Feeding the world better: crop diversification to build sustainable food systems

Eric Malézieux, Damien Beillouin, David Makowski

RÉPUBLIQUE FRANÇAISE
Liberté Égalité Fraternité

perspactive
The CIRAD policy brief

Through *Perspective,* CIRAD provides an opportunity to explore new avenues for discussion and action based on research.

cirad
AGRICULTURAL RESEARCH FOR DEVELOPMENT

Feeding the world better: crop diversification to build sustainable food systems

58

Éric Malézieux - Damien Beillouin - David Makowski

Today, major changes are required in global agricultural systems to produce enough healthy food for all, while preserving the quality of land, air and water and safeguarding biodiversity. But producing enough while simultaneously protecting the environment is a particularly complex equation. Agroecology, a key principle of which is the use of agricultural biodiversity, is a promising pathway to achieve these changes. Extensive qualitative and quantitative evidence demonstrates the agricultural and environmental effectiveness of agroecological practices and confirms their capacity to meet the demands of global production in the long term. Among the possible diversification strategies, agroforestry, intercropping and crop rotation can all significantly increase production and enhance biodiversity and ecosystem services (soil quality, pest and disease control, water use and quality). This evidence can serve as a basis for new public policies to be introduced from the local to the global level. The implementation of such policies is crucial in climate-vulnerable regions where demand for food is growing, such as sub-Saharan Africa.

A food system encompasses a range of different modes of organisation between actors, as well as the technologies and practices that characterise the various modes of food production, processing, packaging, storage, distribution and consumption. This definition reflects the complexity of the linkages between agricultural production and food.

For a long time, local food systems throughout the world have been diversified, but in most countries, standardisation and simplification processes have emerged as a result of the industrialisation of the whole value chain. Food systems today contribute to the degradation of ecosystems (deforestation, cropland expansion, pollution from chemical inputs) and the depletion of natural resources, yet are failing to eradicate hunger and malnutrition in the world. They also impact on the climate through their greenhouse gas emissions, which are estimated at more than a third of all emissions from human activities. In return, climate change weakens food systems, with a greater negative impact if the populations concerned, from producers to consumers, are already economically vulnerable. This vicious circle is exacerbated in the tropical regions, which suffer more from climate change and from human pressure on ecosystems, and thus on biodiversity. Consequently, sub-Saharan Africa, where demand for food is increasing due to high population growth, is facing major challenges.

In this context, which agricultural systems can best reconcile food security objectives with land use that respects biodiversity and limits the negative impacts on the climate?

So-called conventional agriculture – based on monoculture, mechanisation and the massive use of fossil fuels and chemical inputs – has reduced the number of species and crop varieties and has considerably simplified the world's agricultural landscapes. This process is also underway in Africa, where it corresponds to the dominant framework for decision-makers.

On the contrary, agroecological practices that promote crop diversification can increase biodiversity and restore landscape mosaics (see box p. 2). However, these practices are the subject of vigorous debate: are they able to maintain levels of production similar to those observed in conventional agriculture, can they be enhanced in order to improve income, and if so, which practices have the most advantages in terms of the environment and long-term agricultural production?

Evidence of the effectiveness of crop diversification

A recent synthesis review analysed several thousand agronomic studies from around the world that integrate the five crop diversification strategies (see table p. 3): agroforestry, service plants, crop rotation, intercropping, and variety mixtures. This synthesis shows that crop diversification has beneficial effects on agricultural production, on associated biodiversity (in other words the biodiversity naturally present within a cultivated ecosystem: insects, soil microorganisms, etc.), and on numerous ecosystem services, such as soil quality, pest and disease control, water use and quality, and greenhouse gas emissions. It can therefore serve as a cornerstone of agricultural policies for sustainable agriculture.

Some of the key figures of this synthesis review are as follows: in comparison with conventional intensification and monoculture, crop diversification has led to a median increase of 14% in agricultural production and 24% in associated biodiversity. Water quality has improved by 50%, pest and disease control by more than 60%, and soil quality by more than 10%. Certain data is lacking, in particular on yield stability and greenhouse gas emissions – the latter are the result of complex phenomena that depend on the crops, soils and agricultural practices in question. Similarly, far less data is available for the tropical regions, especially sub-Saharan Africa, than for the industrialised countries. Despite this, the advantages of diversification are clear and are observed in all ecosystems.

Agroforestry is the most effective strategy, followed by intercropping, then crop rotation. These practices break with monoculture, by sustainably introducing combinations of species and altering the structure of agricultural biodiversity in space and time. These changes, which are very visible in the case of agroforestry, create new biological interactions in cropping systems, interactions that form the basis of the ecosystem services provided.

