MEANS platform—launched in 2012 by INRAE and co-developed by INRAE and CIRAD since 2018—**provides tools and databases to enable multicriteria decision analysis of plant, animal and product processing systems. It hosts research-derived sustainability assessment tools designed,** for instance, for fruit crops (DEXiFruits), field crops (Masc) and poultry farms (Diamond). Environmental sustainability is addressed through life cycle assessment, with the development of dedicated software, i.e. MEANS-InOut, which underpins the creation of agricultural production inventories. Input interfaces facilitate the reconstruction of technical sequences, with models then used to assess pollutant emissions and resource consumption. This reference tool is used to generate the agricultural component of the Agribalyse database dedicated to the environmental impacts of agricultural and food products in France. The MEANS platform continues to be developed to serve scientists and stakeholders in the sectors impacted by changes in agricultural practices (vegetable and animal production, organic farming, etc.). The platform seeks to better account for the complexity and diversity of agroecological practices and to develop socioeconomic assessment tools.



▲ *An example of a tool hosted on the MEANS platform: DEXIFruits devoted to fruit system sustainability assessment.*

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• Lairez J., Feschet P., Aubin J., Bockstaller C., Bouvarel I., 2015. *Agriculture et développement durable, guide pour l'évaluation multicritère*. Educagri Éditions/Éditions Quae, Dijon/Versailles, 232 p.

• MEANS platform: www6.inrae.fr/means

• ACVBio project, Life cycle assessment of organic products: http://itab.asso.fr/activites/projetacv.php

Evaluating the environmental impacts of organic farming

Life cycle assessment must do better

Life cycle assessment (LCA) is the most widely used method for environmental assessment of agricultural systems and their products[1]. LCA estimates the environmental impact of a given product based on all stages of its life cycle, from the outset (raw material extraction), via its production and use, to its disposal or recycling. Pollutant emissions and resource use for each of these stages are quantified. The data are then aggregated into a small number of impact indicators (climate change, eutrophication, energy use, land use, etc.).

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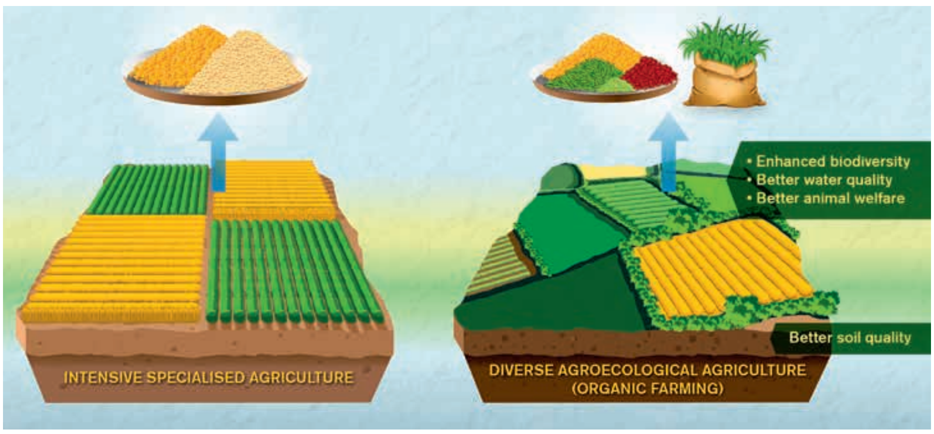

▶ *Conventional farming produces higher yields, but organic farming offers other advantages.*
© Yen Strandqvist/Chalmers University of Technology

Current LCA methods and studies tend to promote intensive high-input agricultural systems while misrepresenting less intensive agroecological systems, such as organic farming. This is partly due to the fact that the LCA approach focuses on products, without taking other ecosystem services of agricultural systems into account, and also because aspects that agroecology targets for improvement (soil quality, biodiversity status, pesticide impacts) are seldom considered. Intensive agricultural systems are further promoted by the current trend of limiting the consideration of indirect effects in LCA studies solely to indirect land use changes based on economic models that overlook societal change factors and the impacts of policy instruments. We identify three key areas (additional indicators, broader outlook, indirect effects) for which we propose recommendations for LCA users, as well as research priorities. **LCA studies must take impacts on biodiversity and soil quality as well as pesticide impacts into account to ensure a balanced comparison of conventional agriculture and agroecology**.

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(1) van der Werf H.M.G., Knudsen M.T., Cederberg C., 2020. Towards better representation of organic agriculture in life cycle assessment. *Nature Sustainability*, 3: 419-425.

Agrosystem modelling and simulation via the RECORD platform

Several disciplines such as agronomy, economics, sociology and ecology need to be combined in the design and development of agroecosystem models. Yet the integration of all of these components into a model is complex and often results in over-specialization with the focus placed on one specific aspect of the system, thereby impeding a holistic approach. **Major gains in modeling quality and efficiency are possible through the use of a platform such as RECORD, which offers modelers different services, including three that are useful when focusing on agroecology: model coupling, decision process modeling and experimental design simulation.**

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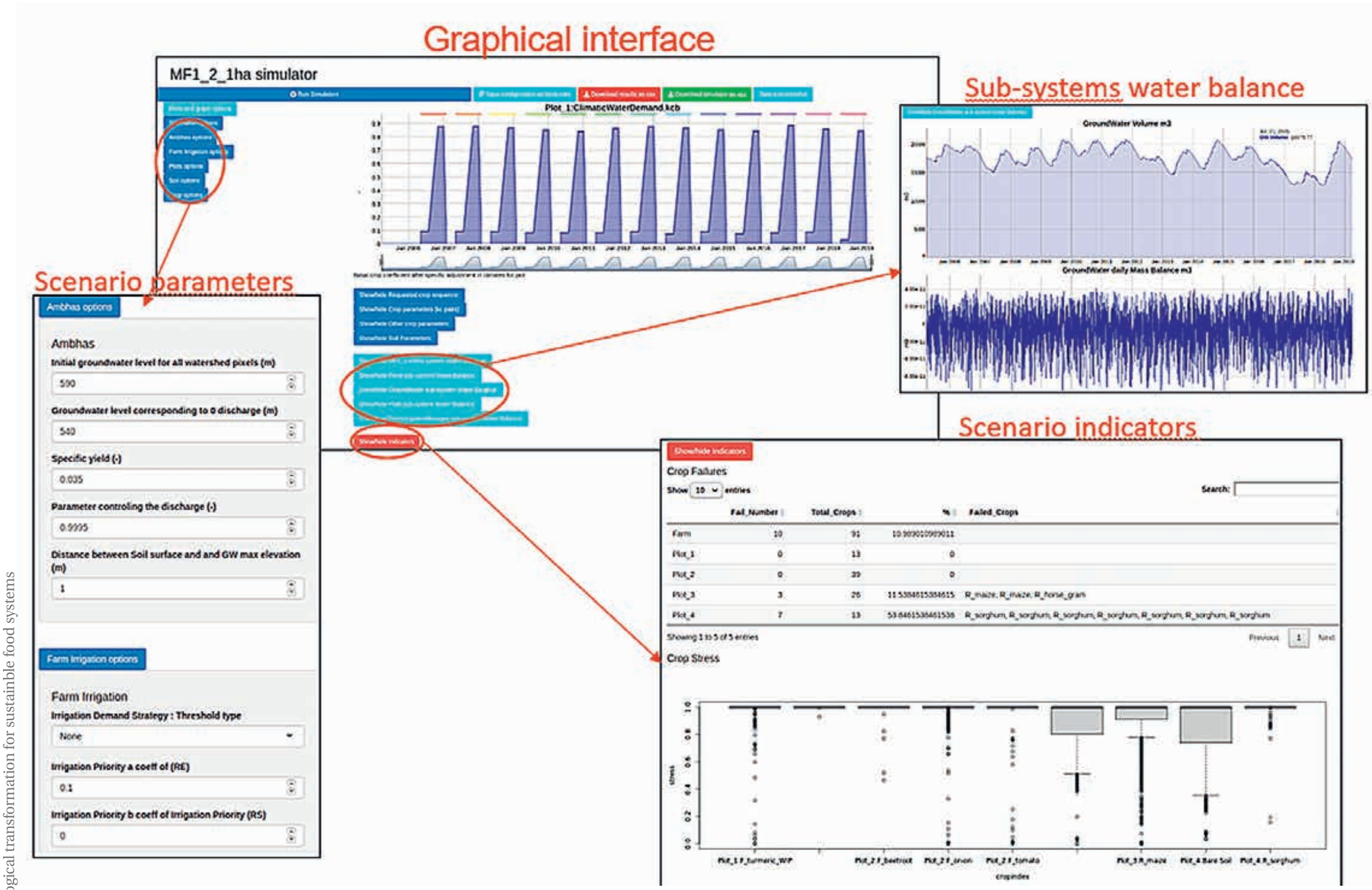
• Bergez J.E. *et al.*, 2014. Evolution of the STICS crop model to tackle new environmental issues: new formalisms and integration in the modelling and simulation platform RECORD. *Environmental Modelling and Software*, Special issue on agricultural systems modelling and software: current status and future prospects. http://dx.doi.org/10.1016/j.envsoft.2014.07.010

• Robert M., Thomas A., Sekhar M., Raynal H., Casellas E., Casel P., Chabrier P., Joannon A., Bergez J.-E., 2018. A dynamic model for water management at the farm level integrating strategic, tactical and operational decisions. *Environmental Modelling and Software*, 100: 123-135. doi: 10.1016/j.envsoft.2017.11.013 - http://prodinra.inra.fr/record/414295

• Tibi A., Therond O., 2017. *Évaluation des services écosystémiques rendus par les écosystèmes agricoles. Une contribution au programme EFESE. Synthèse du rapport d'étude.* Inra, France, 118 p.



