KNOWLEDGE BRIEF

1

Addressing biodiversity loss and agrobiodiversity

DeSIRA LIFT

Towards a shared research and innovation agenda for agroecological transitions of agri-food systems in Africa under AU/EU policy frameworks

Introduction

Agrobiodiversity is essential for the development of resilient and productive agri-food systems, yet it is rapidly declining due to unsustainable practices. This knowledge brief seeks to understand the current state of knowledge and initiatives that support agrobiodiversity in sub-Saharan Africa, while providing ideas on how to increase biodiversity in agri-food systems. Agrobiodiversity can make agri-food systems more efficient and resilient, and contribute to healthier, diversified and seasonally (and culturally) appropriate diets. To prevent further loss, there is a need for stronger partnerships and collaborations to fill knowledge and innovation gaps, aiming for agrobiodiversity to be embedded in food systems and leveraged as a tool for transformation.

Setting the scene

Although existing agri-food systems have been successful at increasing agricultural production at global level, intensive, input-driven agriculture is not a feasible option for many smallholder farmers in marginal and/or remote areas in the global South.

Furthermore, it is increasingly recognised that many agri-food systems are *unsustainable*, are damaging the climate and the environment, causing biodiversity loss, and are negatively impacting human health. *Addressing biodiversity loss* is fast climbing up international agendas as biodiversity is rapidly deteriorating worldwide. Increasing agrobiodiversity is one of the levers for more resilient and productive agri-food systems.

Box 1. The three levels of agrobiodiversity: genetic diversity, species diversity and ecosystem diversity.

Genetic diversity refers to the variety and variability within and between species, distinguishing three levels:

1. **Genetic diversity** refers to the variability within and between populations of a species, for example wild relatives of food crops, or to the variability created by humans (landraces or commercially bred varieties).
2. **Species diversity** refers to the number and abundance of different species used for food and agriculture. The number of species considered to contribute to food alone ranges from 5,538 to 75,000 depending on definitions (Bioversity International, 2017). A conservative estimate is that about 6,000 species are commonly used for food including the vast range of organisms that live in and around food and agricultural production systems.
3. **Ecosystem diversity** refers to the variety and variability of different components in a given geographical area (e.g. landscape, country). In the context of agrobiodiversity, ecosystem diversity refers to the diversity within and between agroecosystems.

Note that aquatic diversity is an important component of agricultural biodiversity.

1 What is agrobiodiversity?

Agricultural biodiversity or agrobiodiversity is a subset of biodiversity pertaining to agriculture. FAO (e.g., 1999a and 1999b) refers to it as: *"The variety and variability of animals, plants and micro-organisms that are used directly or indirectly for food and agriculture, including crops, livestock, forestry and fisheries. It comprises the diversity of genetic resources (varieties, breeds) and species used for food, fodder, fibre, fuel and pharmaceuticals. It also includes the diversity of non-harvested species that support production (soil micro-organisms, predators, pollinators), and those in the wider environment that support agro-ecosystems (agricultural, pastoral, forest and aquatic) as well as the diversity of the agro-ecosystems".*

Agrobiodiversity is directly managed by farmers, pastoralists, fishers and forest dwellers. It provides stability, adaptability and resilience and constitutes a key element of the livelihood strategies of rural communities throughout the world (FAO, 2011). Agrobiodiversity is central to sustainable food systems and sustainable diets. The use of agricultural biodiversity can contribute to food security, nutrition security, and livelihood security, and it is critical for climate adaptation and climate mitigation (e.g., Frison et al., 2011; FAO, 2008).

Jones et al. (2021) developed an Agrobiodiversity Index to assess the status of agrobiodiversity across three pillars of the food system, i.e. consumption and markets, contributing to healthy diets (pillar 1); production systems, contributing to agricultural sustainability (pillar 2); and genetic resource conservation, contributing to safeguarding future use options (pillar 3). The Index includes criteria for varietal diversity, species diversity, functional diversity and underutilised species. Pillar 2 (production systems) assesses agrobiodiversity also by indicating the diversity of pollinators and natural enemies, soil biodiversity and landscape complexity.

2 The loss of agrobiodiversity: What is at stake?

As biodiversity is in decline across the globe (FAO, 2019), this is creating a threat to the resilience and sustainability of our food systems and is negatively affecting human and environmental health (e.g., Jones et al, 2021). Simply put, what we eat (including the way we use our land and water resources, and including the pollution we cause and the GHGs we emit) affects the planet and, in turn, environmental systems affect what we eat (Fanzo et al., 2021).

How ecosystem structures, functions and processes perform is key to resilient and sustainable food systems (e.g., Barrett et al, 2020; Rockström et al, 2020; Willet et al, 2019). IPBES (2019b) warns that the global decline of diversity of (local) varieties and breeds of plants and animals poses a serious risk to global food security by undermining the resilience of many agri-food systems to threats such as pests, pathogens and climate change. Disappearance of pollinators and other organisms that support agricultural production threaten the sustainability of our food system and affect environmental but also human health (e.g., Jones et al., 2021; Willet et al., 2019). FAO's State of the World's Biodiversity for Food and Agriculture Report (FAO, 2019) underlines that many species contributing to vital ecosystem services (e.g., pollinators, natural enemies of pests, soil organisms and wild food species) are in decline in many countries because of the destruction and degradation of habitats, overexploitation, pollution and other threats. The 'Westernization' of diets and their supply chains are seen as driver of the land changes due to increasing monocultures, deforestation and standardization in agricultural practices (e.g., FAO, 2019; Carrington, 2017; Thormann, 2015).

It has been estimated that biodiversity as a whole is being lost at 100–1000 times the natural background rate (e.g., Butchart et al, 2010; Pimm et al, 2014). This extends also to agricultural biodiversity and loss of genetic diversity from farmers' fields (Thormann et al, 2015). Agrobiodiversity loss leads to genetic erosion (the loss of genetic diversity), including the loss of individual genes, and the loss of particular combinations of genes such as those manifested in locally adapted landraces or breeds. Decline in genetic diversity makes the population (of plants or animals) particularly vulnerable to disease, pests, or other factors. The problem of genetic vulnerability often arises with modern crop varieties or animal breeds, which are uniform by design (Virchow, 1999).

Box 2. Biodiversity loss and extinction of species

The Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services (IPBES) estimated that about 77% of the land and 87% of the ocean have been altered by humans, which has led to a loss of 83% of wild mammal biomass, and half of the world's plant biomass. The loss of ecosystem services has negative effects on food security, water supply, livelihoods, and output of many economic sectors (IPBES, 2019b). According to IPBES' Global Assessment of Biodiversity and Ecosystem Services (IPBES, 2019b) existing scenarios fail to halt biodiversity loss and continue to deteriorate regulating ecosystem services in many parts of the world (H. M. Pereira et al., 2020, in: Wyborn et al, 2021). The Summary for Policy Makers of the Global Assessment (figure SPM 3 on page XXX) indicates that human actions threaten more species with global extinction now than ever before: around 1 million species already face extinction, many within decades, unless action is taken to reduce the intensity of drivers of biodiversity loss (IPBES, 2019a).

Source: IPBES (2019a and 2019b); Wyborn et al. (2021)

Box 3. Agrobiodiversity and human diets.

Reduced agrobiodiversity influences, and is influenced by, changes in human diets. Since the mid-1900s, human diets across the world have become more diverse in the consumption of major commodity staple crops, with a corollary decline in consumption of local or regionally important crops, and thus have become more homogeneous globally. The modern 'global standard' diet contains an increasingly large percentage of a relatively small number of major staple commodity crops, which have increased substantially in the share of the total food energy (calories), protein, fat, and food weight that they provide to the world's human population, including wheat, rice, sugar, maize, soybean (by +284%), palm oil (by +173%), and sunflower (by +246%). Whereas nations used to consume greater proportions of locally or regionally important food biodiversity, wheat has become a staple in over 97% of countries, with the other global staples showing similar dominance worldwide. Other crops have declined sharply over the same period, including rye, yam, sweet potato (by -45%), cassava (by -38%), coconut, sorghum (by -52%) and millets (by -45%).

Source: Kinver (2014)

Despite the increasing acknowledgement that preservation of agrobiodiversity is key to the resilience of agri-food systems and landscapes in the face of stressors such as climatic shocks and pest outbreaks, there is a major challenge to scale biodiversity-positive solutions. Moreover, agricultural production that safeguards agrobiodiversity, requires changes in social systems, which in turn rely on how knowledge capacities, social institutions and human incentives can be regenerated (Hubert, 2019). However, there is also increased knowledge and opportunity to leverage ecological processes in production and to embed diversity in food systems in order to enhance resilience (e.g., Corrado et al, 2019).

