KNOWLEDGE BRIEF

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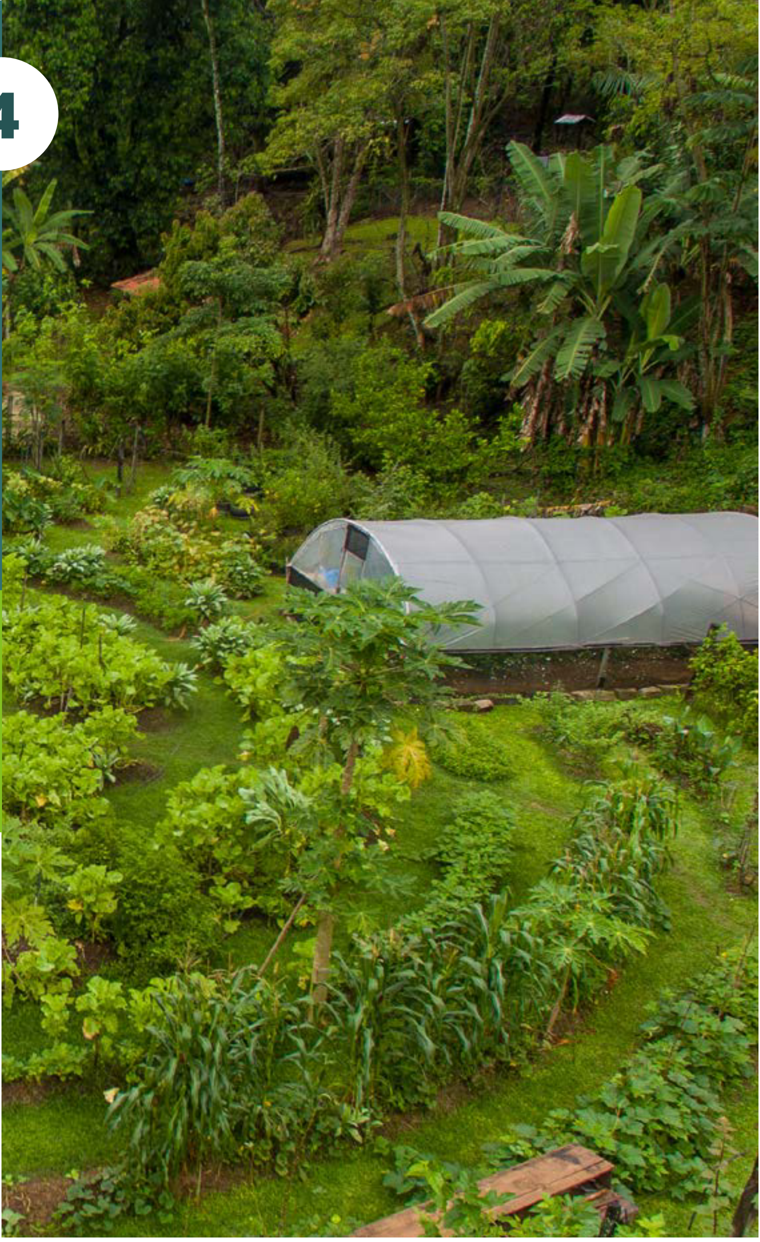
What agroecology brings to food security and ecosystem services: a review of scientific evidence



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Abstract

There is a growing body of scientific evidence regarding the outcomes and impacts of agroecology. This knowledge brief aims to provide a set of evidence, based on a large-scale analysis of scientific articles (literature review, meta-analysis, models).

There is a strong theoretical basis and empirical evidence that food security outcomes (availability, access, utilisation, stability) are as good or sometimes even better for agroecological systems than conventional alternatives. Four levers for agroecology supporting the positive impacts of agroecology on food security are analysed: crop diversification, legume-based systems, agroforestry and mixed crop-livestock systems. Crop diversification is an effective strategy to improve food security by mobilising different biological mechanisms. Due to its biological characteristics for nitrogen (N) fixing, legumes are one of the most important levers for improving food security (both availability and food utilisation/nutrition) based on agroecological principles. Agroforestry contributes to food availability by recycling nutrients, to food stability by increasing the resilience of the farming systems and to food utilisation through better diets. Mixed crop-livestock systems contribute to food availability by recycling nutrients and to food utilisation through meat and milk consumption.

As agroecology is more than a set of practices, this knowledge brief specifically focuses on two approaches with a high potential to increase food security and efficiently address environmental challenges. A set of evidence is analysed for integrated soil health management and agroecological pest management.

Beyond production and food security, agroecology brings multiple services. In fact, such services are the main arguments to support agroecological approaches able to adequately address both food security and environmental challenges. Socio-economic evidence is also analysed.