▲ *Graphical interface of the Atcha model.*
This interface facilitates use of the model via different menus. The 'scenario parameters' menu allows users to input the simulation parameter values (e.g. choice of year) and to launch the simulation (bottom left). Other interfaces display the simulation results, such as the temporal variations in the water table (top right), the crop dynamics on a plot (top center), and statistical representations such as the frequency of crop failure (bottom right). This application is used to test different scenarios.

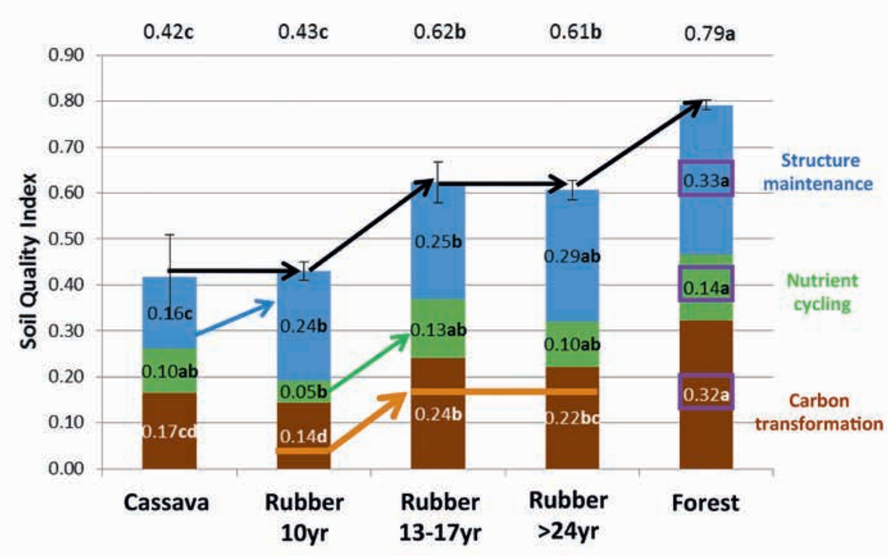
In the framework of water management research carried out under climate change and water scarcity conditions on a small watershed scale in India*, several models developed at different scales reflect the hydrological functioning on farms and in territories. These models are used to test different adaptation scenarios (choice of crops and irrigation methods) with the aim of safeguarding water resources while maintaining farmers' income. These models were designed by coupling existing models developed by several communities (agronomists, hydrologists, economists) in order to represent the different system components and their interactions (see p. 74). Decision-making processes involved in agroecosystem management have been mainstreamed into these models. The integrated ATCHA model* simulates the behavior of farmers who have to make daily decisions regarding the operational management of cultivated plot irrigation. It also simulates strategic farm management scenarios, in terms of the choice of crops to be planted in plots according to the state of water resources and the choice of irrigation level. ATCHA* modelling and scenario development were carried out using a co-design approach with stakeholders. Finally, the multi-simulation tools enable extension of the models on different spatiotemporal scales. A model initially developed at the cultivated field scale was simulated at multiple points (experimental design) for potential application throughout France**.

* ATCHA ANR project, Accompanying the adaptation of irrigated agriculture to climate change: www6.inrae.fr/atcha

** See the EFESE-EA study, *Évaluation française des écosystèmes et des services écosystémiques visant à faire l'évaluation des services écosystémiques rendus par l'agriculture française*: www6.paris.inrae.fr/depe/Page-d-accueil/Actualites/EFESE

Biofunctool®: a low tech field tool for soil health assessment

Assessing the impact of changes in agricultural practices on soil health is a key challenge of the agroecological transition. Soil health implies the capacity of the soil to function and provide ecosystem services. Yet current assessment methods are mainly based on stock indicators (C, N, microbial biomass, etc.) and generally do not incorporate dynamic functional indicators related to the role of the soil biota. When these functional measurements are carried out, this is mostly done under standardized laboratory conditions which do not necessarily reflect the current level of the functions in the field. To overcome these methodological shortcomings, a **new integrative soil health assessment method has been proposed that takes into account the relationships between the physicochemical properties and biological activity of soils.** This so-called Biofunctool® method[1,2] includes nine rapid low-cost field indicators (Fig. A) for assessing three main soil functions: carbon dynamics, nutrient cycling and soil structure maintenance. The ability of all of the indicators to assess the impact of land management on soil health has been validated in many landscapes (> 900 points), mainly in the tropics (Asia and Africa) and under a range of soil-climate conditions. A soil health index (Fig. B) incorporating the indicators was developed to summarize the overall impact of practices on soil health. Another index based on two tools (POXC, which measures labile carbon, and SituResp®, which measures basal respiration) determines the impact of agricultural practices on carbon dynamics (mineralizing system vs. stabilizing system)[3]. Biofunctool® can help farmers to better understand the impact of their cultivation practices on soil functioning.



▲ *Figure A. Biofunctool®: list of indicators used for each function.*

◀ *Figure B. Illustration of a soil health index produced by Biofunctool®. (2019) Impact of land use change (cassava to rubber plantation) on soil functioning along a 24-year rubber plantation chronosequence. From Thoumazeau et al.*

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For further information

(1) Brauman A., Thoumazeau A., 2020. Biofunctool® : un outil de terrain pour évaluer la santé des sols, basé sur la mesure de fonctions issues de l'activité des organismes du sol. *Étude et gestion des sols*, 27(1): 289-303.

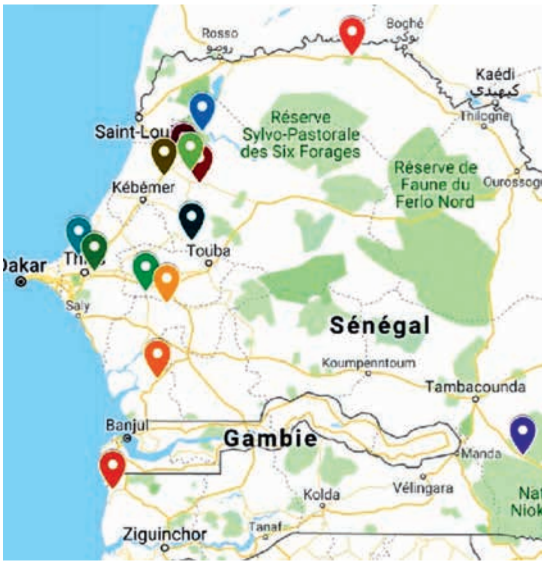
(2) Thoumazeau A., Bessou C., Renevier M., Trap J., Marichal R., Mareschal L., Decaëns T., Bottinelli N., Jaillard B., Chevallier T., Suvannang N., Sajjaphan K., Thaler P., Gay F., Brauman A., 2019. Biofunctool®: a new framework to assess the impact of land management on soil quality. Part A: concept and validation of the set of indicators. *Ecol. Indic.*, 97: 100-110.

(3) Thoumazeau A., Chevallier T., Baron V., Rakotondrazafy N., Panklang P., Marichal R., Kibblewhite M., Sebag D., Tivet F., Bessou C., Gay F., Brauman A., 2020. A new in-field indicator to assess the impact of land management on soil carbon dynamics. *Geoderma*, 375: art. 114496 [10 p.].