3 Agrobiodiversity loss in sub-Saharan Africa: the loss of a symbiotic partner in production

Kim et al. (2021) highlight that "biodiversity loss will potentially have large socio-economic consequences (Johnson et al., 2020)" and that "inequitable impacts will particularly be borne by poorer countries (Chaplin-Kramer et al., 2019)". The World Bank (Johnson et al, 2021) refers to the global decline in biodiversity and ecosystem services therefore as a development issue, which "is likely to affect the poorest countries the most". Zooming in on Africa, many publications refer to the urgent need for addressing Africa's climate emergency, health emergency and biodiversity emergency (e.g., IPCC, 2019). Nielson (2020) underlines that soil degradation is extensive in Africa. An estimated 65% of arable land is said to be degraded (e.g., Rozanov & Wiese, 2018; Auerbach et al., 2020). The 'Africa Group of Negotiators Expert Support' (AGNES), reports even 75-80% of the continent's cultivated area to be degraded (AGNES, 2020).

In addition, the current rapid expansion of cropped area is contributing to further deforestation, soil degradation, and associated losses in biodiversity and environmental resilience (AGRA, 2021). The expansion of agriculture is the most significant cause of ecosystem disruption and biodiversity loss in sub-Saharan Africa (Perrings et al., 2015) while government commitments to preserve biodiversity are currently low in many African countries, resulting in a substantial threat of biodiversity loss in agricultural landscapes (Jones et al., 2021). Agrobiodiversity and improved productivity go hand-in-hand with strategies which address soil fertility and water use efficiency while adapting to local conditions and climate change effects.

4 Embedding agrobiodiversity in food systems

In order to push food systems resilience, the UN Food Systems Summit 2021 tasked national governments to define their own agricultural transition pathways and five action areas, including one to 'Boost Nature-based Solutions'[1]. The European Commission has chosen to remedy negative impacts as explained in the European Green Deal highlighting a shift away from business-as-usual agriculture by supporting an agroecological approach in its EU Farm to Fork and Biodiversity 2030 strategies amongst others. Agroecology is also one of the key strategies promoted by the Intergovernmental Panel on Climate Change (IPCC) in its Sixth Assessment Report (2022)[2].

Embedding biodiversity-positive solutions into agricultural practices requires thorough understanding of the multi-functional nature of agriculture and of agroecological processes such as plant-soil (or plant-soil-animal) feedback outcomes at different levels (field, farm, landscape) which are always highly context-dependent. Besides, it involves attention for the ecological as well as the social context (Bezner Kerr, 2022). More diversified systems are more complex to manage and agrobiodiversity effects may not be immediately noticeable in the short-term, in particular if some crops are not marketable. Promoting biodiversity-positive food systems requires a participatory process that engages multiple stakeholders, not only at farm level but also in other parts of the food systems (e.g., input suppliers, processors, traders, consumers) to understand (and act upon) the context-specific opportunities and challenges to boost agrobiodiversity in local food systems.

It should be recognised though that the starting point of agrobiodiversity and agriculture in sub-Saharan Africa is vastly different from the European industrialised agricultural model. Nature-positive solutions such as mixed cropping, agroforestry, or mixed farming systems are common in sub-

1] See: https://www.un.org/en/food-systems-summit/news/making-food-systems-work-people-planet-and-prosperity
2] Previous IPCC reports have mentioned agroecology, encompassing a range of techniques – e.g., promoting (bio)diversity, intercropping, agroforestry - but AR6 is highlighting the emerging and increased evidence around agroecology as an adaptation and mitigation solution.

Saharan Africa, but innovations are required to boost the productivity of such practices while reducing labour burdens (in particular of women). In addition, more effort is required to sustain and boost neglected and underutilised food crops within African agri-food systems.

The African Union Commission (AUC), amongst others, advocates therefore for investment in extension services and farmer-based research (Auerbach et al, 2020). As small-scale farmers form the majority of the agricultural producer base in African countries, they must participate actively in the processes that affect them, from design up to the monitoring and evaluation of outcomes. Partnerships between farmers, researchers and other stakeholders are required to help understand and evaluate the gains of nature-positive practices that enhance agrobiodiversity (e.g., Jackson et al. 2007; Altieri, 2015). Efforts and experiences of initiatives such as PROLINNOVA or the African Conservation Tillage (ACT) network can -and should- be used to facilitate such partnerships, characterised by farmer empowerment and processes where local communities/farmers engage in adaptation and co-creation of the knowledge/technologies to local circumstances.

Addressing agrobiodiversity is a complex issue but it can serve as an asset and a lever to enhance agroecological thinking and doing, and combat biodiversity loss. In that light, several knowledge and innovation gaps are highlighted in the sections below, but without being complete and without claiming that sector-wide agreement exists!

5 Closing the knowledge gaps: Translating agrobiodiversity into levers of change for African food systems

Although ample evidence exists that agrobiodiversity contributes to more resilient agri-food systems[3], there is a need to close the knowledge and innovation gaps to facilitate the scaling of nature-positive solutions and agroecology through agricultural diversification. Agricultural diversification includes the promoting of traditional, neglected (even forgotten) and underutilised crops, wild food plants and medicinal plants, but also includes the safeguarding of community seed systems, as well as the recording and sharing of knowledge, including local or indigenous knowledge (FAO, 2019).

Currently biodiversity conservation is hindered by incomplete and unrepresentative data (Hoveka et al., 2020). Regarding agrobiodiversity there is a general need to improve methods for recording, storing and analysing data on changes in the status of species and habitats in and around production systems, and making them accessible (see e.g., Jones et al., 2021 and their suggestion to use the Agrobiodiversity Index scores). According to FAO (2019) population trends are relatively well documented but only for some taxonomic groups (particularly vertebrates), but reliable data is almost non-existent at species level and very limited even in general terms. Where agriculture production associated species are monitored, the spatial distribution of data across production systems is rarely known, and hence their potential significance can be difficult to evaluate. In many countries, the contributions of agrobiodiversity to the supply of ecosystem services are poorly understood, as are the effects of particular drivers (including climate change) on population sizes and distributions and on the ecological relationships that underpin the supply of ecosystem services (FAO, 2019). The Agrobiodiversity Index scores (see Jones et al., 2021) show that agrobiodiversity is currently underutilized in national food systems. Therefore, agrobiodiversity data have to be consistently collated so that these can be used to trigger policy dialogue and guide decision-making and research agendas towards enhancing agrobiodiversity's contribution in the global transformation to sustainable food systems. Hence, agrobiodiversity data analysis, starting with data collection, forms an important knowledge gap worldwide.

In this section, apart from data collection and analysis, additional knowledge gaps for a selection of focus areas for agrobiodiversity have been highlighted. These knowledge gaps and the suggested research questions listed, may serve as recommendations for further action and/or commitment.

Agrobiodiversity for healthy soils

Healthy soils are essential for agricultural production and are characterised by a diversity of soil organisms that support nutrient cycling (e.g. Jones et al., 2021). Nutrient cycling is only one of the fundamental services required for agricultural production. Nielson (2020) lists as priority soil services: to host and source nutrients for virtually all crop, livestock, and forest production; provide carbon storage (and mitigation of greenhouse gas emissions); host a variety of in-soil biodiversity; and retain and purify water resources (especially from rainfall). The cleansing and recycling role that soils play in processing organic wastes and recycling nutrients constitutes one of the major benefits provided to humanity (Coleman et al., 2018).

Nielson (2020) argues that overall agricultural productivity is diminishing in nearly one-quarter of Africa's cropland, pastures, and rangelands, and largely as a result of declining soil health. Also, Tittonell and Giller (2013) underline that soil-nutrient depletion through negative nutrient balances is widespread throughout much of sub-Saharan Africa. Besides, areas with most severe soil health challenges have least soil research capacity and soil research activity, according to Nielson (2020). To improve soil health requires, first and foremost, enhancing understanding about complexity in soils, i.e., the interactions between plant litter,

3] Bezner Kerr et al. (2021) examined recent evidence (1998–2019) whether agroecological practices can improve human food security and nutrition. A majority of 56 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 (LMICs). Agroecological practices included crop diversification, intercropping, agroforestry, integrating crop and livestock, and soil management measures.

plant roots, fungi, earthworms, insects, insect predators, pollinators, nitrogen-fixing and nitrogen-decomposing bacteria, air, water, temperature, time, etc. This should be high on every knowledge agenda (e.g., Coleman et al., 2018; Nielson, 2020). Giller et al. (2021) note that current narratives on agrobiodiversity and soil health rarely address the complexity of the multiple soil elements (soil biology, soil chemistry, soil physics, soil hydrology, etc.) that determine soil health, and that trade-offs between soil functions are consistently ignored. Agrobiodiversity for soil health is not about simply adding more species, as it may have little effect given redundancies in many groups, especially soil organisms. It is thus important to gain knowledge on the interactions between species, and introducing assemblages of species that increase nutrient inputs and cycling, or support higher yields or pest resistance (Jackson et al., 2007) by leveraging the symbiotic effects between species under local conditions.

