Food and Agriculture Organization of the United Nations

COMMISSION ON GENETIC RESOURCES FOR FOOD AND AGRICULTURE

ISSN 2412-5474

THE STATE OF THE WORLD's BIODIVERSITY FOR FOOD AND AGRICULTURE

FAO COMMISSION ON GENETIC RESOURCES FOR FOOD AND AGRICULTURE

ASSESSMENTS • 2019

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Rome, 2019

Required citation:
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. (http://www.fao.org/3/CA3129EN/CA3129EN.pdf)
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ISBN 978-92-5-131270-4

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Box 5.10 *(Cont.)*
Projects and initiatives targeting home gardens – examples from around the world

Tonga
The Tonga Health Promotion Foundation (TongaHealth) promotes home gardens as a means of increasing the consumption of a range of local fruit and vegetables. For example, villages wishing to access resources such as seedlings and fencing are provided with grants via the Community Gardening Programme. The aim of this initiative is to increase the consumption of healthy foods among Tongan families. To ensure sustainability, each household is encouraged to plant eight local vegetables and fruits in their residential garden for easy access throughout the year. Over 1 800 households have participated in the Community Gardening Programme since 2009. Tonga's 2015 Census recorded a total of 2 888 home gardens in the country.

Zimbabwe
In 2001, the Municipality of Bulawayo, together with World Vision, established urban allotment gardens to support vulnerable groups such as people living with HIV/AIDS, the elderly, widows and orphans. The main aims were to address acute food shortages and nutritional imbalances, raise awareness on HIV/AIDs, improve well-being and build people's capacities. As of 2008, more than 1 500 people had already benefited from the gardens.

Sources: Country reports of Argentina, Finland, Mexico, Nauru, Nepal, Sri Lanka, Tonga (with additional information from the website of the Tonga Health Promotion Foundation – https://www.tongahealth.org/about_us) and Zimbabwe, and the Lao People's Democratic Republic Agrobiodiversity Programme and Action Plan II (2015–2025). More information on PROHUERTA can be found (in Spanish) at http://prohuerta.inta.gov.ar.

being replaced by more profitable crops. As well as leading to genetic erosion, this trend is reported also to be contributing to the loss of traditional knowledge. Nauru, in contrast, reports renewed interest in home gardens but a lack of relevant local knowledge and technical skills. Panama mentions that, among other factors, the increasing availability of ready-to-eat products is reducing the use of food from home gardens. China reports that rural families are increasingly being drawn towards economically more attractive off-farm work, which leaves them little time to tend to their home gardens, and notes that this is negatively affecting BFA.

Needs and priorities

The main gap identified in the country reports in relation to home gardening is a lack of information on the status and trends of home gardens and on the contributions they make to the conservation of BFA and to the resilience of production in the face of challenges associated with (*inter alia*) climate change and socio-economic trends. Reported priorities in this regard include the provision of funding for thorough assessments of home-gardening practices and their impacts and for adequate dissemination of the data collected. Some countries mention priorities related to capacity development. For example, Panama identifies the need to strengthen the capacity of extension services to support home gardening. A few priorities related to the use of specific components of BFA within home gardens are also noted. The Lao People's Democratic Republic mentions the potential of diversifying livestock and fish production in home gardens, but notes that indigenous poultry are poorly understood and need to be studied systematically. Belarus mentions the importance of developing recommendations on the cultivation of wild plant species used for food, including in home gardens.