1 Context and objective

Agroecology is a science, a set of practices and a social movement. It is defined by the Food and Agriculture Organization of the United Nations (FAO) as “an integrated approach that simultaneously applies ecological and social concepts and principles to the design and management of food and agricultural systems” that “aims to optimise 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”. Many actors referring to agroecology prefer to insist on principles that define what agroecology is. The FAO proposes 10 elements to characterise agroecology, identified during a consultation process carried out between 2015 and 2017, and culminating with an international symposium in 2018.[1] The HLPE report (2019) on agroecology presents 13 principles (both technical, social and organisational)

1] Available at http://www.fao.org/about/meetings/second-international-agroecology-symposium/en/, accessed 8 February 2024.

that must be applied for an agroecological transition. The 10 elements and 13 principles are complementary. The HLPE report is based on large scientific expertise to demonstrate the contribution of agroecology to food system transformation with clear outcomes regarding food production, nutrition, biodiversity and soil fertility, but also jobs and incomes. There is a growing body of scientific evidence regarding the outcomes and impacts of agroecology.

This knowledge brief aims to provide a set of evidence, based on a large-scale analysis of scientific articles (including a literature review, meta-analysis and models). It focuses on the technical dimension of agroecology, especially the development of farming systems based on diversified crop-livestock-tree systems, mobilising a set of agricultural practices. In this sense, agroecology is opposed to monocropping systems and/or farming systems based on standardised practices and a high use of external inputs. First, we will analyse the impacts on food security and nutrition which is one key point of controversy regarding agroecology. Second, we will focus on two approaches with a high potential to increase food security and efficiently address environmental challenges. Third, a set of evidence will be analysed for integrated soil health management and agroecological pest management. Fourth, we will analyse the contribution to other ecosystem services which are usually attributed to agroecology. And finally, socio-economic outcomes will be analysed.

2 Agroecology contributes to food security

Food security is a large concept which includes food availability, food access, food utilisation and food stability. In this sense, the nutrition dimension (including a healthy diet) is part of food security.

With a broad perspective regarding food security, a scientific literature review (Bezner Kerr et al. 2021) published by Cornell University (United States of America) and ISARA (France) examines the evidence for whether agroecological practices can improve food security. As far as the authors are aware, this was the first review over the last 20 years to assess whether agroecological practices have positive impacts on food and nutrition outcomes. A total of 11,771 articles (1998–2019) were screened, 275 articles were included for a full review, and 56 articles were selected. Agroecological practices included crop diversification, intercropping, agroforestry, integrating crop and livestock, and soil management measures. Outcomes are related to a diversity of themes (production, income, costs, nutrition) and could be assessed with quantitative or qualitative studies. Most studies (78%) found evidence of positive outcomes in the use of agroecological practices on food security and nutrition of households in low and middle-income countries. Some studies found mixed outcomes regarding food security and nutrition, and a few studies reported negative outcomes. More complex agroecological systems that included multiple components (e.g., crop diversification, mixed crop-livestock systems and farmer-to-farmer networks) were more likely to have positive food security and nutrition outcomes.

2.1 What do we know about agroecology and food availability?

The scientific literature analysing agroecology mainly focuses on the food availability dimension and less on the other dimensions of food security (access, utilisation, stability). There is a strong theoretical basis and empirical evidence that agroecology results in increasing yields compared to conventional alternatives. A recent study (Dittmer et al. 2023) indicates the positive impact of agroecology on yields. The study, comprising of researchers from USA universities, the global research partnership CGIAR and a French research institute, assessed the outcomes of smallholder agricultural systems and practices in low- and middle-income countries against 35 mitigation, adaptation and yield indicators by reviewing 50 articles with 77 cases of agroecological treatments relative to a baseline of conventional practices. Crop yields were higher for 63% of cases reporting yields.

When comparing organic agriculture (without chemical inputs) with conventional agriculture, a review of 105 studies (de la Cruz et al. 2023) shows that the yields of organic farming were 18% lower than those of conventional farming, regardless of climate conditions, crop types and other categorical variables. Even if 18% is significant, it is not a critical drop taking into account the potential cost reduction of external inputs. Furthermore, organic agriculture is only one component of agroecology, as agroecology intends to limit the dependence on external inputs – not to exclude them.

The level of fertiliser use seems to have an influence on the impact of agroecological systems on yields. Using a novel application of meta-analysis to data from 30 long-term experiments from Europe and Africa (comprising 25,565 yield records), MacLaren et al. (2022) investigated how field-scale agroecological practices (named “ecological intensification” by the authors) interact with each other, and with N fertiliser and tillage, in their effects on long-term crop yields. Here they confirmed that such practices (specifically, increasing crop diversity and adding fertility crops and organic matter) have generally positive effects on the yield of staple crops. However, they showed that these practices had a largely substitutive interaction with N fertiliser, so that agroecological practices substantially increase yield at low N fertiliser doses but have minimal or no effect on yield at high N fertiliser doses. Moreover, agroecological practices had comparable effects across different tillage intensities, and reducing tillage did not strongly affect yields.