Living labs, facilitators of agrifood chain transformation

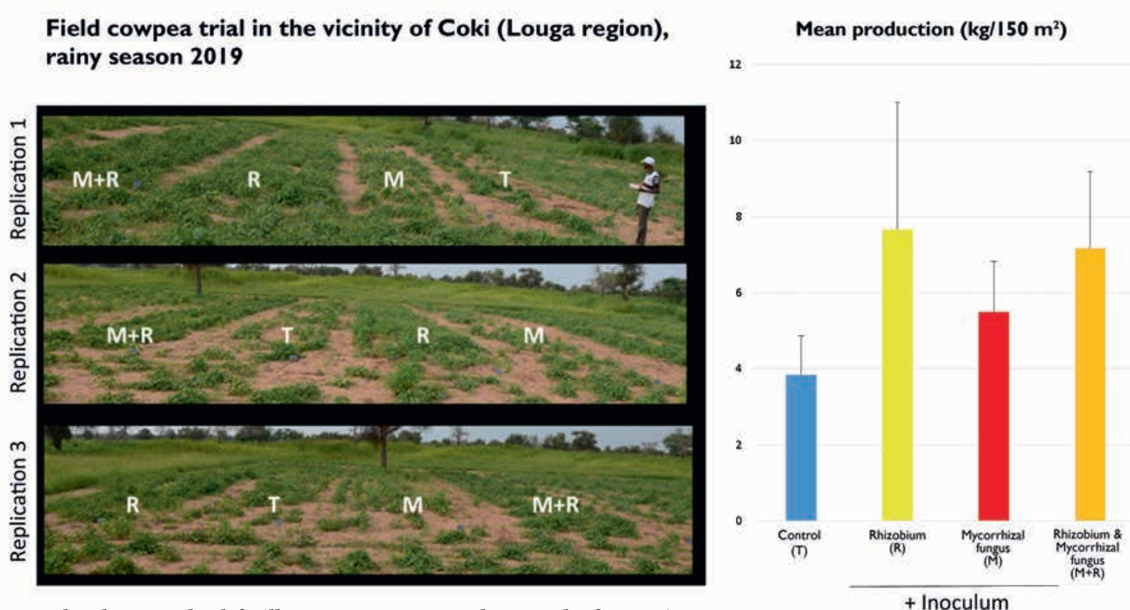
A remote support system for multipartner agroecological research in Senegal

Agroecological practice known for a long time for its beneficial impacts on crop production, inoculation of plants with biofertilizing microorganisms (rhizobia and mycorrhizal fungi) has yet to be applied in West Africa. Researchers, farmers, extension agents, farmers' organizations, NGOs, entrepreneurs and political leaders have gone beyond sporadic trials and developed a system that provides remote support of multipartner research (DIAADEM). It is based on shared decision making and continuous exchange via email and smartphone to ensure collective trial implementation, monitoring and harvesting, capitalization of the results and information, while facilitating training and reciprocal capacity building. DIAADEM was launched in 2019 with more than 30 trials in 14 communities in Senegal and is now gradually being developed in West Africa. This initiative has confirmed that **inoculation influences plant growth, vigor, resistance to pathogens and physical stress, and even taste quality.** The results are sometimes impressive (> 80% yield gain for the Melakh cowpea variety in Coki), although not necessarily statistically significant due to the experimental conditions (few field replications, heterogeneous plots). They may vary according to the sites: inoculation sometimes has no impact, or may even slightly inhibit growth, as noted at Mont-Rolland with the Mbaye Ngagne variety. Far from discouraging stakeholders, the findings have sparked reflection on the importance of selecting the most efficient variety/microorganism pairs and the need to strengthen collective experimental monitoring capacities in order to obtain statistically significant data. Beyond enabling us to define the most efficient application methods according to the species, practices and ecogeographical zones, they have raised **awareness on the need to consider the whole chain, from production to the use of inocula, including quality control, compliance with the Nagoya protocol, information dissemination, etc.** The collective is currently developing its charter, its socioeconomic approach and a numeric platform so as to make DIAADEM a living, equitable and sustainable field laboratory.



▲ *Map of test sites in Senegal.*

◀ ***Trial in the vicinity of the Ndiob, rainy season (2019).*** *Twenty-five rows of cowpeas (accession chosen by the farmer) presented by a DIAADEM member farmer. Photo A. Control plot. Photo B. Dual inoculation plot with mycorrhiza (produced in Darou Mousty) + rhizobium (produced at LCM).*



▲ ***The photographs (left) illustrate cowpea growth 1 month after sowing.*** *Three blocks (replications) each contain four 150 m² elementary plots: a control plot corresponding to the local practice 'T', a plot inoculated with rhizobia 'R', a plot inoculated with mycorrhizal fungi 'M' and a plot inoculated with rhizobia and mycorrhizal fungi 'M+R'. The histogram (right) shows the mean (and standard deviation) cowpea seed production at term for the four treatments.*

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• *Fil'Inoc, une filière de valorisation des microorganismes symbiotiques des plantes pour le développement de l'agroécologie familiale en Afrique de l'Ouest*: https://view.genial.ly/6076e741fbd35a0da5064b6e

• Le Quéré A., Diop S., Dehaene N., Niang D., Do Rego F., Fall S., Neyra M., Karsova-Wade T., Development of an Illumina based analysis method to study bradyrhizobial population structure. Case study on nitrogen fixing rhizobia associating with cowpea or peanut. *Applied Microbiology and Biotechnology* (Under revision).

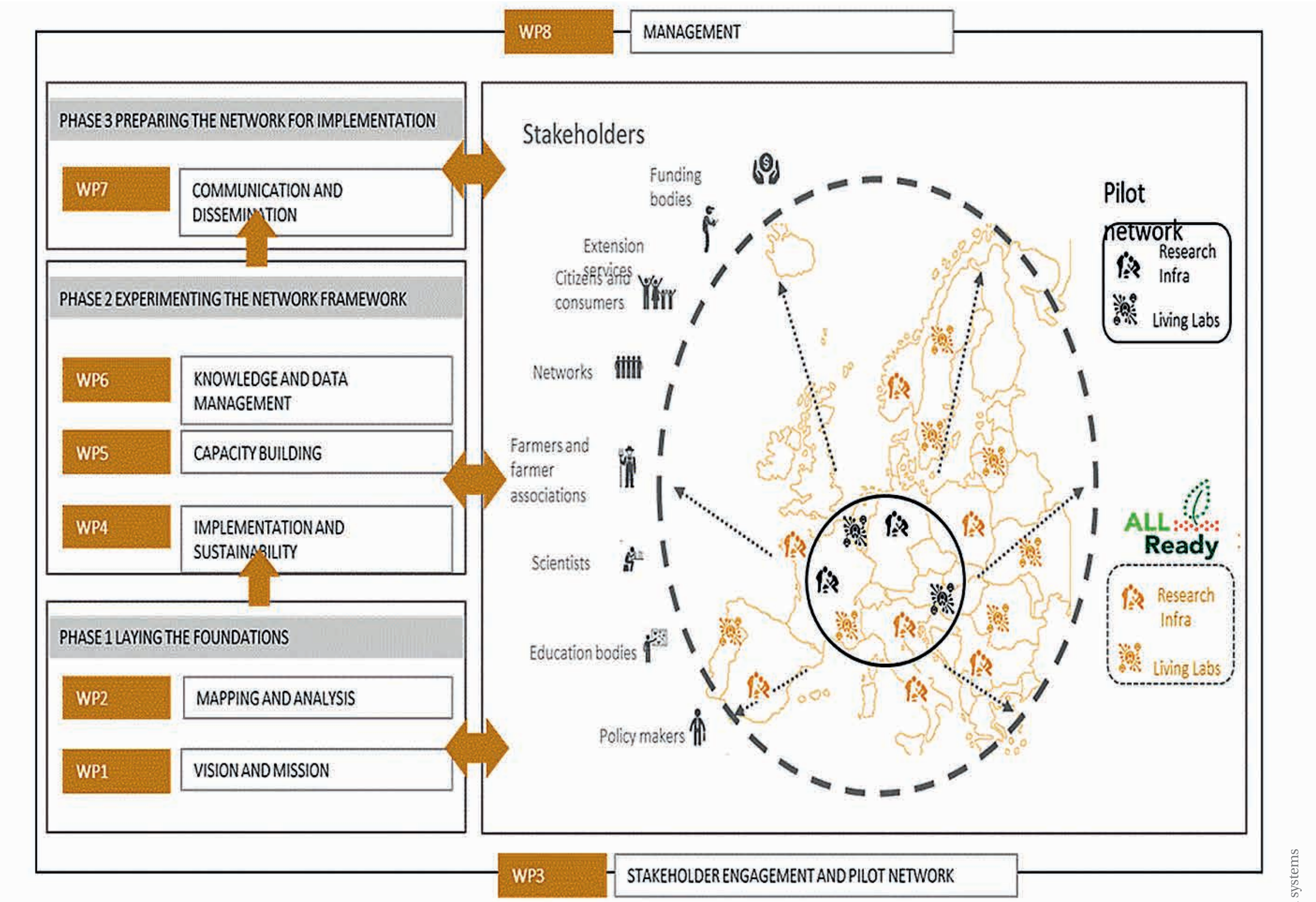
Potential of living labs for the agroecological transition