Several ongoing DeSIRA projects have defined research activities to preserve agrobiodiversity and to replenish soils or enhance soil health (e.g., Yayu Coffee Forest Biosphere Reserve in Ethiopia; FAIR Sahel, in Burkina Faso, Mali and Senegal; Agroforestry Rwanda). La Via Campesina[4] promotes modifying soil biology in order to change the high levels of bacteria into an even mix of fungi and bacteria (or just fungi depending on the crop cultivated) and refers to it as the perfect inoculation against bacteria. Cover crops, no-tillage farming, and crop rotation are methods that help maintaining soil fertility, reduce weeds and eliminate the need for expensive chemical fertilizers and pesticides (e.g., Magdoff & Van Es, 2021) and these techniques have stood the test of time documenting a successful and resilient indigenous agricultural strategy (Altieri et al., 2012). The existing knowledge base for agrobiodiversity, including soil biodiversity, and healthy soils requires enhancing by adding indigenous or traditional techniques to adapt good practices to local agroecological and socioeconomic conditions.

Agrobiodiversity for healthy diets

Global food production has been increasingly homogenized over past decades, shifting from diversified cropping systems towards ecologically simpler systems (e.g., Mannar and Micha, 2020; HLPE, 2019; Khumalo, 2012). The negligence of local or traditional food crops in farming systems and food supply chains, has contributed to decreased dietary diversity resulting in a lack of micro-nutrients (Mannar and Micha, 2020). These so-called 'forgotten foods' are derived from a diversified set of Neglected and Underutilized Species (NUS) conserved and improved by farmers for centuries, but currently underutilized. Yet, they provide vital nutrition for local communities and generate local ecosystem services (GFAR, 2021). Bioversity's programme on African Leafy Vegetables (ALVs) in Kenya[5] showed that agrobiodiversity increased as ALVs were (re)introduced in the local farming systems and communities became more aware of the nutritional value of these crops. Farmers also reported on increased income from ALVs, women being the main beneficiaries, though lack of awareness, problems in transportation and distance to urban markets were constraining factors (Gotor & Irungu, 2010)[6]. At the same time, even though crops may continue to be maintained by cultural preferences and traditional practices (see e.g., Khumalo et al., 2012, for example in Southern Africa), they remain neglected by research. Traditional, neglected and under-utilized crops represent a rich diversity of cultivated plants, important for food and nutrition security and important for agrobiodiversity, that are notably disregarded in the agricultural research and innovation agendas. FiBL, AFAS and Swissaid jointly work on a new project on NUS crops: www.crops4hd.org.

The Agrobiodiversity Index introduced by Jones et al. (2021), recommends to systematically address (and score) agrobiodiversity for healthy diets from the perspective of varietal diversity – since each breed or cultivar has a unique nutritious value (e.g. local banana cultivars are often far more nutritious); species diversity (e.g. the larger the dietary species richness, the larger the likelihood of nutrient adequacy); functional diversity, i.e. the diversity of food groups (fruit, vegetables, etc.); and the use of underutilized or neglected species, i.e. the varieties or breeds, which are often rich in nutrients. Dr. Aggrey Agumya (FARA) stated (pers. comm., 29 June 2022): "Perceptions towards food are changing. There is an increasing interest to cook traditionally and to cook using traditional crops. Also, perceptions regarding the potential of forgotten food is changing: there is an increasing recognition that there is a lot of potential, which we should support with developing a strategy and/ or a plan regarding the productivity of forgotten food crops. Including: 1. access to market; 2. consumption - social status; 3. nutritional benefits; 4. environmental benefits; 5. how to stimulate productivity; 6. the role of non-cultivated biodiversity in food systems." Dr. Agumya specifically underlined: "If we think of our food systems, the non-cultivated biodiversity is important, in other words, the interaction farm-plot-landscape needs to feature on research agendas". Participants of the Deep Dive also pushed 'food sovereignty' forward on the research agenda. Food sovereignty, a term coined by La Via Campesina in 1996 at the United Nations World Food Summit, and a broad concept focused on people's right to control who, how and what kind of food is produced (HLPE, 2019) provides ingredients for a common AU-EU research agenda as key elements of food sovereignty include: more equitable trade relationships; land reform; protection of intellectual and indigenous land rights; agroecological production practices; and gender equity (Wittman, 2011). Food sovereignty has many overlapping themes and approaches with that of the 'right to food' and, by connecting food as a human right (Wittman & Blesh, 2017), there are many lessons learned to be built on.

4] ECVC_Out-Pesticides-Brochure_EN_2018.pdf (viacampesina.org)

5] The impact of Bioversity International's African Leafy Vegetables programme in Kenya (tandfonline.com) 6] See also: Kenya's push to promote traditional food is good for nutrition and cultural heritage (theconversation.com)

Conservation of, and access to, the diversity of genetic resources

Farmers require access to a diversity of crops and varieties to be able to cope more effectively with climate change effects like droughts, pests and diseases. Diversity of genetic resources for food and agriculture includes the diversity within individual crops and livestock species in conservation, i.e. at varietal or breed level (varietal diversity), at species level (species diversity), but also at the level of agronomic, ecological and nutritional traits to meet consumer demands and overcome production challenges (functional diversity) (Jones et al., 2021). Jones et al. (2021) distinguish explicitly the conservation of "local, indigenous, traditional, neglected and underutilized species and varieties or breeds used for food and agriculture, including their wild relatives, landraces and breeds, some of which are threatened with extinction after millennia of selection". The conservation and access to genetic resources is of utmost importance for agroecological approaches. Unfortunately, the diversity that is available in genebanks, plant breeding programs or landraces, rarely reaches the farmers' fields (Coto et al. 2019). Seed security means that farmers have access to sufficient volumes of seed to conduct their farming practices, with full regard to the diversity of seed resources that they need to ensure food and nutrition security while adapting to climate change and other stressors. Seed security implies that a diversity of seed is available, affordable and accessible to farmers in both space and time. However, the focus of crop breeding programs on high-yielding varieties of cereals and legumes have replaced a diversity of landraces across the globe (Lusty et al., 2021). Seed systems have been formalized to multiply and disseminate such commercial varieties, with a focus on the main staple crops (in particular rice, wheat, maize, barley, potatoes, cassava, banana and soybean). These commercial varieties are typically bred for monocultures, but little attention is being paid to breeding crops for mixed cropping systems, which requires the accommodation of inter-specific interactions and compatibilities of crops in breeding programs (Bourke et al., 2021). Cultivar development for intercropping systems requires a systems approach, from the decision to breed for intercropping systems through the final stages of variety testing and release, involving multiple scientific disciplines and stakeholders (Moore et al., 2022).

Currently, farmers' main access to the genetic diversity found in landraces and NUS crops are through the informal seed systems maintained at community level. FAO's LinKS project[7] identified initiatives such as rural seed fairs, community seed banks, and improving traditional seed storage facilities and concluded that the building of community seed systems requires the integration between formal and informal seed systems, with the concerted action of crop scientists, farmers and rural development practitioners (Louafi et al., 2021). Such integration needs to accommodate both farmers' rights to seed as well as breeders' rights. Bioversity International's initiative Seeds for Needs explores low-cost methods to enhance farmers' access to seed and crop diversity for resilience.

Agrobiodiversity and livestock

Narrowing the yield gap while maintaining agrobiodiversity appears to be an essential new paradigm to explore (Akash et al., 2022), also for animal husbandry. In a sample of 40 countries from Africa, Asia and Latin America, the share of locally adapted breeds within five species decreased by an average of 0.76% per year over the last 20 years (Leroy et al., 2020). Decision makers should strategize by tackling livestock agrobiodiversity with a holistic approach rather than a productive focus (Magnani et al., 2019;). "Animal genetic resources can be regarded as the centre of a complex social, environmental and economic system, so policies need to address the challenges related to sustainability in a holistic manner, accepting trade-offs where necessary, and considering, at different scales, the relationships and dynamics between the animals, their herders, the production systems, agroecosystems, and the market" (Leroy et al., 2020). Hence, dedicated focus should be paid to maintaining and even regenerating livestock diversity. Locally adapted breeds might be more adapted for more resilient food systems (Leroy et al., 2020). So called 'modern production systems' will have to better integrate crop and livestock production (including aquaculture) while contributing to enrich agrobiodiversity. Sekaran et al. (2021), especially argue for strategies to increase the adoption of integrated crop-livestock systems in LMICs (rather than focusing on either cropping or livestock systems) claiming it could be a key for achieving both food and nutritional security and environmental sustainability on the short and long-term.