5.5.3 Agroforestry

Introduction

The country-reporting guidelines define agroforestry as "a collective name for land-use systems where woody perennials … are integrated in the farming system." In practice, however, use of the term varies from country to country, reflecting local, national and regional contexts. Moreover, since the word rose to prominence in the late

1970s (Bene, Beall and Côte, 1977), its usage has evolved considerably. Van Noordwijk, Coe and Sinclair (2016) describe three successive paradigms: the first focused on plot-level interactions of trees with crops or livestock; the second based on a landscape-level understanding of agroforestry as a land use with explicit (positive) impacts (Leakey, 1996); and the third encompassing the combination and interface of all agriculture and forestry issues without reference to the institutional barriers that have traditionally separated them. Van Noordwijk, Coe and Sinclair (2016) propose a new definition of agroforestry that recognizes all three paradigms and can be paraphrased as "land use that combines aspects of agriculture and forestry, including the agricultural use of trees." Moreover, usage of the term by farmers and development practitioners is often more specific than usage in scientific circles. Generalizations about the state of agroforestry are thus difficult to make, even at country level. The following paragraphs provide illustrative examples of the types of agroforestry practised in various regions of the world.

In East and Southern Africa, agroforestry systems include cereal-based systems that feature indigenous and introduced tree species valued for timber (*Grevillea robusta*, eucalypts [*Eucalyptus* and *Corymbia* spp.]), fruits (e.g. mango [*Mangifera indica*] and avocado [*Persea americana*]), charcoal (acacias [*Acacia* spp.]), fodder (*Calliandra* spp.) and soil-fertility enhancement (e.g. winter thorn [*Faidherbia albida*]). Systems include many indigenous and exotic tree species that are planted or protected in a variety of niches to supply various ecosystem services (Bein *et al.*, 1996; Kindt *et al.*, 2017). Although many indigenous tree species also feature in priority lists, farmers are increasingly replacing them with exotics (Kehlenbeck *et al.*, 2011).

Traditional "parkland" systems, i.e. mixed crop–tree–shrub–livestock assemblages derived from savannah ecosystems (Maranz, 2009), are the main sources of food, income and environmental services across the Sahelian zone of West Africa (Bayala *et al.*, 2011a). Their species richness ranges from monospecificity to more than 100 species of trees and shrubs, although species-rich systems may be dominated by a few species (Bayala *et al.*, 2011b; Kessler, 1992; Kindt *et al.*, 2008). Shrubs in parklands may be coppiced throughout the rainy (cropping) season. Farmers actively manage and protect trees, including by protecting naturally regenerating trees from livestock and during tillage operations (Brandt *et al.*, 2018; Hanan, 2018; Reij and Garrity, 2016). Tree density is kept low so that canopy cover is not continuous. These practices contribute to agricultural productivity and help to conserve plant and animal biodiversity by offering diverse above-ground and below-ground habitat niches.

In the humid tropics of West and Central Africa, prevalent agroforestry practices include the following: home gardens; perennial tree crop-based systems (cocoa, coffee, oil palm, rubber); slash-and-burn agriculture where high-value species providing timber and non-timber forest products are retained; improved fallows (e.g. with red calliandra [*Calliandra calothyrsus*], leucaena [*Leucaena leucocephala*], gliricidia [*Gliricidia sepium*], ice-cream bean [*Inga edulis*], mangium (*Acacia mangium*) and *Acacia auriculiformis*, pigeon pea [*Cajanus cajan*], Vogel's tephrosia [*Tephrosia vogelii*], sesbania [*Sesbania sesban*]); boundary planting (mostly in hilly areas); and small woodlots with *Eucalyptus* spp., red stinkwood (*Prunus africana*) and grevillea (*Grevillea robusta*) (Atangana *et al.*, 2014).

Mosquera-Losada *et al.* (2012) identified six main categories of European agroforestry: silvoarable practices; silvopasture; forest farming ("forested areas used for production … of natural standing speciality crops for medicinal, ornamental or culinary purposes"); riparian buffers; improved fallow; and multipurpose trees. They noted that many practices that had declined during the period of agricultural intensification that followed the industrial revolution are now reviving as a consequence of policy changes. However, as documented by den Herder *et al.* (2015), the dominant practices in terms of land area continue to be those traditional practices that were relatively unaffected by agricultural intensification, for example the oak-based systems known as *dehesa* (Spain) and *montados* (Portugal) and (particularly) reindeer-husbandry systems in Scandinavia. The reindeer-husbandry systems are practised more widely (41.4 million ha) than all other European systems combined.