Living labs are open innovation arrangements underpinned by three principles—user involvement, co-creation and contextualization. They are called upon to an increasing extent by R&D policymakers for the transition of agricultural systems. In 2015, a report* submitted to the French Ministry of Agriculture proposed the creation of territorial innovation laboratories for agroecology and bioeconomics. Since 2018, Agriculture and Agri-Food Canada has been implementing an innovative incentive policy that engages its research system, administration and partners in the so-called Living Lab Initiative to enhance agricultural resilience. In 2019, France focused its 3rd *Plan d'investissement d'avenir* on transitions at local levels through the development of living labs, and 10 of the 24 selected projects were oriented towards agroecological transition. In 2019, the European Commission confirmed its interest in the development and networking of living labs for agroecology. The ALL-Ready** project is one of the two Concerted Specific Actions selected to design this European network.

Living labs echo the paradigm shifts required by agroecology (think 'diversity and system' first, contextualize rather than isolate, theorize while 'doing'). Multiactor interdisciplinary approaches fueled by novel agronomy, sociology, economics and ergonomics trends are leveraged. **ALL-Ready relies on the complementary expertise of its 13 partners to accelerate the agroecological transition by opening the co-design of proposals to a diverse range of stakeholders (including consumers and citizens), and by involving them in field-tested innovations.** Local experimentation builds on a significant flow of knowledge, know-how and data consolidated through a community of experienced stakeholders. **Indicators have been developed to identify initiatives in Europe that are likely to lead to change and thereby structure a network to underpin these flows of knowledge, data and experience.** Research infrastructures will play a key role in supporting the production system redesign process. The next steps will involve mapping initiatives across Europe and launching a pilot network to ensure that operations undertaken by ALL-Ready will be rooted in the reality of the field situation.

* Report: *Agriculture Innovation 2025, 30 projets pour une agriculture compétitive & respectueuse de l'environnement*

** ALL-Ready project, The European Agroecology Living Lab and Research Infrastructure Network: Preparation phase, www.all-ready-project.eu. This project has received funding from the European Union's Horizon 2020 research and innovation programmme under Grant Agreement No 101000349 (ALL-Ready).



▲ ***Design of the European network of living labs and research infrastructures for the agroecological transition.***
The work of the European ALL-Ready project (2021-2024) is organized in eight work packages (WPs).

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For further information

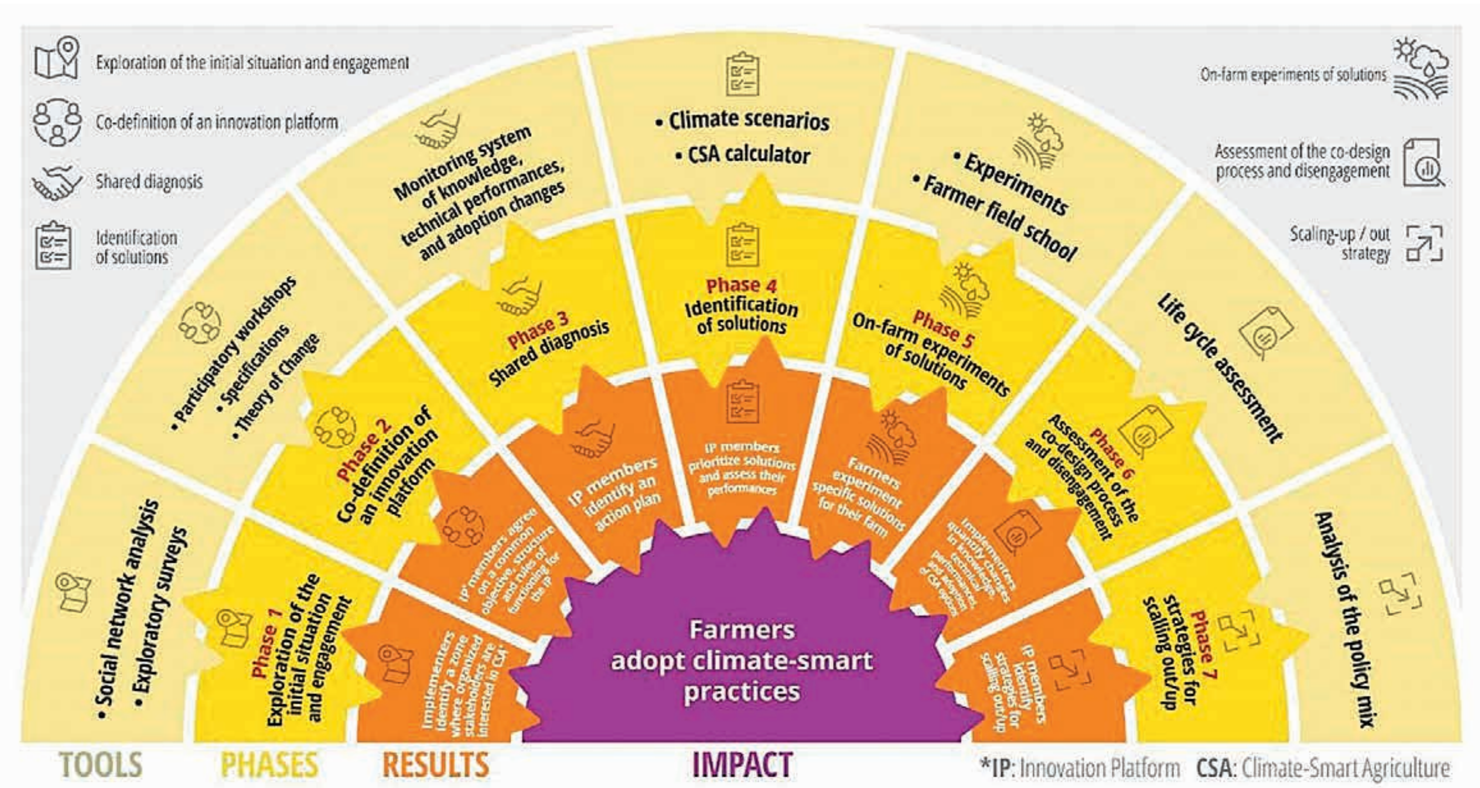
• Caquet T., Gascuel C., Tixier-Boichard M., 2020. *Agroecology: research for the transition of agri-food systems and territories.* Ed. Quae, Versailles. 96 p.

• Mc Phee C., Bancerz M., Mambrini-Doudet M., Chrétien F., Huyghe C., Gracia-Garza J., 2021. The defining characteristics of agroecosystem living labs. *Sustainability*, 13(4): 1718. https://doi.org/10.3390/su13041718

Participatory design of new production systems with better ecosystem service and climate adaptation performances in Colombia and Honduras

Although agroecology and climate-smart agriculture are generally presented as opposed concepts, designing agroecological farming systems can generate synergies between the three pillars of climate-smart agriculture: (i) food security; (ii) adaptation to climate change; and (iii) mitigation of greenhouse gas emissions. This implies tailoring existing frameworks to codesign agroecological farming systems. **A study conducted in Cauca (Colombia) and (Lempira) Honduras explored the specific features of such a framework involving seven phases:**

1. Identification of an area where the community and/or local stakeholders have an interest in developing practices to tackle climate change.
2. Identified stakeholders agree on specific objectives of the platform and how it will operate. In our study sites, the platforms involved organizations or farmers, NGOs that acted as facilitators, public institution representatives and scientists.
3. Platform members characterize the strengths and weaknesses of their farms in order to draw up an action plan combining trials, workshops and exchanges. The project also includes a system for monitoring the project outputs and outcomes.
4. Platform members define the technical and organizational options they want to explore based on agroecological principles (particularly diversity, recycling, efficiency and resilience). A calculator is used to *ex-ante* assess outcomes under the three CSA pillars. Solutions such as vegetable home gardens with drip irrigation, a solar dryer for banana co-products, improved drought-tolerant bean, sorghum and maize varieties were selected to help diversify the production system and enhance food security on farms growing cash crops. Compost, water harvesting tanks and biopesticides were selected to curb chemical agricultural input use.
5. Platform members test the identified solutions on their farms. At both sites, 60 farmers tested portfolios of selected solutions.
6. Data generated by the monitoring system defined in phase 3 are used to validate the ability of the process to meet the agreed objectives and to decide on whether it is worthwhile continuing with a new cycle of the process (restarting at phase 3). We showed positive changes in farmers' knowledge on concepts such as climate change, along with a positive process of adoption of tested practices since farmers increased the initial experimental area or invested their own resources to continue implementing them.
7. Public policies and enabling conditions are analyzed to identify scaling mechanisms (programs, subsidies, incentives, etc.) of the options tested within the platforms.