Diversity of crop pollinators and natural enemies of crop, fish and livestock pests

According to FAO (2019), the availability of data on the status and trends of pollinators varies significantly by region, country and type of pollinator. Major knowledge gaps remain on the actual degree of pollinator dependence for some major crops (Bartomeus et al., 2014) though fruit and vegetable production systems with an abundance of suitable pollinator species are more likely to have plentiful harvests, which in turn benefit agriculture and biodiversity (Bartomeus et al., 2014 in: Jones et al., 2021). Jachuła et al. (2022) plead that more efforts should be made to secure habitat heterogeneity: "a diversity of natural, semi-natural and man-made, non-cropped areas is required to support the seasonal continuity of pollen resources for pollinators in an agricultural landscape" and also Bartual et al. (2019) highlight the importance of semi-natural habitats to sustain pollinators for their pollination and natural enemies for

7] FAO launched the LinKS project in 1998 as a regional effort in Southern Africa aimed at raising awareness about how rural men and women use and manage biological diversity. The project is called LinKS because it explores the linkages among the crucial issues of local knowledge systems, gender roles and relationships, food provision, and the conservation and management of agro-biodiversity. See also: https://www.fao.org/3/y5572e/y5572e05.pdf their pest control services. However, too few studies have compared the trade-offs between pollination and pest-control services, despite some pollinators and natural enemies having compatible responses to complexity (Shackelford et al., 2013). Managing agroecosystems for the benefit of both seems beneficial, however, it can still not be concluded that there are no negative interactions between pollinators and natural enemies (Shackelford et al., 2013) especially because Bartual et al. (2019) focussed on European agricultural landscapes only. Scientific studies, citizen-science projects and indigenous and local knowledge, according to FAO (2019): "(...) all help to build up understanding of the economic, environmental and sociocultural values of pollination, threats to pollinator populations, and the status and trends of wild and managed pollinators, pollinator dependent crops and wild plants at various scales" and the same is true for ecosystem services like pest control.

6 "A time to leap because small steps won't cut it"[8] - Closing the innovation gaps

To combat the widespread degradation of land, water, ecosystems and the huge biodiversity losses including the livelihood stresses for -in particular- smallholder producers, a fundamentally different model of agriculture is needed based on diversifying farms and farming landscapes that optimise agroecosystems (IPES-Food, 2016). The changes that need to happen include a complex mix of political, economic and social and/or cultural interventions, investments and incentives (e.g., changes in subsidy schemes, laws, regulations, taxes; investing in technology and education; reducing consumption of food with large environmental footprints). Insights from farmers, being innovators by definition as they constantly adapt to changing conditions, need to be better integrated when addressing innovation gaps. In particular, because "Innovation is not just technology, but is rather a comprehensive vision of what the future should look like and what changes are required in many ambits. Innovation is driven by people's needs, ambitions and dreams, and requires that people at different positions in society change the way they work and live" (Klerkx et al., 2012). Most studies mentioning innovation, change, transition or transformation refer to the need for strengthened capacities (at individual and organisational level), and an enabling institutional setting including supportive policies (see e.g., Fazy & Leicester, 2022). Fazey and Leicester (2022) particularly refer to new modes of stewardship, but also the development of new kinds of capacities that help stewards sustain transitions and transcend many current and past approaches. In addition, they highlight the need to "marry the practical, more on-ground, insights with those from larger scale studies". Recognising that agricultural innovations are ultimately co-determined by interactions between actors (individuals and organisations) and institutions, including policies (e.g., Klerkx, 2012; Ensor and De Bruin, 2022), how do we then best address the innovation gaps specific to improving agrobiodiversity? Below, a few innovation gaps for a selection of focus areas or topics for agrobiodiversity are being highlighted. This selection has been discussed during the Deep Dive on 29 June 2022 and has been updated to mark points of attention raised by participants of the Deep Dive Dialogue. This selection remains a non-exhaustive one, requiring further exploring and discussion.

Societal change requires a new role for research

Over the past decades, there has been a rethinking of using natural resources: from 'simple' extraction (often degrading nature) to 'do less harm' or 'do no harm' approaches to 'restoration' (restoring what has been damaged) and 'regeneration' (building natural capital). When moving to a regenerative model, most peer-reviewed publications refer to the importance of better understanding natural systems (e.g. Klomp et al. 2021;). Producing our food 'regeneratively', whether we refer to it as nature-inclusive farming, conservation agriculture, carbon farming, agroforestry, regenerative agriculture, agroecology or other approaches, solutions and measures that have potential to provide benefits to both agriculture and biodiversity, will not be implemented spontaneously. Whether enhancing agrobiodiversity for the provision of ecosystems services through highly heterogeneous landscape mosaics, semi-natural habitats and high nature value farmlands (Redman and Hemmami, 2008; Gerits et al., 2021) or by increasing the conservation value of farmlands locally at field level, there are many barriers to overcome. Gerits et al. (2021) even underline that enhancing agrobiodiversity without considering the broader ecological landscape context is likely to be ineffective and cost-inefficient. They advocate therefore for multi-actor efforts at a landscape scale.

This makes a transformation towards nature-inclusive agriculture not only a matter of governance (Runhaar, 2017), but requires societal learning by involving citizens in science and doing transdisciplinary research. Fazey & Leicester (2022) conclude that major societal change is inevitable, requiring an interplay of innovation, 'mindsets about the future', and modes of governance that together can maintain transformational intent. They refer to larger scale system change studies not only as knowledge gap but particularly as innovation gap. New modes of capacity development "and knowledge creation that integrate larger scale system change studies with more action oriented on ground and creative efforts will be required". In supporting any transitions, HLPE (2019) underlines that it will remain important to recognize that there are areas of convergence and divergence amongst approaches. Societal change requires it all at the same time: local solutions adapted to local contexts, and therefore many different approaches and solutions; not only converging and diverging approaches,

8] Naomi Klein (2017) "No Is Not Enough" (book)

but also multiple transition pathways and trajectories at multiple scales to make food system transformation sustainable, inclusive and fair.

Management practices supporting agrobiodiversity

Diversity in land use, including agrobiodiversity, allows farmers to mitigate risk (e.g., by diversifying their resource base) and facilitates adaptation to changing conditions. Complexity of agricultural landscape composition and configuration are associated with higher levels of biodiversity and improved ecosystem service provision to agriculture (e.g., Jones et al., 2021). Examples of how farmers sustain or enhance diversity include the introduction of new varieties, or reviving the use of traditional food crops and local breeds, changing cultivation techniques (e.g., no-tillage, mulching, intercropping, agroforestry), investing in soil fertility, participation in informal seed exchange networks, seed fairs and community seed banks etc. To support agroecological transitions of agri-food systems on the African continent, it is essential to “unfold this locally” (Cummins, 2020) and be context specific (Auerbach et al., 2020). But also, partial solutions or reforms cannot bring about systems change (Cummins, 2020) meaning that biodiversity-positive practices at field or farm level require biodiversity-positive innovations for landscape management but also at institutional level (e.g. policies and regulations). This also means that local initiatives have to be linked to activities at national, regional or even global level.

Agrobiodiversity and access to seeds

Access to a diversity of seed is a challenge. Around 80% of smallholder farmers access seed through the informal sector, that is farmer-managed seed systems, particularly in instances where food production is predominantly used for home consumption. The formal system has witnessed “a remarkable change in the seed law landscape”, moving towards more harmonised regulations for the formal seed sector though policy incoherence remains a huge obstacle (Munyi, 2022). However, farmer-managed seed systems encompass a diversity of indigenous varieties (including neglected and underutilised species) and landraces, and are thus a source for genetic diversity, yet they are barely recognized in current policies. Both formal and farmer-managed seed systems are needed to facilitate agrobiodiversity. Civil society expresses concerns that an increase in formalisation of seed standards and regulation, which target the formal seed sector, threatens farmers’ rights to (re)use, save, exchange and sell seeds. More recognition of the importance (and protection) of farmer-managed seed systems to sustain and lever genetic diversity of plants and animals in Africa is essential.