Agroforestry practice in Latin America is thousands of years old (Miller and Nair, 2006). Dominant current types of agroforestry include the following: cacao and coffee systems (Somarriba *et al.*, 2014); silvopasture (Montagnini, Ibrahim and Murgueitio, 2013); tree fallows (improved or otherwise) in swidden agriculture (Cotta, 2017; Smith *et al.*, 1999); home gardens (Padoch and de Jong, 1991); and native trees and shrubs in field boundaries and along contour lines in mountain areas (Mathez-Stiefel, 2016). Use of both natural regeneration – particularly timber and shade species – and planted trees is common. The acronym SAF (an abbreviation of the Portuguese and Spanish words for "agroforestry system") has wide currency, and usually refers to multistorey systems of varying complexity. In Brazil, market-oriented systems may consist of intercropping three or more, mostly perennial, planted crops, for example cacao (*Theobroma cacao*), açai *(Euterpe oleracea*), black pepper (*Piper nigrum*), *cupuaçu* (*Theobroma grandiflorum*) or some timber species or oilseeds (Bolfe and Batistella, 2011), or much more complex high-biodiversity systems in which natural regeneration is managed, for example *cabruca*[49] systems (Sambuichi *et al.*, 2012) and successional agroforests (Cezar *et al.*, 2015).

Agroforestry practice and concepts in Oceania vary widely. Agroforestry has traditionally been an important farming system for Pacific Islanders (Thaman, Elevitch and Kennedy, 2006). On the smaller, land-scarce Pacific islands, tree fruits and nuts are important components in intensive farming systems (Evans, 1999). In rural communities in Papua New Guinea, native and exotic tree species such as casuarina (*Casuarina oligodon*), betelnut palm (*Areca catechu*) and gliricidia (*Gliricidia sepium*) provide important agroecological services and products for sale or home consumption (Page *et al.*, 2016; Bourke and Harwood, eds., 2009). In Australia, the term "agroforestry" is used broadly, but with some emphasis on timber production and agroforestry as "farm forestry" (e.g. Reid, 2017).

Prominent agroforestry systems in South Asia include: poplar-based commercial agroforestry (especially in India); fruit orchards; home gardens; cardamom and alder mixtures (Bhutan, India and Nepal); tree and shrub fodder production; silvopastoral systems; coastal shelterbelts (India and Sri Lanka); shifting cultivation ("chena" in Sri Lanka); trees interspersed on farmland; taungya (India, Sri Lanka); and tea and coffee agroforestry. In India, trees outside forests, of which trees grown on farms are a subset, account for 65 percent of timber production and almost half of fuelwood production (Government of India, 2017).

Southeast Asian farmers use a rich variety of agroforestry practices. These include: high-diversity home gardens; improved fallow (e.g. with naturalized leucaena [*Leucaena* spp.] in the Philippines); commodity-based agroforestry systems (in Indonesia these smallholder mixed systems produce 96 percent of the national coffee yield, 92 percent of the cacao, 80 percent of the rubber, 39 percent of the oil palm and 26 percent of the tea – DGEC, 2012); agroforests such as the damar agroforests and "jungle rubber" of Sumatra and Kalimantan, taungya and *tumpangsari* in teak or pine plantations in Indonesia and Thailand; trees planted at wide spacing in open-field agriculture (e.g. forest–rice terrace systems in the southern and northern Philippines); SALT (sloping agricultural land technologies), for example hedgerow planting, alley cropping and NVS (natural vegetative strips) on sloping land in Indonesia, the Philippines and Viet Nam; and boundary planting around farms and fields (e.g. of fodder trees in Indonesia and the Philippines). In Indonesia, agroforestry has become one of the land-based strategies for the national climate change adaptation and mitigation, and social-forestry, programmes.