Such statements on the relationship between fertiliser use and agroecology do not indicate that agroecology is only well suited for low-input systems. In the case of European agriculture, including intensive farming systems and based on empirical studies, Van der Ploeg et al. (2019) show that agroecology not only allows for more sustainable production of healthier food but also considerably improves farmers' incomes. Many local studies provide more contextualised data on the impacts of agroecology on food security. For example, a large-scale transition to agroecological farming in Andhra Pradesh (India) without external inputs has maintained crop yield (Duddigan et al. 2022) and at the same time reduced production costs and provided positive externalities for the environment.

In conclusion, agroecological systems lead to increased yields in comparison with conventional systems, especially in low-input systems. Without external inputs, agroecological organic systems could maintain yields or experience a modest yield decrease but with positive externalities.

2.2 Levers for agroecology to improve food security

To better understand the impact of agroecology on food security, we will analyse four levers of agroecology which support the positive impacts of agroecology on food security: crop diversification, legume-based systems, agroforestry systems and mixed crop-livestock systems.

Agroecology and crop diversification

The impacts of agroecology on production are mainly explained by better biodiversity management at crop and farm level. Scientific evidence shows that as crop diversity increases, total yields (the sum of the yields of all crops in a mixture) are higher than for monoculture when the level of fertiliser use is similar. In cases where combined crops are complementary rather than competitive in their acquisition of light, water and nutrients, total yields are even higher. This contrasts with monocultures, where all plants are the same and thus competing for the same resources in the same way or are submitted to the same pests and diseases with the same capacities to react.

A review by Beillouin et al. (2021) analysed several thousand agronomic studies from around the world that integrate five crop diversification strategies: agroforestry, service plants (cover crops to complement the main crop and provide services), crop rotation (different crops from one year to another on the same plot), intercropping (different crops in a given plot), and variety mixtures (several varieties of the same species in a given plot). The review shows that crop diversification has beneficial effects on agricultural production and has led to a median increase of 14% in agricultural production in comparison with monocropping systems. Certain data are lacking, in particular on yield stability. However, the study mentions that the advantages of diversification are clear and observed in all ecosystems. Agroforestry is the most effective strategy, followed by intercropping and 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 increase in production and the ecosystem services provided.

Another study (Li et al. 2023) demonstrates that agroecology based on intercropping performs at least as well as monocropping in terms of production. To objectively assess the benefits of intercropping, this team of Chinese, Dutch and French researchers undertook an in-depth analysis of the productive performance of associated crops, based on the results of 226 agronomic experiments. Their conclusion highlights that intercropping performs well in producing a diverse set of crop products and performs almost similar to the most productive component sole crop to produce raw products. Furthermore, intercrops provide additional advantages for making agriculture more sustainable by limiting diseases, pests and weeds, and using N more efficiently.

In conclusion, crop diversification is an effective strategy to improve food security. The mechanisms to explain these results are diverse with crop diversification effects on plant nutrition, water access, pest control and mitigation.

Agroecology and legume-based systems

Legumes are an important element for nutrition as they contribute to a diversified diet with high protein content. In this review we focus on the production side. Legumes play an important role due to the N fixation capacities from the atmosphere. The review by Falconnier et al. (2023) provides some insights regarding N fixation which explains the increase in yield. Based on 13 studies, the researchers indicate that legume trees and shrubs could contribute as much as 100 kg N/ha/year through N fixation. However, the net N inputs vary considerably, because perennials are integrated into cropping systems, and which plant parts are left on or incorporated into the soil. Based on 20 studies, the researchers also point out that green manures have similar potential net N inputs to crop land compared with trees and shrubs (median of 91 kg N/ha/year). Grain legumes and fodder legumes could provide additional benefits to farmers but with less N left for the following crops (20 to 40 kg/ha in a low-yield system, less or negative in a high-yield system).

A global systematic review with meta-analysis demonstrates the yield advantage of legume-based rotations (Zhao et al. 2022). This team of scientists from the Agricultural University of China, the University of Aarhus (Denmark), CIRAD, the University of Western Australia and the University of Aberdeen (United Kingdom) have synthesised more than 460 field experiments, which include nearly 12,000 yield observations across 53 countries. The experiments aimed at comparing legume-based (mainly rotation) and non-legume-based cropping systems. The conclusion is clear: the introduction of legumes into cropping systems improves yields of main crops by around 20%. Yield benefits are consistent among main crops (e.g., rice, wheat, maize) and evident across pedo-climatic regions. However, there are variations between continents. Of the 844 field observations analysed in Africa, legumes increased yields by 43% on average (compared to only 15% in Europe). This higher increase in Africa is linked to the fact that the starting point, in terms of yield, is lower. The study of Franke et al. (2018) confirms this observation. The authors looked at 44 unique publications, providing 199 observations comparing continuous cereal performance with that of a grain legume-cereal rotation. The overall mean yield increase of 0.49 t grain/ha, equal to an increase of 41% of the continuous cereal yield, is highly significant, but the variability in residual effects is large.