Mobilising co-learning initiatives for agrobiodiversity

Practices to increase agrobiodiversity are highly context-specific and knowledge-intensive[9] and should thus be developed through social processes and farmers’ knowledge and experimentation. Ensor and De Bruin (2022) refer to mobilising multiple forms of expertise as farmer-led innovation, “the collaborative endeavour of farmers together with other stakeholders (including e.g., scientists, engineers)”. It emphasizes the capability of smallholder farmers, even entire local communities (Altieri & Toledo, 2011) to experiment, evaluate, learn and scale-up innovations through farmer-to-farmer research and grassroots extension approaches. Unfortunately, innovation that is farmer-driven is not well documented and “efforts to measure farmers’ innovation in absence of outside intervention are in their infancy” (Bragdon and Smith, 2015). Also food sovereignty innovations are most likely ones to originate from a grassroots process, often through the advocacy of social movements, with explicit beneficiaries being local populations (HLPE, 2019). HLPE (2019) also highlights the importance to build on approaches as the right to food, food justice and/or lessons learned from e.g. ‘nutrition-sensitive agriculture’. Though participatory approaches such as Farmer Field Schools and Living Labs are experimented with in projects, they are not well embedded in innovation processes at scale.

Building coalitions for agrobiodiversity

Innovations supporting agrobiodiversity grow through social interaction, through informal social and economic networks. Farmers cooperate in farmers’ organisations to lower transaction costs, to increase bargaining power within the market, but also to allow groups of individuals to share in the risks associated with experimentation and adopting new innovations. A reconfiguration of knowledge systems is urgently needed: “shifting towards a co-learning paradigm, bringing research and extension closer together and better linking international and national research and extension systems with local knowledge and farmer-to-farmer knowledge exchange” (HLPE, 2019). In addition, strengthening of knowledge systems and a better use of their learning outcomes in policy-making (beyond the mere acknowledgement of the necessity to change) and setting long-term objectives will ensure policy coherence across sectors (HLPE, 2019). However, there are few multi-stakeholder coalitions on the ground that seek to enhance agrobiodiversity.

9] Think of recycling of nutrients and energy on the farm (rather than introducing external inputs); enhancing soil organic matter and soil biological activity; diversifying plant species and genetic resources in agroecosystems (over time and space); integrating crops and livestock; optimizing interactions and productivity of the total farming system, rather than the yields of individual species (e.g., Altieri & Toledo, 2011; Gliessman, 2022).

Governance supporting agrobiodiversity

Governance highly influences how (agro)biodiversity-positive innovation takes shape at national level (Bragdon and Smith, 2015). Governance of agrobiodiversity links to formal and informal agreements and policies, but is defined as a set of relationships that influences the access to and conservation, exchange, and commercialization of agrobiodiversity and its components (Visser et al., 2019). Governance that supports agrobiodiversity, requires farmers' traditional knowledge to both sustain biodiversity and to ensure food and nutrition security[10], but farmers alone cannot control agricultural policies, incentives, markets or consumption patterns. It is important to identify the actors involved, from local to global, to understand the power dynamics that influence the interactions among these various actors and their ability to influence or control the management of agrobiodiversity. Lessons learnt from e.g., Seeds4All, helping operators with new marketing regimes for diversified seed populations[11], or from NGOs like GRAIN and from all initiatives they supported on the ground towards biodiversity-based and community-controlled food systems, provide a valuable source of actions taken to address constraints, e.g. the asymmetry of power in decision making.

Incentives for agrobiodiversity

Many instruments (both incentives and restrictions) have been used to either support or regulate activities that affect nature. For instance, current policy debates consider a carbon tax (a 'price') which "does not dictate a specific process or technology, as well as restrictions on level of output" (IPBES, 2019b). Payments for ecosystem services (PES) offer compensation for the voluntary acceptance of restrictions in land use to reduce practices that lead to degradation of natural resources or pollution. PES are conditional on beneficial actions or outcomes, thus generating incentives for voluntary provision of ecosystem services by varied private actors[12]. Taxes, subsidies or incentives are important drivers of change in agri-food systems. Subsidy schemes require revision as to what inputs to support financially and under which conditions to promote biodiversity-positive and resilient agri-food systems. Mauritius provides an interesting case to learn about alternative subsidy policies. While the country uses subsidisation to help smallholder farmers (by reducing input costs) and also to increase productivity (through improved soil health), it has linked the compost subsidy to longer-term sustainable development goals (ACB, 2016; in: Auerbach, 2020). However, such policy instruments and incentives that encourage agrobiodiversity are still rare in many African countries.

7 Final remarks and recommendations: priorities to enhance agrobiodiversity

Increasing agrobiodiversity in agri-food systems can make them more ecologically and economically efficient and resilient and can contribute to the development of healthier, diversified and seasonally (and culturally) appropriate diets, states the HLPE (2019). This paper, zooming in – as much as possible – on the context of sub-Saharan Africa, has aimed to provide ideas for partnership development and collaboration to address a selection of research and innovation gaps with the specific aim to increase biodiversity in agri-food systems. The selection of topics provided is nor complete nor exhaustive. They are aimed for further exploration by existing partnerships or new coalitions to advance innovation and transformation at scale.

10] See Convention on Biological Diversity's specific section on agrobiodiversity, e.g., What's the Problem? (cbd.int) 11] In April 2018, after several years of tough negotiations at the European scale, the sustainable seed sector won a crucial battle in Brussels, through the adoption of a new European Regulation on organic production. Regulation n°2018/848 on organic production has opened the possibility, for all operators and from January 2022, to place seeds of "organic heterogeneous material" on the market, for use in organic farming, home gardening but also in conventional farming

12] IPBES (2019b) reports an example (from Bolivia) to raise the incentives for ecosystem services suppliers by allowing multiple ecosystem services to be sold on the basis of a single shift in land use. Suppliers receiving a separate payment for each service, can therefore be more socially efficient for PES programmes.

References used for the Deep Dive on Agrobiodiversity

African Centre for Biodiversity (ACB). (2016). *Soil fertility: agro-ecology and not the green revolution for Africa*. www.acbio.org.za Available at: https://www.acbio.org.za/sites/default/files/2016/07/Soil-Fertility-ACBio.pdf

AGNES (2020). *Land Degradation and Climate Change in Africa. Policy Report 2*. Based on Chapter 4 of the IPCC Special Report on Climate Change, Desertification, Land degradation, Sustainable Land Management, Food Security and Greenhouse gas fluxes in Terrestrial Ecosystems, 2019. https://agnes-africa.org/wp-content/uploads/2020/07/Policy-brief-2_Land-Degradation_Final_09032020.pdf

AGRA. (2021). *Africa Agriculture Status Report. A Decade of Action: Building Sustainable and Resilient Food Systems in Africa (Issue 9)*. Nairobi, Kenya: Alliance for a Green Revolution in Africa (AGRA).

Akash, Hoque, M., Mondal, S., Adusumilli, S. (2022). Chapter Four—Sustainable livestock production and food security. In S. Mondal & R.L. Singh (Eds.), Emerging Issues in Climate Smart Livestock Production (pp. 71–90). Academic Press. https://doi.org/10.1016/B978-0-12-822265-2.00011-9

Allan, et al. (2022). The minimum land area requiring conservation attention to safeguard biodiversity." Science. June 2, 2022.
Altieri, M.A., Toledo V.M. (2011). *The agroecological revolution in Latin America: rescuing nature, ensuring food sovereignty and empowering peasants*. The Journal of Peasant Studies, 38:3, 587-612. http://dx.doi.org/10.1080/03066150.2011.582947

Altieri, M.A., Funes-Monzote, F.R. & Petersen, P. (2012). *Agroecologically efficient agricultural systems for smallholder farmers: contributions to food sovereignty*. Agron. Sustain. Dev. 32, 1–13 (2012). https://doi-org.ezproxy.library.wur.nl/10.1007/s13593-011-0065-6

Altieri, M.A., Nicholls, C.I., Henao, A., Lana, M.A. (2015). *Agroecology and the design of climate change-resilient farming systems. Agronomy for Sustainable Development* 35(3), pp. 869-890. https://doi.org/10.1007/s13593-015-0285-2

Auerbach, R., Oelofse, M., Mentz-Lagrange, S., Ross, A., deGrassi, A. (2020). *Assessment for the African Union Commission of North, West, Central and Southern Africa, with a view to mainstreaming Ecological Organic Agriculture.* Technical Report, March 2020. https://doi.org/10.13140/RG.2.2.19957.32488

Barrett, C.B., Benton, T.G., Cooper, K.A., Fanzo, J., Gandhi, R., Herrero, M., James, S., Kahn, M., Mason-D'Croz, D., Mathys, A., Nelson, R.J., Shen, J., Thornton, P., Bageant, E., Fan, S., Mude, A.G., Sibanda, L.M., Wood, S. (2020). *Bundling innovations to transform agri-food systems*. Nature Sustainability 3(12), pp. 974-976. https://doi.org/10.1038/s41893-020-00661-8