▲ ***Phases of the codesign process***. *Source: Andrieu* et al. *(2019)*

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For further information

• Acosta-Alba I., Boissy J., Chia E., Andrieu N., 2020. Integrating diversity of smallholder coffee cropping systems in Environmental Analysis. *The International Journal of Life Cycle Assessment*, 25: 252-266.

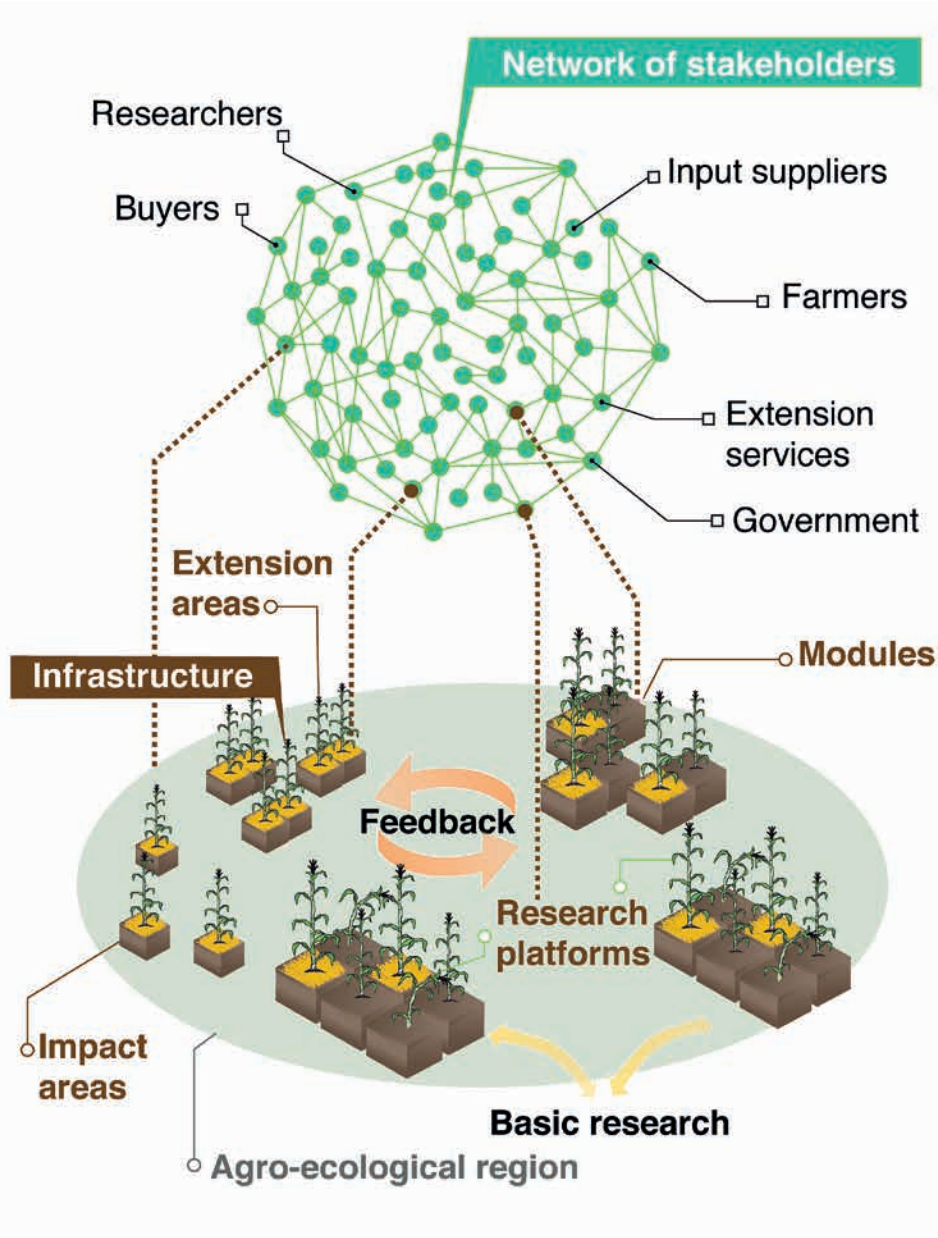
• Andrieu N., Howland F., Acosta Alba I., Le Coq J-F. Osorio A.M., Martinez-Baron D., Gamba Trimiño C., Loboguerrero A.M., Chia E., 2019. Co-designing climate-smart farming systems with local stakeholders: a methodological framework for achieving large-scale change. *Front. Sustain. Food Syst.* https://doi.org/10.3389/fsufs.2019.00037

• Osorio-García A.M., Paz L., Howland F., Ortega L.A, Acosta-Alba I., Arenas L., Chirinda N., Martinez-Baron D., Bonilla Findji O., Loboguerrero A.M., Chia E., Andrieu N., 2020. Can an innovation platform support a local process of climate-smart agriculture implementation? A case study in Cauca, Colombia. *Agroecology and sustainable food systems*, 44(3): 378-411.

• Acosta-Alba I., Chia E., Andrieu N., 2019. The LCA4CSA framework: using life cycle assessment to strengthen environmental sustainability analysis of climate smart agriculture options at farm and crop system levels. *Agric. Syst.*, 177: 155-170. https://doi.org/10.1016/j.agsy.2019.02.001

Knowledge management for innovation in agrifood systems based on equity, participation and sustainability

Knowledge is a critical enabling factor for healthy agrifood innovation systems. CIMMYT has led the development of an agricultural knowledge management for innovation (AKM4I) framework that addresses systemic interactions favoring innovation by formalizing flows and management of information and knowledge between diverse sets of stakeholders; while explicitly considering previously unresolved practical and relational barriers, with the aim of facilitating more equitable, rapidly evolving and actionable knowledge generation and management for innovation and transformational change. The AKM4I framework was developed during CIMMYT's decade-long work on innovation in maize- and wheat-based systems in Mexico, organized in agroecologically distinct hubs. Each hub has a physical infrastructure, including research platforms, modules, extension and impact areas, which are used for networking, knowledge exchange and co-creation. In the research platforms, local partners evaluate technologies and local tacit knowledge to develop research-based recommendations for farmers. In the modules, farmers—alongside other stakeholders—implement and adapt identified best practices and compare them with conventional practices. Extension areas are fields where farmers test new technologies in connection with modules or research platforms, whereas in impact areas farmers have adapted and adopted similar knowledge, technologies and innovations on their own. **This infrastructure is used to build a network of stakeholders—farmers, farm advisors, scientists, research centres, private initiative, government actors, etc.—that collaborate around a common objective: innovation in the agrifood system to make it more sustainable, productive, profitable and resilient.** CIMMYT hubs prioritize the development of strong partnerships, where operations and activities are defined through reciprocal alliances formed around common objectives. The model considers farmers as important change agents who are pivotal to the approach. The hub model structure has fostered real interactions among farmers and the scientific community, leading to a more equitable approach to knowledge generation, adaptation and adoption.



▲ *A schematic illustration of CIMMYT hubs.*
Adapted from Gardeazabal et al. (2021)

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For further information

• Gardeazabal A., Lunt T., Jahn M.M., Verhulst N., Hellin J., Govaerts B., 2021. Knowledge management for innovation in agri-food systems: a conceptual framework. *Knowledge Management Research & Practice*, In press.