The results on production are also positive for intercropping systems (e.g., legumes and cereals grown in the same plot). Namatsheve et al. (2020) used 60 unique publications combining 1196, 998 and 25 observations of yield, land productivity and N2-fixation, respectively, for crops grown as intercrops and monocrops. The results show that land productivity of cowpea intercropped with maize, sorghum and pearl millet is better than monocropping with average land equivalent ratios (which describe the relative land area required under monocropping to produce the same yield as under intercropping) of 1.42 ± 0.47, 1.26 ± 0.35 and 1.30 ± 0.32, respectively. However, the total amount of fixed N was higher in cowpea monocropping systems due to higher biomass production; nitrogen fixation was 57 kg N/ha and 36 kg N/ha in monocrops and intercrops, respectively.

The results on production also depend on the level of input use. Based on 460 field experiments, Zhao et al. (2022) compare legume-based with non-legume-based cropping systems. Greater yield advantages (32% vs. 7%) are observed in low- vs. high-yielding environments, suggesting legumes increase crop production with low inputs (e.g., in Africa or organic agriculture). Based on the results of 226 agronomic experiments, Li et al. (2023) state that intercrops with legumes, especially maize/legume intercrops, showed transgressive overyielding under low N fertiliser input, indicating their potential for developing more sustainable low N input cropping systems. These studies suggest that legume-based rotations offer a critical pathway for enhancing global crop production, especially when integrated into low-input systems.

While there is a strong evidence base for the positive impacts of integrating legumes in cropping systems, there are also a few crucial limitations that have been identified: legumes' short fallows may compete with land dedicated to food production; N fixation by legumes is usually insufficient to cover the N needs of high yield cereals; there are losses of N due to leaches; N fixation requires soil with unlimited phosphorus (P) and efficient inoculum. Economic and social limitations also exist, such as access to profitable markets for farmers or consumers' preferences. Some limitations ask for more research and innovation investments to be overcome.

In conclusion, due to their biological characteristics, legumes are one of the most important levers for improving food security (both food availability and food utilisation/nutrition) based on agroecological principles.

Agroecology and agroforestry systems

Agroforestry is a crucial component of agroecological transitions in many agroecosystems. Through mimicking natural forests, these systems offer multiple benefits such as soil fertility enhancement with carbon sequestration and recycling of other nutrients from deep soil layers, potential reduction in pest and disease pressure depending on the context, erosion control thanks to the shade and roots, and adaptation to climate change thanks to the shade and better water retention. Agroforestry systems also contribute to diversification in terms of food production, nutrition and incomes. Due to the diversity of agroforestry systems, the existing scientific synthesis focuses only on specific issues.

Based on an in-depth synthesis, Barrios et al. (2023) show that the impacts of agroforestry on soil health derive from five major sources or functions. The study mentions the following:

- Organic inputs above and below ground. Agroforestry trees can contribute to up to 20 t of dry matter per ha/year just from pruning, which can contain as much as 358 kg N, 28 kg P, 232 kg potassium (K), 144 kg calcium (Ca) and 60 kg magnesium (Mg) (Palm 1995). Tree roots also contribute significant organic matter to soil through rhizodeposition.
- Biological nitrogen fixation (BNF). Agroforestry trees, particularly leguminous ones, can contribute to N inputs through their BNF, which has been found to range from 56 to 675 kg N/ha/year depending on climate, tree species and management systems (Nygren et al. 2012).
- Deep uptake and recycling of nutrients from below the crop root zone. During the dry season, some agroforestry tree species, e.g., Vitellaria paradoxa, have been found to take up as much as 50% of their water from below the rooting zone of crops, which means that they are not competing so much with crops (Bayala and Prieto, 2020). Trade-offs due to competition for nutrients and water with crops can be found, however, with certain trees, e.g., fast-growing species, in particular contexts such as drylands.
- Water filter and accumulation functions of agroforestry trees, which create water infiltration sinks that absorb water and also barriers to overland flows of water and sediment. This can reduce soil erosion rates by as much as 50% (Muchane et al. 2020) and can increase infiltration rates by up to 2.8 times (Ilstedt et al. 2007).
- Protection of the soil surface by tree litter cover, up to 68% during the cropping season (Pauli et al. 2010).