Bartomeus, I., Potts, S.G., Steffan-Dewenter, I., Vaissière, B.E., Woyciechowski, M., Krewenka, K.M., Tscheulin, T., Roberts, S.P.M., Szentgyörgyi, H., Westphal, C., Bommarco, R. (2014). *Contribution of insect pollinators to crop yield and quality varies with agricultural intensification*. PeerJ, 2014 (1), art. no. e328. https://doi.org/10.7717/peerj.328

Bartual A.M., Sutter L., Bocci G., Moonen A.-C., Cresswell J., Entling M., Giffard B., Jacot K., Jeanneret P., Holland J., Pfister S., Pintér O., Veromann E., Winkler K., Albrecht M. (2019). *The potential of different semi-natural habitats to sustain pollinators and natural enemies in European agricultural landscapes*. Agriculture, Ecosystems and Environment, 279, pp. 43 – 52. https://doi.org/10.1016/j.agee.2019.04.009

Bezner Kerr, R. (2022). *Agroecology is one of those strategies that links people to nature in a very explicit way*. In: Mongabay Series: Agroecology; From traditional practice to top climate solution, agroecology gets growing attention by Anna Lappé on 13 April 2022. https://news.mongabay.com/2022/04/from-traditional-practice-to-top-climate-solution-agroecology-gets-growing-attention/#

Bezner Kerr, R. Madsen, S., Stüber, M., Liebert, J., Enloe, S., Borghino, N. Parros, P., Munyao Mutyambai, D., Prudhon, M., Wezel, A. (2021). *Can agroecology improve food security and nutrition?* A review. Global Food Security, Vol. 29, 2021. 100540. ISSN 2211-9124. https://doi.org/10.1016/j.gfs.2021.100540.

Bioversity International (2017). *Mainstreaming Agrobiodiversity in Sustainable Food Systems: Scientific Foundations for an Agrobiodiversity Index*. Rome, Italy: Bioversity International. p. 3. ISBN 978-92-9255-070-7.

Bourke, P.M., Evers, J.B., Bijma, P., van Apeldoorn, D.F., Smulders, M.J.M., Kuyper, T.W., Mommer, L., Bonnema, G. (2021). *Breeding beyond monoculture: putting the "intercrop" into crops.* Front Plant Sci 12:734167. https://doil.org/fpls.2021.734167

Bragdon, S., Smith, C. (2015). *Small-scale farmer innovation*. Quaker United Nations Office, Geneva. Available at: https://quno.org/sites/default/files/timeline/files/2016/SSF%20Innovation%20WEB.pdf

Bragdon S, et al. (2009). *The agricultural biodiversity policy development process: exploring means of policy development to support the on-farm management of crop diversity.* International Journal of Biodiversity Science & Management 5(1):10–20

Butchart, S. H. M.; Walpole, M.; Collen, B.; van Strien, A.; Scharlemann, J. P. W.; Almond, R. E. A.; Baillie, J. E. M.; Bomhard, B.; Brown, C.; Bruno, J.; Carpenter, K. E. (2010-05-28). "Global Biodiversity: Indicators of Recent Declines". Science. 328 (5982): 1164–1168. Bibcode:2010Sci...328.1164B. doi:10.1126/science.1187512. hdl:10019.1/117493. ISSN 0036-8075. PMID 20430971. S2CID 206525630.

Carrington, Damian (26 September 2017). "Sixth mass extinction of wildlife also threatens global food supplies". *The Guardian*. Retrieved 10 February 2020.

Capelli S.L., Domeignoz-Horta, L.A. Loaiza, V., Laine, A.L. (2022). Plant biodiversity promotes sustainable agriculture directly and via belowground effects. *Trends in Plant Science*. https://doi.org/10.1016/j.tplants.2022.02.003

Coleman, D.C., Mac A. Callaham, Jr., D.A. Crossley, Jr. (2018). *Fundamentals of Soil Ecology. Third edition.* Academic Press publications. Elsevier Inc. USA. ISBN: 978-0-12-805251-8. https://www.elsevier.com/books-and-journals.

Corrado, C., Elena, T., Giancarlo, R., Stefano, C. (2019). The Role of Agrobiodiversity in Sustainable Food Systems Design and Management. In: Nandwani, D. (eds) Genetic Diversity in Horticultural Plants. Sustainable Development and Biodiversity, vol 22. Springer, Cham. https://doi.org/10.1007/978-3-319-96454-6_9

Chaplin-Kramer, R., Sharp, R.P., Weil, C., Bennett, E.M., Pascual, U., Arkema, K.K., Brauman, K.A., Bryant, B.P., Guerry, A.D., Haddad, N.M., Hamann, M., Hamel, P., Johnson, J.A., Mandle, L., Pereira, H.M., Polasky, S., Ruckelshaus, M., Shaw, M.R., Silver, J.M., Vogl, A.L., Daily, G.C., (2019). Global modeling of nature's contributions to people. Science 366, 255–258. https://doi.org/10.1126/science.aaw3372

Coto, A., de Sousa, K., Fadda, C., Gebrehawaryat, Y., van de Gevel, J., Gotor, E., Gupta, A., Madriz, B., Mathur, P., Mengistu, D.K., Paliwal, A., Quirós, C.F., Scafetti, F., Sharma, N., Steinke, J., van Etten, J. (2019) Seeds for Needs: crop diversity for resilience. Poster and handout presented at the 2nd Meeting of the Joint Boards of Bioversity International and CIAT. Maccarese, Italy, May 2019. Rome (Italy) Bioversity International.

Crowther, L.I., Gilbert, F. (2020). *The effect of agri-environment schemes on bees on Shropshire farms*. Journal for Nature Conservation, Volume 58, 2020. https://doi.org/10.1016/j.jnc.2020.125895.

Cummins, R. (2020). Grassroots Rising. *A Call to Action on Climate, Farming, Food, and a Green New Deal*. Chelsea Green Publishing, February 11, 2020. ISBN: 9781603589758.

Ensor J., Bruin, A. de (2022). *The role of learning in farmer-led innovation, Agricultural Systems*, Volume 197, 2022, 103356, ISSN 0308-521X. https://doi.org/10.1016/j.agsy.2021.103356.

Fanzo, J., et al., (2021). Viewpoint: *Rigorous monitoring is necessary to guide food system transformation in the countdown to the 2030 global goals*. In: Food Policy (Vol. 104) ISSN: 0306-9192. https://doi.org/10.1016/j.foodpol.2021.102163

FAO. (1999a). "What is Agrobiodiversity". *United Nations Food and Agriculture Organization.*

FAO. (1999b). *Agricultural Biodiversity, Multifunctional Character of Agriculture and Land Conference, Background Paper 1*. Maastricht, Netherlands. September 1999.

FAO and the Platform for Agrobiodiversity Research (2011). *Biodiversity for Food and Agriculture*. Rome, Italy. p. 2. ISBN 978-92-5-106748-2.

FAO. (2008). *Climate Change and Biodiversity for Food and Agriculture*. http://www.fao.org/uploads/media/FAO_2008a_climate_change_and_biodiversity_02.pdf

FAO. (2019). *The State of the World's Biodiversity for Food and Agriculture*, J. Bélanger & D. Pilling (eds.). FAO Commission on Genetic Resources for Food and Agriculture Assessments. Rome. 572 pp. Available at: http://www.fao.org/3/CA3129EN/CA3129EN.pdf. Licence: CC BY-NC-SA 3.0 IGO.

Fazey, I., & Leicester, G. (2022). *Archetypes of system transition and transformation: Six lessons for stewarding change*. Energy Research and Social Science, 91. https://doi.org/10.1016/j.erss.2022.102646

Frison, E.A.; Cherfas, J.; Hodgkin, T. (2011). "Agricultural Biodiversity Is Essential for a Sustainable Improvement in Food and Nutrition Security". *Sustainability*. 3: 238–253. doi:10.3390/su3010238.