Status and trends

Estimates of the global extent of agroforestry have differed by orders of magnitude. Reasons for this include the many different ways of using trees

[49] Cocoa trees grown under a thinned natural-forest canopy.

in agriculture, the "invisibility" of agroforestry in official statistics and differing understandings of what constitutes agroforestry (see above). What is clear is that where tree growth is not limited by environmental factors – usually temperature or precipitation (Runyan and D'Odorico, 2016) – trees are ubiquitous in agricultural landscapes, the most obvious exceptions being some agro-industrial landscapes.

Under a landscape-level definition of agroforestry, global datasets assembled for other purposes can be used to estimate the extent of agroforestry. For example, Zomer *et al.* (2014), using 1 km^2 resolution gridded data layers of tree cover and land use, defined agroforestry as occurring in pixels that are classified as "agricultural land" and have a certain level of tree cover. They estimated the global land area under agroforestry (based on three-year averages for 2008 to 2010) to be 3.1 million km^2 if taken to include agricultural land with ≥30 percent tree cover, and 9.6 million km^2 if taken to include agricultural land with ≥10 percent tree cover.[50] These are vast areas, roughly equivalent, respectively, to the areas of India and China. Table 5.5 shows regional estimates of the area under agroforestry, using an intermediate (≥20 percent tree cover) criterion. In absolute area, South America and Southeast Asia are easily the most significant "agroforestry regions", together constituting about 45 percent of the global total. In proportional terms, agroforestry is far more preponderant in Central America and Southeast Asia than in any other region. It should be noted that in some cases the regional values mask important intraregional variation.

Global recognition of the contributions of agroforestry has increased over the past decade, as have the mainstreaming of agroforestry into development and environmental agendas and appreciation of its potential impact on rural livelihoods, climate-smart agriculture, biodiversity conservation and land restoration. This higher profile also reflects wider acceptance and adoption of agroecological practices in agriculture. In individual countries and regions, the move towards mainstreaming is related – as both cause and effect – to policy and legal changes. Examples from several regions are provided in Box 5.11. A number of the country reports mention policies and programmes supporting agroforestry, including through education and extension, research and the provision of payments for ecosystem services. France's Agroforestry Development Plan is described in Box 5.12.

Increasing levels of awareness and support can be expected to lead to increases in the land area under agroforestry. Globally, there seems already to have been a slight increase (Table 5.5), although unravelling the causes of particular regional trends would require more detailed analysis. Increases in tree cover are not necessarily the result of policy measures or other high-level support, i.e. they may reflect wider macroeconomic and societal factors (e.g. Redo *et al.*, 2012).

Countries' responses on the state of and trends in the adoption of agroforestry practices are summarized in Table 5.1 and Table 5.2. Across all systems, reports of increasing trends outnumber reports of decreasing trends, in most cases by a substantial margin. Many country reports mention that agroforestry is a traditional element of local production systems, in many cases noting its importance to food security, to the supply of ecosystem services such as soil protection and carbon sequestration and to the resilience of farms to both biophysical (e.g. climatic) and economic shocks and trends. Countries generally do not provide detailed information about the causes of the trends reported. A number, however, mention

[50] Two aspects of the methodology used in this analysis should be noted. First, pixels corresponding to 1 km^2 area were used as the basis for tree cover classification. A given percentage tree cover in a given pixel may indicate various things. For example, 30 percent tree cover might mean 70 percent treeless and 30 percent forested or an intimate mixture of trees and crops in which tree crowns overlay 30 percent of the area (or anything in between). Although all pixels are located on land classified as "agricultural", it is possible that some pixels that consist of contrasting treeless areas and closed canopy forest areas may not constitute agroforestry as commonly understood. Second, the estimates will have excluded some areas under agroforestry, because these occur on land classified as non-agricultural (Zomer *et al.*, 2014).