What do these positive outcomes mean for yield? Niether et al. (2020) present a meta-analysis of 52 articles that compare cocoa agroforestry systems and monocultures. They analysed the differences in cocoa and total system yield, economic performance, soil chemical and physical properties, incidence of pests and diseases, potential for climate change mitigation and adaptation, and biodiversity conservation. Cocoa agroforestry systems outcompeted monocultures in most indicators. Cocoa yields in agroforestry systems were 25% lower than in monocultures but compensated by the longer productive lifetime of cocoa trees grown under shade. The total system yields (all products) were about ten times higher for agroforestry systems, even if this difference is not reflected in higher revenues for farmers but with a clear contribution to food security and diversified incomes. The studies are showing the complex effects of shade trees on the incidence of pests and diseases with mixed effects depending on influencing factors such as the management of the agroforestry system, the specific characteristics of the pest or disease considered and the particular microclimatic conditions, which highly depend on the structural complexity of the cocoa agroforestry system.

A global analysis of the impact of integrating trees with rice reviewed 87 publications addressing the association with 204 woody perennial species (Rodenburg et al. 2022). Across all types of agroforestry practices analysed, the average effect of adding trees compared to a non-fertiliser and non-tree control is 38%. Yield benefits and risks from integrating trees with smallholder rice cropping depend on the type of agroforestry practice used and how each practice interacts with fertiliser application. Finally, the study is showing higher yields of rice with trees than without, where no or low levels of fertiliser are applied.

In conclusion, agroforestry contributes to food availability by recycling nutrients, to food stability by increasing the resilience of the farming systems but also to food utilisation through better diets (fruits, leaves). However, the impacts vary depending on the type of agroforestry systems (composition, management, climate, etc.).

Agroecology and mixed crop-livestock systems

The synergies between cropping and livestock husbandry offer many opportunities for sustainably increasing production by raising productivity and increasing resource use efficiency. This, in turn, can increase incomes and secure availability and access to food for people while maintaining environmental services. Herrero et al. (2010) highlight that mixed systems produce close to 50% of the world's cereals and most of the staples consumed by poor people: 41% of maize, 86% of rice, 66% of sorghum and 74% of millet production. They also generate the bulk of livestock products in the developing world, that is, 75% of milk and 60% of meat.

An agroecological model for Europe (Poux et al. 2018), based on the deployment at a large scale of mixed crop-livestock farming with extensive grasslands including legumes and landscape infrastructure (hedges, humid zones, etc.), demonstrates the potential to develop sustainable farming systems. The model makes use of the N fixation by legumes and the use of manure to manage nutrient cycles. The quantitative model (TYFAm) is based on the widespread adoption of agroecology, the phasing out of vegetable protein imports and the adoption of healthier diets with less meat. Despite an induced drop in production of 35% compared to 2010 (in kilocalories), this scenario provides healthy food for Europeans while maintaining export capacity, reduces Europe's global food footprint, leads to a 40% reduction in greenhouse gas (GHG) emissions from the agricultural sector, regains biodiversity and conserves natural resources. Further work is needed and underway on the socio-economic and policy implications of the TYFAm scenario.

In Africa, crop-livestock systems make a significant contribution to productive and sustainable production (Vall et al. 2023). Based on different studies (Pieri 1989, Andrieu 2015, Falconnier et al. 2023), one tropical livestock unit produces around 1 t of manure per year and provides the required N quantity for around 700 kg of maize grain and the related stover. The manure provides also P and K, even if the concentration remains quite low (more than 1% for N, less than 1% for P and K). In general, the current crop-livestock system is not able to provide all nutrients for the cropping systems of the majority of African farmers. However, due to complex nutrient flows at territorial scales, positive balances are found regarding nutrient flows for pastoral farmers in West Africa or in fields close to the homestead or in home gardens (Diarisso et al. 2015). Vall et al. (2023) found that most agroecological agricultural systems in Burkina Faso are characterised by the importance of livestock with its function in recycling and recovering crops in organic manure and mulch. These recycling practices are facilitated by better rates for equipment and tools for transport and storage of crop residues and livestock by-products, by better soil water and crop residues conservation measures, and by better maintenance of the wooded park in the cultivated fields. Moreover, improved manure collection and storage practices, reduced nutrient losses of manure (especially of N), increased forage use including forage trees, and adjusted amounts of manure applied on fields, may substantially expand the area of crop land benefiting from livestock excretions (Schlecht et al. 2006).

In conclusion, mixed crop-livestock systems contribute to food availability by recycling nutrients and to food utilisation through meat and milk consumption.

2.3 Agroecological approaches contributing to food security and perspectives for improvement

Agroecology is more than a set of practices. Two approaches addressing soil health and crop health with a holistic perspective are key for agroecological transitions: integrated soil health management and agroecological integrated pest management. We provide some insights regarding these two approaches and some innovative perspectives to illustrate the progress which might be achieved by investing in research and innovation (R&I) for agroecology. To be agroecological, both incremental and radical innovations must be embedded and contribute to systemic changes taking into account the complex interactions between ecological and social processes. These agroecological innovations are context-specific, mobilising local and scientific knowledge. Change at scale requires particular mechanisms and policies to scale out (geographical extension), up (institutional arrangements for change) and deep (change of values).