Gatto, M., de Haan, S., Laborte, A., Bonierbale, M., Labarta, R., Hareau, G. (2021). *Trends in Varietal Diversity of Main Staple Crops in Asia and Africa and Implications for Sustainable Food Systems*. Frontiers in Sustainable Food Systems. Vol. 5. https://www.frontiersin.org/article/10.3389/fsufs.2021.626714; https://doi.org/10.3389/fsufs.2021.626714

Gerits, F., Messely, L., Reubens, B. et al. (2021). *A social–ecological framework and toolbox to help strengthening functional agrobiodiversity-supported ecosystem services at the landscape scale*. Ambio 50, 360–374 (2021). https://doi-org.ezproxy.library.wur.nl/10.1007/s13280-020-01382-0

Giller, K.E., Hijbeek, R., Andersson, J.A., Sumberg, J. (2021). *Regenerative Agriculture: An agronomic perspective*. Outlook on Agriculture. 2021;50(1):13-25. https://doi.org/10.1177/0030727021998063

Gliessman, S. (2022). *Why is ecological diversity important?* Agroecology and Sustainable Food Systems, 46(3), 329-330. doi:10.1080/21683565.2022.2032513

Gotor, E., Irungu C. (2010). *The impact of Bioversity International's African Leafy Vegatables programme in Kenya*. Impact Assessment and Project Appraisal 28(1): 41-55

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. https://www.fao.org/3/ca5602en/ca5602en.pdf

Hoveka, L.N., van der Bank, M., Bezeng, B.S. et al. (2020). *Identifying biodiversity knowledge gaps for conserving South Africa's endemic flora*. Biodivers Conserv 29, 2803–2819. https://doi.org/10.1007/s10531-020-01998-4

Hubert, B. (2019). *The need for a conceptual paradigm shift. Update*. (p.148) In: *Transformation of our food systems. The making of a paradigm shift*. Edited by Hans R. Herren, Benedikt Haerlin and the IAASTD+10 Advisory Group. ISBN 978-3-00-066209-6. www.globalagriculture.org

Hussain, A. and Qamar, F.M. (2020). Dual Challenge of Climate Change and Agrobiodiversity Loss in Mountain Food Systems in the Hindu-Kush Himalaya, One Earth, Volume 3, Issue 5, 2020, Pages 539-542, ISSN 2590-3322. https://doi.org/10.1016/j.oneear.2020.10.016.

IPBES (2019a). *Summary for policymakers of the global assessment report on biodiversity and ecosystem services of the Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services*. S. Díaz, J. Settele, E. S. Brondízio, H. T. Ngo, M. Guèze, J. Agard, A. Arneth, P. Balvanera, K. A. Brauman, S. H. M. Butchart, K. M. A. Chan, L. A. Garibaldi, K. Ichii, J. Liu, S. M. Subramanian, G. F. Midgley, P. Miloslavich, Z. Molnár, D. Obura, A. Pfaff, S. Polasky, A. Purvis, J. Razzaque, B. Reyers, R. Roy Chowdhury, Y. J. Shin, I. J. Visseren-Hamakers, K. J. Willis, and C. N. Zayas (eds.). IPBES secretariat, Bonn, Germany. 56 pages. https://doi.org/10.5281/zenodo.3553579

IPBES (2019b). *Global assessment report on biodiversity and ecosystem services of the Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services*. E. S. Brondizio, J. Settele, S. Díaz, and H. T. Ngo (editors). IPBES secretariat, Bonn, Germany. 1148 pages. https://doi.org/10.5281/zenodo.3831673

IPES-Food (2016). *From uniformity to diversity: a paradigm shift from industrial agriculture to diversified agroecological systems*. International Panel of Experts on Sustainable Food systems. www.ipes-food.org

IPCC (2022). Climate Change 2022. *Impacts, adaptation and vulnerability. Summary for Policymakers*. IPCC WGII Sixth Assessment Report. https://report.ipcc.ch/ar6wg2/pdf/IPCC_AR6_WGII_SummaryForPolicymakers.pdf.

Jachuła J., Denisow B., Wrzesień M., Ziółkowska E. (2022). *The need for weeds: Man-made, non-cropped habitats complement crops and natural habitats in providing honey bees and bumble bees with pollen resources*. Science of the Total Environment, 840, art. no. 156551. https://doi.org/10.1016/j.scitotenv.2022.156551

Jackson, L., Pascual, U., Hodgkin, T. (2007). *Utilizing and conserving agrobiodiversity in agricultural landscapes*. Agriculture, Ecosystems & Environment 121(3): 186-210.

Johnson, J.A., Baldos, U., Hertel, T., Liu, J., Nootenboom, C., Polasky, S., and Roxburgh, T. (2020). *Global Futures: modelling the global economic impacts of environmental change to support policy-making*. Technical Report, January 2020. https://www.wwf.org.uk/globalfutures

Johnson, J.A., Ruta, G., Baldos, U., Cervigni, R., Chonabayashi, S., Corong, E., Gavryliuk, O., Gerber, J., Hertel, T., Nootenboom, C., Polasky, S. (2021). *The Economic Case for Nature: A Global Earth-Economy Model to Assess Development Policy Pathways*. World Bank, Washington, DC. © World Bank. License: CC BY 3.0 IGO. https://openknowledge.worldbank.org/handle/10986/35882

Jones, S.K., Estrada-Carmona, N., Juventia, S.D. et al. (2021) *Agrobiodiversity Index scores show agrobiodiversity is underutilized in national food systems*. Nat Food 2, 712–723. https://doi.org/10.1038/s43016-021-00344-3

Khumalo, S., Chirwa, P., Moyo, B.H., Syampungani, S. (2012). *The status of agrobiodiversity management and conservation in major agroecosystems of Southern Africa*. Agriculture, Ecosystems & Environment. 157. 17–23. https:/doi.org/10.1016/j.agee.2012.01.028

Kim, H., Peterson, G., Cheung, W., Ferrier, S., Alkemade, R., Arneth, A., ... Pereira, H. (2021). *Towards a better future for biodiversity and people: modelling Nature Futures.* https://doi.org/10.31235/osf.io/93sqp

Kinver, Mark (2014-03-03). "Crop diversity decline 'threatens food security'". BBC News. BBC.

Klerkx L., van Mierlo B., Leeuwis, C. (2012) *Evolution of systems approaches to agricultural innovation: Concepts, analysis and interventions.* I. Darnhofer, David Gibbon, B. Dedieu (Eds.), Farming Systems Research into the 21st Century: The New Dynamic, Springer, Netherlands (2012), pp. 457-483, https://doi.org/10.1007/978-94-007-4503-2_20

Klomp, K., Oosterwaal, S., & Raworth, K. (2021). *Thrive : fundamentals for a new economy* (Ser. Business bibliotheek). Uitgeverij Business Contact.

Kloppenburg, J.R. Jr. (2004). *First the Seed: The political economy of plant biotechnology, 2nd edition.* University of Wisconsin Press 2004. 163.

Leroy, G., Boettcher, P., Besbes, B., Peña, C. R., Jaffrezic, F., & Baumung, R. (2020). *Food securers or invasive aliens? Trends and consequences of non-native livestock introgression in developing countries.* Global Food Security, 26, 100420. https://doi.org/10.1016/j.gfs.2020.100420

Louafi S., Thomas, M., Berthet, E., Pélissier, F., Vaing, K., Jankowski, F., Bazile, D., Pham, J.L., Leclercq, M. (2021). *Crop diversity management system commons: Revisiting the role of genebanks in the network of crop diversity actors.* Agronomy (Basel), 11, n.spéc. The Role of Policies in Plant Breeding—Rights and Obligations:1893, 15 p. https://doi.org/10.3390/agronomy11091893

Magdoff, F., van Es, H. (2021). *Building soils for better crops. Ecological management for healthy soils.* Fourth edition. Handbook Series Book 10. Published by the Sustainable Agriculture Research and Education (SARE) program, with funding from the National Institute of Food and Agriculture, U.S. Department of Agriculture. https://www.sare.org/wp-content/uploads/Building-Soils-for-Better-Crops.pdf

Magnani, S. D., Ancey, V., & Hubert, B. (2019). *Dairy Policy in Senegal: The Need to Overcome a Technical Mindset.* The European Journal of Development Research, 31(5), 1227–1245. https://doi.org/10.1057/s41287-019-00208-4

Mannar, M.G.V. and Micha, R. (Eds.) (2020) *Global Nutrition Report: action on equity to end malnutrition*, Development Initiatives (2020) https://globalnutritionreport.org/reports/2020-global-nutrition-report/

Marshall, K., Gibson, J.P., Mwai, O., Mwacharo, J.M., Haile, A., Getachew, T., Mrode, R., & Kemp, S.J. (2019). *Livestock Genomics for Developing Countries – African Examples in Practice.* Frontiers in Genetics, 10. https://www.frontiersin.org/article/10.3389/fgene.2019.00297

Millennium Ecosystem Assessment (Program). (2005). *Ecosystems and human well-being: Synthesis.* Washington, DC: Island Press ISBN 1-59726-040-1. OCLC 59279709.