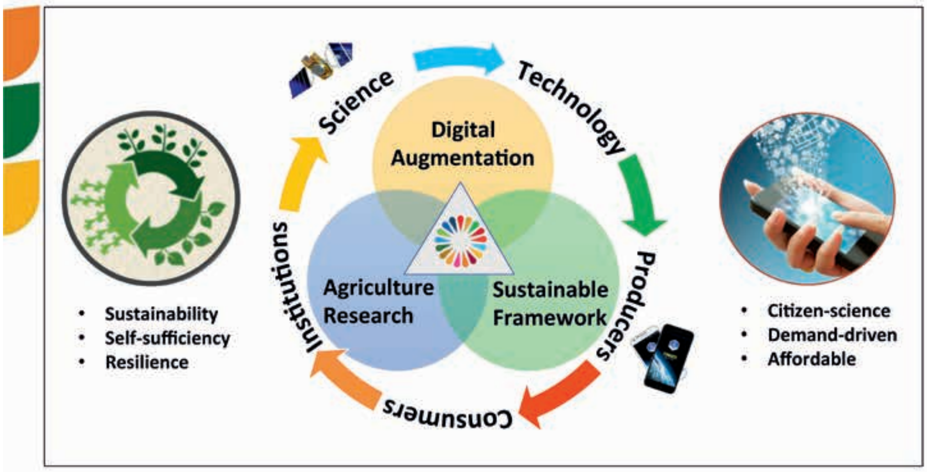
• Liedtka J., Salzman R., Azer D., 2017. Design Thinking for the greater good: innovation in the social sector. Columbia University Press, USA. http://cup.columbia.edu/book/design-thinking-for-the-greater-good/9780231179522

Contribution of digital technology to agroecology

Digital augmentation supports agroecological transformation of agrifood systems in African and Asian drylands

The way we farm, grow and consume our food has a significant impact on the long-term sustainability of agrifood systems and global health. Sustainable production systems cannot be built on monocropping. They require a certain level of diversification of farming systems and landscapes with mixed crops, trees and livestock to preserve soil health and biodiversity, which provide the basis for human health and that of the planet. Agrifood systems are at the crossroads of agroecological transformation. Scaling of such transformation requires systematic quantification and characterization of farming system dynamics and farm typologies at much higher site- and agroecological zone-specific spatiotemporal granularity. **This requires state-of-the-art digital augmentation to interlink various elements of systems level solutions for inclusive development.**

This involves crop/variety choices and management practices that address the needs of a specific place and resource-use efficiency target, while prioritizing areas for inclusive agroecosystems. Therefore, GeoAgro(1) based digital augmentation—driven by geotagging, agrotagging, Earth observation, machine learning and with ICT-enabled citizen science—provides essential entry points for scaling site-specific advisory services/information. For example, real-time mapping of rice-fallow dynamics, farm typologies in terms of the length of the crop fallows, start and end dates, residual soil moisture, nutrition, duration of rice and pulse varieties help prioritize areas suitable for growing pulses within a short window between two cereal crops, with the aim of boosting income, nutrition and resource-use efficiency, while restoring ecosystem functions. Timely access to contextual information also enhances decision-making for target scaling of pulses in rice fallows in eastern India. Similarly, site-specific demand driven in-season agronomic advisory outputs supports Egyptian agriculture which is dominated by an irrigated wheat-based system that is highly inefficient with regard to water use, fertilizer application and agronomic gain. Digitalization of agricultural research and outreach also helps empower extension advisories and foster farmer adoption of site-specific packages of practices for crop, water and nutrient management driven by in-season decision-making. Such digital innovation tools(2) are accelerating agroecological transformation with inclusive development of smallholder farming systems in Asia and Africa.



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(1) ICARDA GeoAgro web portal, 2021: https://geoagropro.icarda.org/ (accessed on April 29, 2021)

(2) ICARDA GeoAgro Pro digital advisory tools, 2021: https://geoagropro.icarda.org/tools-apps/ (accessed on April 29, 2021)

Agroecology and digital technology – a synergic interface

Imaging and signal processing breakthroughs have led to spectacular progress over the last decade. The current rapidity of information processing facilitates integration for real-time action. An emblematic example concerns the tailoring of pesticide treatments only to specific necessary situations, thereby enabling savings while reducing pollution that is harmful to health and the environment. Combining signal analysis with plant development models helps identify situations that requiring intervention(1). Real-time phenotyping in the field will thus gradually become a tool for crop(2) and herd(3) management. These advances are being assimilated by the market, in a 'ready-made' vision of agroecology. Actors embrace this technological agriculture because it offers improvements without disrupting the conventional agriculture rationale.

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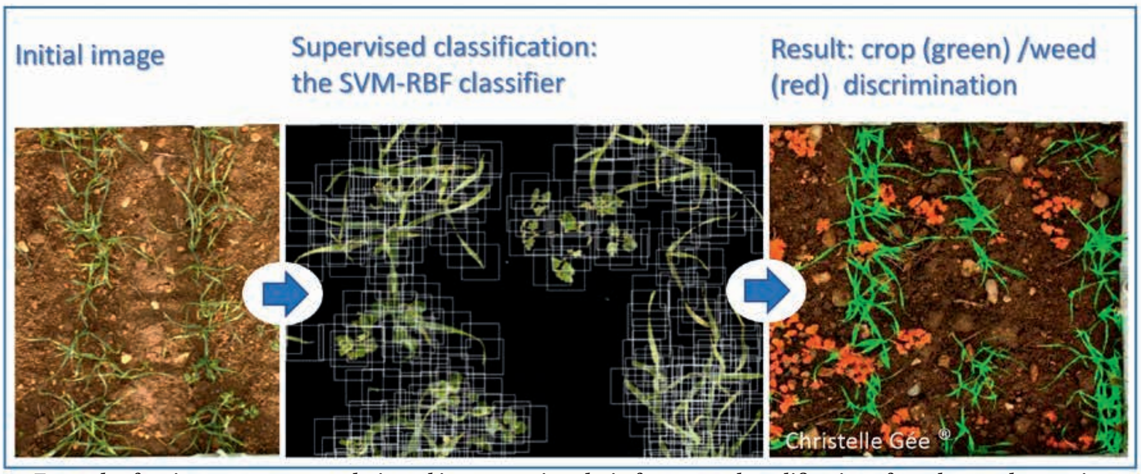

▲ ***Example of an image capture, analysis and interpretation chain for targeted modification of weed control operations.***
Image processing chain that successfully discriminates the crop to be preserved from the weeds to be managed. The process uses image processing algorithms backed up by registered registers. This round trip between acquired and stored data illustrates the importance of internet coverage of the territory. From Gée et al. (2021).

The current hypothesis is that a conservation biological control strategy, combined with a diversification of crop risks and the choice of adapted varieties, with or without the use of protective microbiota, will be able to mitigate the risks in many situations. These genetic, agronomic and ecological levers are based on in-depth digital technology generated knowledge of the agrosystem functioning. Such a system has yet to be developed, but a growing number of elements make it increasingly credible.

Sensors are already installed in the fields, others on livestock and beehives, which makes them real environmental sentinels (see bellow). Mobile sensors mounted on machines enable real-time measurement of crop biophysical parameters. New technologies help streamline interventions. Future situations can even be better foreseen while securing the systemic and preventive dimension of the ecosystem—curative pesticide interventions then become exceptional. Management above all aims to boost the robustness of the agrosystem by preserving all functions necessary to keep it in good health. Agroecology will be successful if it manages to decarbonize the economy and restore certain degraded environments. Under this paradigm, agroecology sets the objectives, while digital technology provides the means to manage this transition.

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For further information

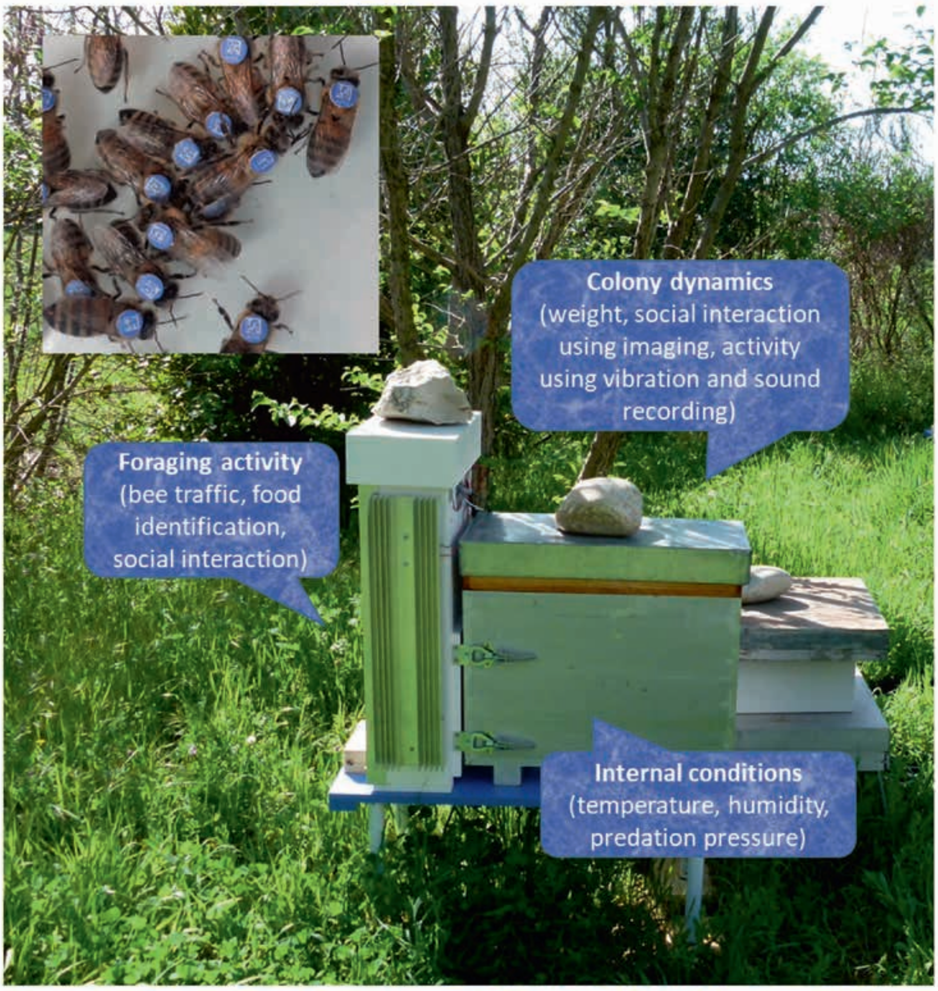
(1) Gée C., Denimal E., Merienne J., Larmure A., 2021. Evaluation of weed impact on wheat biomass by combining visible imagery with a plant growth model: towards new non-destructive indicators for weed competition. *Precision Agriculture*, 1-19.