Integrated soil health management

Integrated soil health management aims at addressing the use and management of soils for agricultural production and ecosystem services with a holistic approach, integrating the physical, chemical and biological dimensions of soil. It is a set of complementary practices related to soil conservation and rehabilitation at farm level and landscape level. Integrated soil health management largely mobilises the four levers of agroecology which are highlighted in this knowledge brief: diversification, legumes-based systems, agroforestry systems and crop-livestock systems.

Among different domains, soil health addresses the questions related to the cycles of nutrients. The above scientific review shows that not a single practice is able to bring the required nutrients to sustain yields. However, by promoting a systemic farm approach, the set of practices mobilising legumes, livestock and trees is able to cover a significant part of the required nutrients and to stimulate the biological soil life. For low-yield farming systems, such a set of practices could cover all the nutrient needs of the crops (the reason why many small farmers adopt these practices). For high-yield farming systems, there is a need to complement with external fertilisers. Inorganic fertilisers (including lime) are an important source of nutrients among other sources. However, agronomic and economic constraints limit their use in Africa. Better inorganic fertiliser use efficiency is thus required to achieve better yields. Inorganic fertilisers' efficiency is low in degraded soils, as low pH and a low level of carbon are limiting factors which have to be addressed.

Off-farm organic fertilisers are a promising solution as they bring both the minerals required by the crops and the carbon to address the soil organic matter content. They include recycled waste along the value chains with a circular economy approach, urban waste and human excreta considering that urine contains most of the nutrients of human excreta (Nagy et al. 2017). In Africa, urban waste could provide between 20% to 40% of the nutrients which are required by the crops (Freyer et al. 2023). Biochar is an option when the required resources to produce biochar are available (Farhangi-Abriz et al. 2021). Biofertilisers and biostimulants are also promising avenues to increase the capacities of bacteria to capture atmospheric N, solubilise P in the soil, stimulate the capacities of plants to mobilise nutrients or resist to pests (Freyer et al. 2023). Other R&I investments may lead to better N fixation by legumes (crop, trees and shrubs). Authors mentions new avenues to improve soil fertility. For example, Husson (2013) highlight the role of the Redox potential (Eh) with the he hypothesis that plants physiologically function within a specific internal Eh-pH range and that, along with microorganisms, they alter Eh and pH in the rhizosphere to ensure better access to nutrients.

Agroecological integrated pest management

Agroecological integrated pest management or agroecological crop protection is the application of the principles of agroecology to crop protection to promote virtuous and sustainable changes in agriculture and food systems (Deguine et al. 2018). Promoting agroecological integrated pest management could yield several important benefits, such as a reduced reliance on pesticide use, but also greater crop yields due to better control on crop damages and increased biodiversity in agricultural landscapes. At field level, the diversity of varieties of the same crop, the diversity of crops and the diversity of weeds and habitats surrounding the fields may lead to an increase in natural enemies of pests but also to a better control of the dissemination of pests. However, systematic reviews quantifying the effect of agroecological pest management on pest damages and yield are scarce due to the complex and context-specific interactions between plants, environment and pathogens.

A systematic review (Petit et al. 2020) of 258 articles focusing on four agroecological farming systems or practices (organic farming, conservation tillage, crop diversification, adjacent non-cropped habitats) provides evidence that each of the four agroecological approaches can benefit natural enemies and biological control, although this could have no effect in some situations or in some years.

Many studies exist on specific situations. For example, a study (Deguine et al. 2018) on mango in Réunion Island (tropical area) demonstrates that agroecological crop protection practices, mainly the suppression of pesticides, use of prophylaxis and permanent vegetal cover, which are the bases of conservation biological control, have positive impacts. These practices were found to reduce pest populations and damage largely caused by bugs and flies, and had no negative impact on flowering levels. The treatment frequency index (the number of full doses applied, per cropping season on the whole surface) decreased from 22.4 before the intervention to 0.3 after the intervention. Production costs were reduced by 35% without any loss in yield, except in a few specific circumstances. Such a result is explained by the growing population of arthropods of which many are parasitoids or predators (ants).

Several examples could well be viewed as innovative agroecological practices for integrated pest management, as they focus on harnessing ecological processes. For example, monitoring the entomofauna to reinforce push and pull practices (Adesina et al. 2023) or the production and use of biostimulants based on bacteria and fungi (Freyer et al. 2023) are promising avenues. Emerging strategies might include long-term plant colonisation, microbiome engineering and breeding of microbe-optimised crops (Ab Rahman et al. 2018).