The different types of crop diversification

Crop diversification, which consists in increasing the number of plant species grown in agricultural plots, is one of the key principles of agroecology. Numerous strategies exist, associating crop species according to different rules: agroforestry, service plants, crop rotation, intercropping, and variety mixtures.

Agroforestry entails the association of trees and crops in cropland and pastures. It encompasses a wide range of practices according to the ecosystem, the climate and the number and type of crop species. Trees are planted in fields or grasslands, and can also surround crops or even form biodiversity-rich forest systems, such as humid tropical agroforests that provide cocoa, latex and many other products.

Service plants, also known as "cover crops ", are grown to complement the main crop. They are chosen for a specific goal, such as limiting nitrate loss, preventing soil erosion, or increasing soil organic matter.

Crop rotation is the successive cultivation of different crops from one year to another in a given field according to a predefined cycle. It takes advantage of the different characteristics of the successive crops. Three-year rotation systems of soybean or pea or rapeseed then wheat then maize are common in temperate regions. In Sahelian Africa, the same principle is applied, with the rotation of cowpea or groundnut then sorghum or millet followed by a fallow period.

Intercropping is the cultivation of several crop species simultaneously in a given plot. Many different methods exist. For example, relay cropping is a practice where a second crop is planted into an established crop, such as soybean into wheat. Strip cropping involves alternating strips of different crops. In family vegetable plots in tropical regions, intercropping practices can be complex, involving many different species. Intercropping implements specific ecological processes that can result in more efficient resource use and higher yields from plots.

Variety mixtures consist in simultaneously growing several different varieties of the same species in a given plot to take advantage of the properties of each variety and to limit the risks linked to monogenotypic crops (diseases, parasites, etc.).

Crop diversification: a tool for food security

Diversifying crops at the plot level has direct positive effects on agricultural production and ecosystem services. These effects work in synergy at the local levels (village, watershed, territory, etc.), where they result in an increase in agricultural diversity, thereby broadening the range of products, foodstuffs and income available for the territories concerned.

When the number of crop species increases, the diversity of available food products also increases. Crop diversification can therefore have a positive impact on the different attributes of food security at the territorial level, in other words on the stability of food supply, and on access to and availability of food. This effect is particularly beneficial for vulnerable populations (whether marginalised populations in cities or poor rural populations), in both industrialised countries and low-income countries.

Today, technical and organisational innovations aimed at developing crop diversification are emerging in many food systems, some of which are supported by incentive policies. New agricultural systems are promoting healthier food by introducing fruit and vegetables, while reducing pesticide use. The continued development of urban agriculture, often in the form of diversified horticulture, is having positive impacts on food security and wellbeing for the vulnerable populations involved in this practice. Very different examples in urban gardens in Europe or in rural parts of the Sahel (vegetable gardens and fruit farming) show similar positive effects of diversification on food consumption, which is more stable throughout the year and more diversified, and therefore likely to reduce nutritional deficiencies. The effect can be direct, through the products consumed at home, or indirect, through the increase in income for producers, especially when they are involved in more

Agricultural and environmental impacts of the crop diversification strategies

The synthesis review by D. Beillouin *et al.* (2021, in *Global Change Biology*, https://doi.org/10.1111/gcb.15747) compiles the results of 95 meta-analyses integrating 5 156 agronomic studies.

These studies represent 54 554 field experiments distributed across 85 countries, from 1936 to today. They concern more than 120 crop species.

Impacts of crop diversification strategies on each of the variables of agricultural production, biodiversity, and ecosystem services.

Variables (agricultural production, biodiversity, ecosystem services)	Diversification strategy				
	Agroforestry	Service plants	Crop rotation	Intercropping	Variety mixtures
Characteristics of agricultural production					
Crop yields	+	+	+	+	+
Yield stability	?	?	0	?	?
Input use efficiency	?	0	?	+	?
Product quality	?	?	0	0	?
Cost-effectiveness	+	?	-	?	?
Biodiversity					
Associated biodiversity	+	+	+	+	0
Regulatory ecosystem services					
Soil quality	+	+	+	+	0
Pest and disease control	+	+	?	+	?
Water quality	+	+	?	+	?
Water use	+	0	0	?	?
Greenhouse gas emissions	?	-	+	?	?

+ significantly positive effect on the variable | - significantly negative effect | 0 no effect | ? no data available

lucrative sectors (such as organic agriculture in urban and periurban areas). Crop diversification can provide territory-based solutions, which contribute to a better balance at the global level.

Implications for research and public policy

Despite these positive elements, much remains to be done to ensure crop diversification is adopted and implemented on a large scale by farmers. There are still obstacles in the sectors and territories, at different levels.

First, these obstacles arise from the way in which public and private farm advisory and development support systems operate, in liaison with sectoral support systems, which give priority to conventional models based on chemical intensification and specialisation in their sector.