(2) Jin S., Sun X., Wu F., Su Y., Li Y., Song S., ... Guo Q., 2021. Lidar sheds new light on plant phenomics for plant breeding and management: recent advances and future prospects. *ISPRS Journal of Photogrammetry and Remote Sensing*, 171: 202-223.

(3) Lerch S., De La Torre A., Huau C., Monziols M., Xavier C., Louis L., ..., Pires J.A., 2021. Estimation of dairy goat body composition: A direct calibration and comparison of eight methods. *Methods*, 186: 68-78.

Connected beehives – successfully dovetailing digital technology and biological monitoring

Major breakthroughs have been achieved in remote monitoring of connected beehives. Hives were initially equipped with a simple sensor box that warned beekeepers on their smartphone of any unexpected sensor movements. Then other sets of sensors of weight, temperature, humidity or sounds inside the hive helped beekeepers monitor the situation in and around the hive, thereby reducing the number of beekeeper movements and hive inspections, which are always stressful for bees. Different sensors document the harmonious functioning of the colony, which indirectly reflects the suitability of the external environment[1]. Equipping a beehive with a bee counting system to track bee entries and exits provides reliable early warning of potential issues regarding the environment foraged by the 30,000 or so bees, i.e. an increase in returns to the hive could indicate a depletion of resources, while a discrepancy between numbers of entries and exits could reflect excess bee mortality. This example highlights that **fitting a hive with digital monitoring equipment gives it a new 'mission' as an environmental sentinel**. Many high-risk industrial sites have already been equipped with connected hives to enhance their environmental monitoring and the capacity to quantify malfunctions as early as possible.



◀ ***A digitally connected beehive monitoring system providing information on the colony health and, more broadly, on the quality of the foraging environment.***

Bee counter device equipping a connected hive. The top left overlay shows 2D bee tags for individual tracking. Different sensors fitted to the hive make it possible to monitor some key elements of the health of the swarm.
© D. Crauser

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For further information

(1) Marchal P., Buatois A., Kraus S., Klein S., Gomez-Moracho T., Lihoreau M., 2020. Automated monitoring of bee behaviour using connected hives: towards a computational apidology. *Apidologie*, 51: 356-368.

List of acronyms & abbreviations

ACP	Agroecological crop protection
AFD	French Development Agency
CA	Conservation agriculture
CIAT	International Center for Tropical Agriculture
CRP	CGIAR Research Program
DGD-RS	Office of the Director General in charge of Research and Strategy, CIRAD
EMBRAPA	Empresa Brasileira de Pesquisa Agropecuária
ES	Ecosystem service
FAP	Farming with alternative pollinators
FAW	Fall armyworm
FMNR	Farmer-managed natural regeneration
GHG	Greenhouse gas
HLPE	High Level Panel of Experts on Food Security and Nutrition
ICT	Information Communication Technology
IPM	Integrated pest management
ISFM	Integrated soil fertility management
LCA	Life cycle assessment
LIA	Internationally associated laboratory
LMI	International joint laboratory
MENA	Middle East and North Africa
NARS	National agricultural research systems
NGO	Non-governmental organization
PGS	Participatory guarantee system
R&D	Research and development
SDG	Sustainable development goal
SRIV	Service régional d'innovation et de valorisation, IRD
UMI	International joint unit
UN	United Nations

French research unit acronyms

ABSYS	Biodiversified Agrosystems
ACT-ASTER	AgroSystèmes - Territoires - Ressources
AGAP	Genetic Improvement and Adaptation of Mediterranean and Tropical Plants
AGIR	Agroecologies-Innovations-Ruralities
AIDA	Agroecology and Sustainable Intensification of Annual Crops
ART-DEV	Actors, Resources and Territories in Development
ASTRE	Animals health, Territories, Risks, Ecosystems
BAGAP	Biodiversity, Agroecology and Landscape Management
CEFE	Centre for Functional and Evolutionary Ecology
CIRED	Center for International Research on Environment and Development
DIADE	Plant Diversity, Adaptation and Development
DYNAFOR	Dynamics and Ecology of Agroforestry Landscapes
Eco&Sols	Functional Ecology & Biochemistry of Soils & Agroecosystems
EGCE	Evolution, Genomes, Behaviour, Ecology
ESPACE-DEV	Spatial Dynamics of Socio-ecological Systems in Developing Countries
F&S	Forests and Societies
FERLUS	Fourrages, Ruminants et Environnement
GABI	Animal Genetics and Integrative Biology
GDEC	Genetics, Diversity and Ecophysiology of Cereals
G-EAU	Water Resource Management, Actors and Uses
GECO	Functional Ecology and Sustainable Management of Banana and Pineapple Agrosystems
GET	Environmental Geosciences, Toulouse
GIMIC	Genetic Improvement of Indian Cattle and Buffaloes
HORTSYS	Agroecology and Performance in Horticultural Systems
IATE	Agropolymer Engineering and Emerging Technologies
iEES	Institute of Ecology and Environmental Sciences of Paris
IESOL	Ecological Intensification of Cultivated Soils in West Africa
IHAP	Host-Pathogen Interactions
Innovation	Innovation and Development in Agriculture and Food
INTERTRYP	Host-Vector-Parasite-Environment Interactions in Neglected Tropical Diseases caused by Trypanosomatids
ISEM	Montpellier Institute of Evolutionary Sciences
LAM	Les Afriques dans le monde
LAPSE	Plant and associated microorganisms adaptation to environmental stresses
LCM	Common Microbiology Laboratory
LEPSE	Ecophysiology Laboratory of Plants under Environmental Stress
LISIS	Laboratoire Interdisciplinaire Sciences Innovations Sociétés
LISST	Interdisciplinary Solidarity, Societies and Territories Laboratory
LSTM	Laboratory of Tropical and Mediterranean Symbioses
MARBEC	Marine Biodiversity, Exploitation and Conservation
MIAT	Mathématiques et informatique appliquées de Toulouse
MOISA	Markets, Organisations, Institutions and Stakeholders Strategies
PHIM	Plant Health Institute Montpellier
PSH	Plant and Garden Cropping Systems
PVBMT	Plant Populations and Bioaggressors in Tropical Environments
Qualisud	Integrated Approach to Food Quality
SAD-APT	Science Action Développement - Activités Produits Territoires
SAS	Sol Agro et hydrosystème Spatialisation
SELMET	Mediterranean and Tropical Livestock Systems
SENS	Knowledge, Environment and Societies
TETIS	Territories, Environment, Remote Sensing and Spatial Data

French organizations, CGIAR Centers and Programs, and partners involved in this Dossier

FRENCH RESEARCH AND HIGHER EDUCATION ORGANIZATIONS
- AgroParisTech
- AgroSup Dijon
- CIRAD, Agricultural Research Centre for International Development
- CNRS, French National Centre for Scientific Research
- ENVT, National Veterinary School of Toulouse
- IFCE, Institut français du cheval et de l'équitation
- INRAE, National Research Institute for Agriculture, Food and Environment
- Institut Agro (including Agrocampus Ouest and Montpellier SupAgro)
- IRBI, Institut de Recherche sur la Biologie de l'Insecte
- IRD, French National Research Institute for Sustainable Development
- UFR, University of Tours, François Rabelais
- UM, University of Montpellier
- UT, University of Toulouse
- UP Saclay, Université Paris-Saclay