3 Agroecology provides additional ecosystem services

Besides production and food security, agroecology brings multiple services. In fact, such services are the main arguments to support agroecological approaches able to adequately address both food security and environmental challenges.

3.1 Agroecology's beneficial effects on associated biodiversity and other ecosystem services

The recent synthesis review by Beillouin at al. (2021) analysed several thousand agronomic studies from around the world and showed that crop diversification has beneficial effects 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 GHG. 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 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%. Less data are available for tropical regions, especially sub-Saharan Africa, than for industrialised countries.

Another comprehensive global synthesis (Tamburini et al. 2020) of 5,160 original studies comprising 41,946 comparisons between diversified and simplified practices shows the interactions between biodiversity and ecosystem services. The practices are crop diversification, non-crop diversification (e.g., agroforestry), organic amendment, addition of beneficial microorganisms into the soil, reduced tillage and organic farming). The article shows that, compared to conventional agriculture, crop diversification significantly increases the delivery of ecosystem services such as above- and below-ground biodiversity, pollination, pest control, nutrient cycling, water regulation and soil fertility, while having a neutral effect on yields. Practices targeting above-ground biodiversity boost pest control and water regulation, while those targeting below-ground biodiversity enhance nutrient cycling, soil fertility and water regulation. Most often, diversification practices result in win-win support of services and crop yields. Variability in responses and occurrence of trade-offs highlight the context dependency of outcomes.

Based on this evidence, the United Nations Convention on Biological Diversity COP 15[2] adopted Target 10,[3] mentioning agroecology to contribute to halting biodiversity loss: "Ensure that areas under agriculture, aquaculture, fisheries and forestry are managed sustainably, in particular through the sustainable use of biodiversity, including through a substantial increase of the application of biodiversity friendly practices, such as sustainable intensification, agroecological and other innovative approaches contributing to the resilience and long-term efficiency and productivity of these production systems and to food security, conserving and restoring biodiversity and maintaining nature's contributions to people, including ecosystem functions and services".

Furthermore, the United Nations Convention to Combat Desertification's Global Land Outlook 2022[4] is referencing agroecology with other approaches such as regenerative practices, agroforestry, grazing management or integrated soil and water management as priority actions to halt and reverse desertification and degradation in rural/agricultural landscapes.

3.2 Agroecology contributes to climate change adaptation and mitigation

Agroecology is well positioned to address climate change challenges. It plays a pivotal role in adapting more resilient farming systems, largely through diversification at plot, farm and landscape levels regarding mitigation mostly through agroforestry and partially through pastoralism.

In 2021, a CGIAR programme carried out a study commissioned and co-funded by the Foreign, Commonwealth and Development Office and the Bill & Melinda Gates foundation (Snapp et al. 2021). This study assessed evidence regarding (i) the impact of agroecological approaches on climate change mitigation and adaptation in low- and middle-income countries and (ii) the programming approaches and conditions supporting large-scale transitions to agroecology and transitions. The researchers conducted a systematic literature review analysing more than 20,000 scientific articles (including 18 synthesis articles) to identify primary evidence for agroecological approaches related to nutrient management, pest and diseases, and climate change outcomes. The results show that the agroecological approach with the strongest body of evidence for impacts on climate change adaptation was farm

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[2] Available at COP15: Nations adopt four goals, 23 targets for 2030 in landmark UN biodiversity agreement | Convention on Biological Diversity, accessed 8 February 2024.

[3] Available at https://www.cbd.int/gbf/targets/10/, accessed 8 February 2024.

[4] Available at https://www.unccd.int/sites/default/files/2022-04/GLO2_SDM_low-res_0.pdf, accessed 8 February 2024.

diversification (strong evidence and high agreement). This included positive impacts of diversification on pollination, pest control, nutrient cycling, water regulation and soil fertility. Tropical agroforestry is strongly associated with carbon sequestration in biomass and soil. Mitigation of nitrous oxide (N2O) is often associated with organic farming and ecological management of nutrients (medium evidence, medium agreement).

The CGIAR analysis confirms results from other scientific articles. Through a large literature review, Bezner Kerr et al. (2023) analysed the recent evidence showing the potential for agroecology as a transformative approach, to positively address adaptation and mitigation challenges, and to also meet key societal goals such as healthy ecosystems, food security and nutrition. More context-specific studies confirmed these results. For example, in Latin America Quintero et al. (2024) made a review of existing evidence of the role of agroecological systems on climate change adaptation and mitigation. Based on a literature review and surveys in Colombia, Ecuador and Peru, they found clear evidence that the various dimensions of agroecology support both the various socio-technical dimensions of resilience and mitigation. As one example concerning agroforestry, the study of Niether et al. (2020), presenting a meta-analysis of 52 articles comparing cocoa agroforestry systems and monocultures, shows that cocoa agroforestry contributes to climate change mitigation by storing 2.5 times more carbon and to adaptation by lowering mean temperatures and buffering temperature extremes.