Second, the changes needed to achieve the agroecological transition must also be accompanied by new scientific research strategies. Certain points remain to be confirmed, for example on yield stability and the economic margin. Moreover, while there is a need for innovative mechanisms to support new agroecological practices, it is important to adopt a holistic approach to food systems to enable their deep transformation towards better human and ecosystem health. New multi-disciplinary approaches are needed, bringing together biologists, agronomists, economists, sociologists and food experts. Only research tools and strategies that associate these different viewpoints will be able to propose solutions adapted to individual contexts, ensuring an equitable response to the wide range of stakeholders in the territories concerned.

Finally, significant changes are needed in public policies, which have for a long time supported conventional models.

In Europe, the new Common Agricultural Policy 2023-2027 advocates crop rotation, but gives little attention to the other types of diversification – these strategies remain fragile, as shown by the urgent EU action plan to ensure food security adopted in March 2022 in response to the Ukraine conflict.

At the global level, signs of change are emerging: for example, the Food and Agriculture Organization of the United Nations (FAO) recently adopted a position in favour of agroecology, and the United Nations High-Level Panel of Experts on Food Security and Nutrition (HLPE) expressed the need to implement the 13 agroecological principles set out in its report 14 (2019). These important changes were confirmed at the United Nations Food Systems Summit in September 2021, during which a coalition on agroecology was established. Although the subject remains controversial, a growing number of countries, organisations and civil society members are joining the coalition.

These elements all seem to indicate that the conditions needed for a substantial reform of food systems towards more sustainable food are now emerging. ■

Perspective n° 58 is based on research conducted by CIRAD and its partners on the issues of diversification in food systems. It also builds on the results of the two following projects:

> the GloFoodS research metaprogramme, conducted jointly by INRAE (National Research Institute for Agriculture, Food and Environment, France, https://www.inrae.fr/en) and CIRAD, from 2014 to 2020 (https://www.cirad.fr/en/press-area/press-releases/2020/research-projects-food-security-cirad-inrae);

> the EU project DiverIMPACTS (https://www.diverimpacts.net/index.html).

The scientific synthesis mentioned in this *Perspective* and based on these two projects is the following:

> Beillouin, D., Ben-Ari, T., Malézieux E., Seufert V., Makowski D., 2021. Positive but variable effects of crop diversification on biodiversity and ecosystem services. *Global Change Biology* 27 (19): 4697-4710. https://doi.org/10.1111/gcb.15747

Perspective n°58 is also based on the following publications:

Alpha A., Bousquet F., Caron P., De Lattre-Gasquet M., Dury S., Hainzelin E., Klander E., Malézieux E., Moustier P., Pallet D., Vaast P., Zakhia-Rozis N., 2021. Le Cirad s'engage pour des systèmes alimentaires durables, résilients et inclusifs. Montpellier, CIRAD, 5 p. https://agritrop.cirad.fr/598775/

Andriamampianina L., Temple L., de Bon H., Malézieux E., Makowski D., 2018. Évaluation pluri-critères de l'agriculture biologique en Afrique subsaharienne par élicitation probabiliste des connaissances d'experts. *Cahiers Agricultures* 27 (4) : 45002. https://doi.org/10.1051/cagri/2018030

Beillouin D., Ben-Ari T., Makowski D., 2019. Evidence map of crop diversification strategies at the global scale. *Environmental Research Letters* 14 (12): 123001. https://doi.org/10.1088/1748-9326/ab4449

Beillouin D., Ben-Ari T., Makowski D., 2019. A dataset of meta-analyses on crop diversification at the global scale. *Data in Brief* 24: 103898. https://doi.org/10.1016/j.dib.2019.103898

Bricas N., Malézieux E., 2021. Faut-il doubler la production alimentaire ? In : Ecologie des systèmes alimentaires. Bricas N., Conaré D., Walser M. (Eds.). Versailles, Editions Quæ, pp. 167-177. ISBN 978-2-7592-3352-6. https://doi.org/10.35690/978-2-7592-3353-3

Lesur-Dumoulin C., Malézieux E., Ben-Ari T., Langlais C., Makowski D., 2017. Lower average yields but similar yield variability in organic versus conventional horticulture. A meta-analysis. *Agronomy for Sustainable Development* 37 (5): e45. https://doi.org/10.1007/s13593-017-0455-5

Malézieux E., Corbeels M., 2019. Limited food availability. In: Food systems at risk. New trends and challenges. Dury S., Bendjebbar P., Hainzelin É., Giordano T., Bricas N. (Eds.). Rome, CIRAD-FAO, p. 99-102. ISBN 978-2-87614-751-5. https://doi.org/10.19182/agritrop/00103