CGIAR CENTRES
- AfricaRice
- Alliance of Bioversity International and the International Center for Tropical Agriculture (CIAT)
- CIFOR, Center for International Forestry Research
- CIMMYT, International Maize and Wheat Improvement Center
- CIP, International Potato Center
- ICARDA, International Center for Agricultural Research in the Dry Areas
- ICRAF, World Agroforestry
- ICRISAT, International Crops Research Institute for the Semi-Arid Tropics
- IFPRI, International Food Policy Research Institute
- IITA, International Institute of Tropical Agriculture
- ILRI, International Livestock Research Institute
- IRRI, International Rice Research Institute
- IWMI, International Water Management Institute
- WorldFish

CGIAR teams, French researchers and institutes are involved in the following **CGIAR Research Programs (CRP)**: A4NH, Agriculture for Nutrition and Health; CCAFS, Climate Change, Agriculture and Food Security; FISH; FTA, Forests, Trees and Agroforestry; GLDC, Grain Legumes and Dryland Cereals; LIVESTOCK; MAIZE; PIM, Policies, Institutions, and Markets; RICE; RTB, Roots, Tubers and Bananas; WHEAT; WLE, Water, Land and Ecosystems.
The research led by French and CGIAR teams involves and leverages many other partners (see box below).

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Research and higher education organizations

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- Michigan State University, USA
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- Scotland's Rural College, UK
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- University of Greenwich, UK
- University of Natural Resources and Life Sciences, Austria
- University of Parma, Italy
- University of Vermont, USA
- Wageningen University of Research, The Netherlands
- Washington State University, USA

AFRICA
- CERD, Centre d'étude et de recherche de Djibouti
- CREAD, Center for Research in Applied Economics for Development, Algeria
- Ethiopian Biodiversity Institute
- Ethiopian Environment and Forest Research Institute
- FOFIFA, Centre National de Recherche appliquée au Développement Rural, Madagascar
- Hassan II Institute of Agronomy and Veterinary Medicine, Morocco
- ICIPE, International Centre of Insect Physiology and Ecology, Kenya
- INERA, Institut de l'Environnement et de Recherches Agricoles, Burkina Faso
- Institut Polytechnique Rural de Formation et de Recherche Appliquée, Mali
- Mekelle University, Ethiopia
- National Agricultural Research Organization, Uganda
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ASIA
- Can Tho University, Vietnam
- CATAS, Chinese Academy of Tropical Agricultural Sciences
- IIRR, Indian Institute of Rice Research
- Indian Institute of Science
- ITC, Institute of Technology of Cambodia
- KKU, Khon Kaen University, Thailand
- KU, Kasetsart University, Thailand
- NOMAFSI, The Northern Mountainous Agriculture and Forestry Science Institute, Vietnam
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LATIN AMERICA AND CARIBBEAN
- Federal Rural University of Amazonia, Brazil
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- INIFAP, National Institute of Research for Forestry, Agricultural and Livestock, Mexico
- Universidad Técnica Estatal de Quevedo, Ecuador
- Universidad Veracruzana, Mexico

Other organizations
- Agrisud International, Madagascar
- ANR, French National Research Agency
- ARMEFLHOR, Association réunionnaise pour la modernisation de l'économie fruitière, légumière et horticole, Réunion, France
- Arvalis, France
- BAIF, India
- Bioline Agrosciences, France
- Chambre d'agriculture de La Réunion, France
- Ethiopian Economics Association
- FAO, Food and Agriculture Organization of the United Nations
- FDGDON, Fédération Départementale des Groupements de Défense contre les Organismes Nuisibles, France
- GSDM, Professionnels de l'agroécologie, Madagascar
- Ministry of Agriculture and Rural Affairs, China
- Ministry of Agriculture Development, Nepal
- Tropenbos International, The Netherlands
- WRI, World Resources Institute

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Mulani A., Muller B., Mulumba J.W., Muthuri C., Mutuo P, Nabahungu L., Najjar D., Nangia V., Nankya R., Napoléone C., Naudin K., Navarrete M., Nelson K.M., Neyra M., Ngethe E., Nguyen H.T.T., Nguyen T.T., Nigir Hailemariam B., Nordey T., Novak S., Nurhsien J., Nziguheba G, Obonyo J., Ochoa J., Odjo S., Omondi A., Otieno G., Otieno M., Ouin A., Paez Valencia A.M., Paillat J.-M., Pailleux J.-Y., Pè M.E., Peng H., Penot E., Petit-Michaut S., Peyre M., Piraux M., Plassard C., Pratyusha S., Prin Y., Prudent M., Pypers P., Quintero M., Raharison T., Rakotoniamonjy T.H., Rakotovao N., Rala A., Ramarofidy M.A., Ramos H., Rana J., Paut R., Rapidel B., Ratnadass A., Raynal H., Razafimbelo T., Rebaudo F., Reboud X., Rekik M., Remans R., Resque G., Ribeyre F., Richard G., Rieux A., Risede J.M., Rizvi J., Robligio V., Rodenburg J., Roger F., Romero M., Ruiz L., Rusinamhodzi L., Sabatier R., Sabourin E., Saj S., Salgado P., Sanchez-Garcia M., Sander B.O., Sanjaya M., Sanz-Sanz E., Sarter S., Sawsan H., Schoneveld G., Scopel E., Seghieri J., Sekhar M., Shanker C., Sheeren D., Sib O., Silvie P., Simons A., Sinclair F., Sirami C., Snapp S., Solano P., Sourisseau J.-M., Sousa L., Srinivas V., Stadlmayr B., Staver C., Steel E.A., Stoian D., Strohmeier S., Suarez Capello C., Sudhanshu Singh S., Sultan B., Swaminathan M., Sylla A., Tabo R., Tamò M., Tardieu F., Taulya G., Tchamitchian M., Temani F., Teresa Borelli T., Termote C., Tesfahun Kassie G., Thanh Nghi N., Thein A., Thenail C., Thiam A., Thibord J.-B., Thomas E., Thomas M., Thoumazeau A., Thuita M., Tilahun Melaku M., Tiwari T.P., Toillier A., Traore S., Trap J., Trines E., Trouche G., Valdivia R., Vall E., Van der Werf H., Van Deynze A., Van Do H., Van Hieu N., Van Nguyen H., Van Nguyen T., Van Rooyen A., Vanhuffel L., Vanlauwe B., Verger E., Verhulst N., Vernoy R., Vialatte A., Viaud V., Vincent B., Vinceti B., Vom Brocke K., Wang Y., Wardell D. A., Waris Zaidi N., Wassenaar T., Wery J., Whitbread A., Winkel T., Winowiecki L.A., Wollenberg L., Yadav S., Yana-Shapiro H., Yila J.O., Yitayih M., Zhong S.

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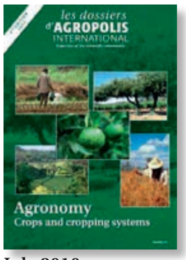

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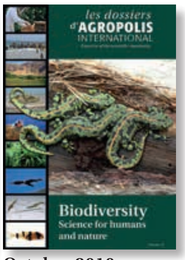

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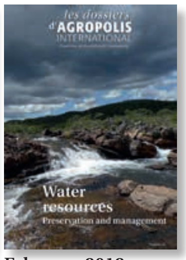

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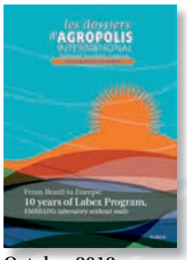

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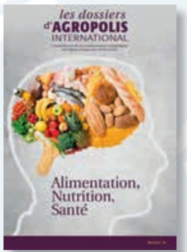

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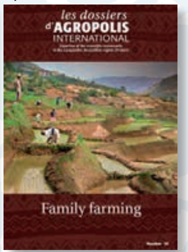

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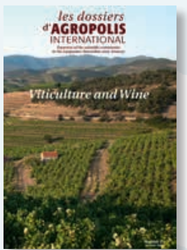

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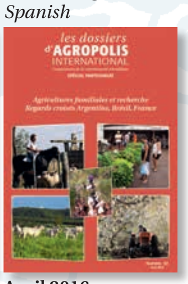

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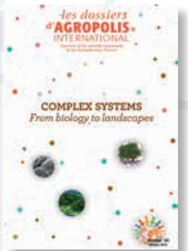

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