Monbiot, G. (2017). *How Did We Get Into This Mess?* Politics, Equality, Nature. London: Verso, 2017.q

Moore, V.M., Schlautman B., Fei, S.Z., Roberts, L.M., Wolfe, M. Ryan, M.R., Wells, S., Lorenz, A.J. (2022). *Plant breeding for intercropping in temperate field crop systems: a review*. Front Plant Sci 13:843065. https://doi.org/10.3389/fpls.2022.843065

Munyi, P. (2022). *Current developments in seed laws harmonisation in Africa*. European Commission. https://www.desiralift.org/wp-content/uploads/2022/11/161122-DeSIRA-LIFT-Current-Developments-in-Seed-Laws-Harmonisation-in-Africa.pdf

Nielson, D. (2020). *Considering a soil initiative for Africa.* Chicago Council on Global Affairs. Stable URL: http://www.jstor.com/stable/resrep21291

OECD (2021). *Making Better Policies for Food Systems*, OECD Publishing, Paris, https://doi.org/10.1787/ddfba4de-en.

Perrings, C., Halkos, G. (2015). *Agriculture and the threat to biodiversity in sub-Saharan Africa.* Environmental Research Letters 10:095015. https://doi.org/10.1088/1748-9326/10/9/095015

Pimm, S.L., Jenkins, C.N., Abell, R., Brooks, T.M., Gittleman, J.L., Joppa, L.N., Raven, P.H., Roberts, C.M., Sexton, J.O. (2014). "*The biodiversity of species and their rates of extinction, distribution, and protection*". Science. 344 (6187): 1246752. doi:10.1126/science.1246752. ISSN 0036-8075. PMID 24876501. S2CID 206552746.

Pretty, J., Toulmin, C., Williams, S. (2011). *Sustainable intensification in African agriculture.* International Journal of Agricultural Sustainability, 9:1, 5-24, DOI: https://doi.org/10.3763/ijas.2010.0583

Redman, M., Hemmami, M., 2008. *Developing a National Agri-environment Programme for Turkey*. Ankara. Avalon, IEEP and Bugday.

Rockström, J., Edenhofer, O., Gaertner, J. et al. (2020). *Planet-proofing the global food system*. Nat Food 1, 3–5 (2020). https://doi.org/10.1038/s43016-019-0010-4

Rozanov, A., Wiese, L. (2018). *On Soil Scientists and Where to Find Them in Africa: Assessment of Human Capital.* (Moscow: Eurasian Centre for Food Security, Lomonosov Moscow State University) http://doi.org/10.13140/RG.2.2.19448.90885.

Runhaar, H. (2017) *Governing the transformation towards 'nature-inclusive' agriculture: insights from the Netherlands.* International Journal of Agricultural Sustainability, 15:4, 340-349. https://doi.org/10.1080/14735903.2017.1312096

Sekaran, U., Lai, L., Ussiri, D. A. N., Kumar, S., Clay, S. (2021). *Role of integrated crop-livestock systems in improving agriculture production and addressing food security – A review.* Journal of Agriculture and Food Research, Vol. 5. 100190. ISSN: 2666-1543. DOI: https://doi.org/10.1016/j.jafr.2021.100190

Shackelford G., Steward P.R., Benton T.G., Kunin W.E., Potts S.G., Biesmeijer J.C., Sait S.M. (2013). *Comparison of pollinators and natural enemies: A meta-analysis of landscape and local effects on abundance and richness in crops.* Biological Reviews, 88 (4), pp. 1002 – 1021. https://doi.org/10.1111/brv.12040.

Tamariz, G., Baumann, M.D. (2022). *Agrobiodiversity change in violent conflict and post-conflict landscapes.* Geoforum, 128, 217–222. https://doi.org/10.1016/j.geoforum.2021.11.010

Thormann, I., Engels, J. M. M. (2015). Ahuja, M. R.; Jain, S. Mohan (eds.). *Genetic Diversity and Erosion in Plants. A Global Perspective.* Springer International Publishing, vol. 7, pp. 263–294, doi:10.1007/978-3-319-25637-5_10, ISBN 978-3-319-25635-1

Tittonell, P., Giller, K.E. (2013). *When Yield Gaps Are Poverty Traps: The Paradigm of Ecological Intensification in African Smallholder Agriculture.* Field Crops Research, 143, 76-90. https://doi.org/10.1016/j.fcr.2012.10.007

Virchow, Detlef. (1999). *Conservation of genetic resources: Costs and implications for a sustainable utilization of plant genetic resources for food and agriculture* Springer, 1999. p22

Visser, B., Brush, S.B., Aistara, G.A., Andersen, R., Jäger, M., Nemogá, G., Padmanabhan, M., Sherwood, S.G. (2019). *The Governance of Agrobiodiversity.* In: Zimmerer, Karl S.; de Haan, Stef (Eds). (2019). Agrobiodiversity: Integrating Knowledge for a Sustainable Future. The MIT Press. 408 p. (Strüngmann Forum Reports Book 24). 383-305 pp.

Willett, W., J. Rockström, B. Loken, M. Springmann, T. Lang, S. Vermeulen, T. Garnett, D. Tilman, F. DeClerck, A. Wood, M. Jonell, M. Clark, L.J. Gordon, J. Fanzo, C. Hawkes, R. Zurayk, J.A. Rivera, W. De Vries, L.M. Sibanda, C.J.L. Murray. (2019). *Food in the Anthropocene: the EAT–Lancet Commission on healthy diets from sustainable food systems.* The Lancet, 393 (10170) (2019), pp. 447-492, https://doi.org/10.1016/S0140-6736(18)31788-4

Wittman, H., 2011. 'Food Sovereignty: A New Rights Framework for Food and Nature?' Environment and Society: Advances in Research, 2 (1): 87– 105.

Wittman, H., & Blesh, J. (2017). Food sovereignty and fome zero: connecting public food procurement programmes to sustainable rural development in brazil. Journal of Agrarian Change, 17(1), 81–105. https://doi.org/10.1111/joac.12131

Wyborn, C., Montana, J., Kalas, N., Clement, S., Davila, F., Knowles, N., Louder, E., Balan, M., Chambers, J., Christel, L., Forsyth, T., Henderson, G., Izquierdo Tort, S., Lim, M., Martinez-Harms, M.J., Merçon, J., Nuesiri, E., Pereira, L., Pilbeam, V., Turnhout, E., Wood, S. and Ryan, M. (2021). An agenda for research and action toward diverse and just futures for life on Earth. Conservation Biology, 35: 1086-1097. https://doi.org/10.1111/cobi.13671

Zimmerer, K.S., Duvall, C.S., Jaenicke, E.C., Minaker, L.M., Reardon, T., Seto, K.C. (2021). *Urbanization and agrobiodiversity: Leveraging a key nexus for sustainable development.* One Earth, 4(11), 1557–1568. https://doi.org/10.1016/j.oneear.2021.10.012

For further reading

Convention on Biological Diversity Agricultural Biodiversity (cbd.int)

Our food system isn't ready for the climate crisis | Food The Guardian

What is biodiversity and why does it matter to us? | Biodiversity The Guardian

Climate change is only half the problem | The Correspondent

Why should biodiversity be Africa's top priority? Our Africa, Our Thoughts (afdb.org)

How much land is needed to stop the biodiversity crisis? anthropocenemagazine.org)

Acknowledgements

This paper has been prepared in the framework of the European Commission's funded DeSIRA-LIFT project. A particular focus of DeSIRA-LIFT's advisory work is to support and promote agroecological pathways as a viable transition option for sustainable agri-food systems in Africa. This knowledge brief, inspired by a multitude of sources, is a concrete follow-up of the 'Deep Dive Dialogue on biodiversity loss and agrobiodiversity' held on 29 June 2022. The knowledge brief will feed into the formulation of activities or research and innovation projects funded by DG INTPA.

The feedback from the participants of the online deep-dive dialogue on 29 june 2022 has been incorporated into the paper. Participants included: Aggrey Agumya (FARA), Ioannis Dimitriou (DeSIRA-LIFT), Morris Egesa (AFAAS), Diedhiou Famara (AFSA), Wole Fatunbi (FARA), Guy Faure (DG INTPA), Justify Shava (SADC Plant Genetic Resources Centre), Ibrahim Hamadou (SWISSAID), Remi Kahane (CIRAD), Esther Koopmanschap (DeSIRA-LIFT), Christophe Larose (DG INTPA), Moses Odeke (ASARECA), Max Olupot (AFAAS), Baitsi Podisi (CCARDESA), Helena Posthumus (DeSIRA-LIFT), Amritbir Riar (FiBL), Darrell Sexstone (DG INTPA), Brice Sinsin (University of Abomey Calavi), Damian Sulumo (MVIWATA), Mathieu Thomas (CIRAD).

Funded by the European Union

Website:
https://www.desiralift.org/
LinkedIn:
https://www.linkedin.com/company/desira-lift
Email:
info@desiralift.org

Address:
Wageningen Centre for Development Innovation

P.O. Box 88
6700 AB Wageningen
The Netherlands