Malézieux E., Dabbadie L., 2019. Resource over-exploitation and running out. In: Food systems at risk. New trends and challenges. Dury S., Bendjebbar P., Hainzelin É., Giordano T., Bricas N. (Eds.). Rome, CIRAD-FAO, p. 55-58. ISBN 978-2-87614-751-5. https://doi.org/10.19182/agritrop/00092

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: The agroecological transition of agricultural systems in the Global South. (Côte F.-X., Poirier-Magona E., Perret S., Roudier P., Rapidel B., Thirion M.-C., Eds.). Versailles, Éditions Quæ, p. 199-217. ISBN 978-2-7592-3056-3. https://agritrop.cirad.fr/593014/ - https://www.quae-open.com/produit/114/9782759230570/the-agroecological-transition-of-agricultural-systems-in-the-global-south

Temple L., Malézieux E., Gautier D., Aubry C., Pourias J., Asuero R. P., de Bon H., (*in press* 2022). Agroecological innovations, food and nutrition security and food safety for small farmers: Africa-Europe perspectives. In: Sustainable food systems as a pathway to food and nutritional security. Need for combination of local and global approaches (Thomas A., Alpha A., Barczak A., Zakhia-Rozis N., Eds). Versailles, Éditions Quæ, pp. 99-112

A few words about...

Éric Malézieux is an agronomist and researcher at CIRAD in the HortSys research unit (Agroecological functioning and performances of horticultural systems, https://ur-hortsys.cirad.fr/en). His work focuses on the functioning and design of agroecological horticultural systems and agroforestry systems. After coordinating the agronomy field at CIRAD, then directing the HortSys research unit for 10 years, he now studies the changes in food systems throughout the world.
eric.malezieux@cirad.fr

Damien Beillouin is an agronomist and researcher at CIRAD in the HortSys research unit, specialising in global agronomy and data analysis. His work focuses on quantifying the impacts and benefits of agricultural production models on biodiversity and climate change.
damien.beillouin@cirad.fr

David Makowski is director of research at the French National Research Institute for Agriculture, Food and Environment (INRAE, https://www.inrae.fr/en) in the joint research unit MIA-Paris-Saclay (Applied mathematics and computer science, https://www6.inrae.fr/mia-paris). He specialises in agricultural and environmental data analysis, and studies the impact of climate change on global agricultural production and the assessment of agroecological system performance.
David.Makowski@inrae.fr

A few links

Crippa M. Solazzo E., Guizzardi D., Monforti-Ferrario F., Tubiello F. N., Leip A., 2021. Food systems are responsible for a third of global anthropogenic GHG emissions. *Nature Food* 2: 198-209. https://doi.org/10.1038/s43016-021-00225-9

High Level Panel of Experts on Food Security and Nutrition (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. HLPE Report 14, 163 p. https://www.fao.org/cfs/cfs-hlpe/hlpe-reports/report-14-elaboration-process/en/

United Nations - Food Systems Summit 2021. https://www.un.org/en/food-systems-summit

Food and Agriculture Organization of the United Nations (FAO), 2021. Agroecology Knowledge Hub. https://www.fao.org/agroecology/overview/fr/

European Parliament, 24 March 2022. Texts adopted. P9_TA(2022)0099 - European Parliament resolution of 24 March 2022 on the need for an urgent EU action plan to ensure food security inside and outside the EU in light of the Russian invasion of Ukraine (2022/2593(RSP)). https://www.europarl.europa.eu/doceo/document/TA-9-2022-0099_EN.html

European Parliament, 2021. EU farm policy reform: Parliament and Council strike a deal. https://www.europarl.europa.eu/news/en/press-room/20210617IPR06468/eu-farm-policy-reform-parliament-and-council-strike-a-deal

To cite this document
Malézieux E., Beillouin D., Makowski D., 2022. Feeding the world better: crop diversification to build sustainable food systems. Montpellier, CIRAD, *Perspective* 58. https://doi.org/10.19182/perspective/36932

cirad
AGRICULTURAL RESEARCH FOR DEVELOPMENT

42, rue Scheffer
75116 Paris • France
www.cirad.fr

Publication Director: Élisabeth Claverie de Saint Martin, CIRAD Chief Executive Officer
Editors: Patrick Caron, UMR ART-Dev (Actors, Resources and Territories in Development)
Cécile Fovet-Rabot, Scientific and Technical Information Service
Étienne Hainzelin, General Management
Translation: Anna Kiff
Graphic design: Laurence Laffont
Distribution: Nolwenn Servant, Scientific and Technical Information Service

https://revues.cirad.fr/index.php/perspective
perspective ISSN-L 2275-9190 - **Email :** perspective@cirad.fr

MUSE
MONTPELLIER UNIVERSITÉ D'EXCELLENCE
https://muse.edu.umontpellier.fr