Based on multiple scientific evidence, the sixth assessment report of the Intergovernmental Panel on Climate Change (IPCC), Bezner Kerr et al. (2022) conclude that (i) ecosystem-based approaches such as diversification, land restoration, agroecology and agroforestry have the potential to strengthen resilience to climate change with multiple co-benefits, but trade-offs and benefits vary with socio-ecological context (high confidence); and (ii) agroecological approaches can increase food system resilience (robust evidence, medium agreement), while some agroecological practices such as agroforestry can provide mitigation measures (medium confidence).

3.3 The socio-economic performance of agroecology

There are less reviews regarding specifically the socio-economic performance on agroecology. A review of 80 articles comparing the socio-economic performance of agroecological practices vs. conventional management (Mouratiadou et al. 2024) found that agroecological practices are more often associated with positive socio-economic outcomes (51% positive outcomes, 10% neutral, 9% inconclusive, 30% negative). Interestingly, the findings with neutral outcomes can be seen favourably since the socio-economic performance of these practices is not significantly different from conventional ones, while they potentially provide positive effects in terms of environmental benefits and well-being. In particular, results concerning the financial capital category indicate that higher productivity and efficiency are often mirrored by improvements in income (56% and 60% positive outcomes for these sub-themes, respectively). Based on a meta-analysis, Sánchez et al. (2022) found that diversified farming systems, strongly promoted under agroecology, are associated with higher labour costs but also with higher gross income, thus resulting in farm profits equivalent to those of simplified systems.

4 Conclusion

This knowledge brief demonstrates that agroecological farming systems maintain or increase crop yield in comparison with standardised monocropping systems. To achieve such results, agroecological systems may use inorganic fertilisers but take full advantage of the ecological processes and the recycling of local resources to limit their use. With the same level of inorganic fertiliser use, agroecological systems are more productive (per crop, with a system yield perspective). Agroecological systems are relevant for all types of farms (intensive vs. extensive, large vs. small). However, the increase in yield due to agroecological practices is more significant for low-yield systems. Without inorganic fertilisers, average yields could decrease except if the organic fertilisers are not limited or other sources of nutrients are well managed.

Besides the production and nutrition sides, the main outcomes of agroecology are more sustainable and more resilient farming systems thanks to biodiversity management, recycling processes and ecological processes. It generates many ecosystem services including carbon sequestration, water conservation, pollination, etc. The main levers for agroecology are crop diversification, legumes-based systems, agroforestry systems and crop-livestock systems.

However, the outcomes and impacts of agroecology depend on the context: the agroecological zone, the type of farming systems and the level of intensification, especially the level of fertilisation. Some agroecological systems (especially low-yield systems) need to evolve to achieve better outcomes. Intensive farming systems should embrace agroecological principles to both maintain their production and limit the negative consequences on the environment. Agroecology is a process supporting and orienting the transition to achieve productive and sustainable food systems.

There is a need to unleash the potential of agroecology to address current challenges (food security, climate change, biodiversity loss, etc.). Significant progress is forecast due to under-investments in R&I for agroecology. New R&I fields require frontier science investments such as (i) biological soil life with increased interaction between plant-bacteria and fungi; (ii) evolutionary breeding and new breeding techniques for more diversity at plot level; (iii) agroecological crop protection including better management of the useful entomofauna and bio-control with microorganisms or organic compounds; (iv) adapted water management by taking into account soil dynamic (pH, Redox potential); (v) artificial intelligence to build new knowledge platforms valorising local experiences and a large range of knowledge. This list is not limited and some organisations aim to define the research gaps for agroecology (the Transformative Partnership Platform on Agroecological Approaches to Building Resilience of Livelihoods and Landscapes (Agroecology TPP), coalition “agroecology”, etc.).

Such investments could lead to promising innovations (bio-inputs including biofertilisers, seeds for agroecology, agroecological pest management, digital tools for agroecology, etc.). In this perspective, support to responsible innovations is required based on co-construction and participatory processes with hybridisation of local and scientific knowledge.

However, to scale agroecology, there is a need to design and implement a set of coherent policies for an enabling environment. Advisory services must be strengthened to be able to address the systemic dimension of agroecology, to develop participatory methods and to strengthen the capacities of farmers to innovate. If more traditional services are still needed (e.g., access to credit), new services are required to provide bio-inputs (biopesticides, organic fertilisers, bio-stimulants, etc.). Access to markets for agroecological products should be strengthened (e.g., organic products, labelling, etc.). Beyond these specific markets, there is a need for structured value chains and fair sharing of the added value among the value chain actors which is a recurrent topic for agricultural development. In fact, public policies should be supportive to agroecology and less supportive to intensive monocropping systems or standardised industrial farming systems.

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