TABLE 5.5
Land area under agroforestry (2008–2010) and trends (2000–2010), by region

Region	Area (million km^2)	Proportion of total agricultural land (%)	Increase (2000–2010) (%)
Central America	0.2	79.0	8.2
East Asia	0.4	22.1	3.4
Europe	0.5	20.4	1.6
North Africa and Western Asia	0.1	5.5	0.3
North America	0.6	26.3	2.2
Northern and Central Asia	0.2	9.7	1.2
Oceania	0.2	23.8	3.4
South America	1.2	31.8	3.5
South Asia	0.1	7.8	0.9
Southeast Asia	1.0	62.9	2.0
Sub-Saharan Africa	0.6	15.0	0.0
World	**5.1**	**23.1**	**1.8**

Notes: Figures refer to agricultural land with ≥20 percent tree cover. Land area estimates are based on three-year averages for 2008 to 2010.
Source: Zomer *et al.*, 2014.

policies that provide support to the development of agroforestry via measures such as knowledge transfer and the provision of subsidies.

Needs and priorities

At the turn of the millennium, regional studies in Southeast Asia identified the following priority areas for support to agroforestry: germplasm quality and availability; marketing and market access; supportive policies; tree and system (particularly timber and fruit) management; and training and information dissemination (Gunasena and Roshetko, 2000; Roshetko and Evans, 1999). A global review by Leakey *et al.* (2012) found that, while significant progress had been made, many of those topics remained in need of attention. The following subsections present gaps and needs under five broad, partially overlapping, headings: concepts; policy; development approaches; germplasm; and research.

Concepts of agroforestry

Although diversity of concepts and practices across regions and countries is practically inevitable and not necessarily undesirable, it becomes a problem when limited concepts of agroforestry – for example, agroforestry as only multistorey systems – lead to limited understanding of its relevance to issues such as poverty, climate change adaptation and mitigation and land degradation. This underscores the importance of not only clarifying agroforestry definitions, but also of sharing experiences of different types of agroforestry and how they can successfully contribute to addressing problems and opportunities.

Policy

Agroforestry often continues to occupy a "no man's land" between forestry and agriculture, and benefits neither from specific supportive policies nor from an institutional home. In many cases, farmers are still not allowed to harvest trees, or even tree products, on their land. Even where such activities are allowed under current law, the complexity or cost of fulfilling requirements may be beyond the capacities of resource-poor farmers (Foundjem-Tita *et al.*, 2013; Sears *et al.*, 2018).

Box 5.11
Policy and legislative frameworks promoting agroforestry – examples from around the world

East and Southern Africa
Policy changes have been key to wider inclusion of trees on farms in East and Southern Africa. For example, Kenya's Agriculture (Farm Forestry) Rules of 2009[1] – a response to deforestation, increased demand for agricultural land and farmers' desire to plant trees – require at least 10 percent tree cover on all farms. The country's government has allocated funds to assist farmers to meet this requirement (Jamnadass *et al*., 2013). Kenya and other East African countries have pledged millions of hectares to the Bonn Challenge[2] and AFR100[3] restoration initiatives (e.g. 15 million ha in Ethiopia, 5.1 million ha in Kenya and 2 million ha in Rwanda). Agroforestry plays a prominent role in these pledges (e.g. Ministry of Natural Resources – Rwanda, 2014).

West and Central Africa
Analysis suggests that both rainfall patterns and land-management practices are responsible for the "re-greening" of the Sahel (Ouedraogo *et al*., 2014). In the case of Niger, widespread adoption of farmer-managed natural regeneration (FMNR) (Reij, Tappan and Smale, 2009a) led the government to relax provisions in the Forest Law, allowing farmers the right to harvest trees nurtured or planted on their own land. This policy change is thought to have contributed to the spread of FMNR to over 5 million ha (Garrity *et al*., 2010). The trend towards increasing tree cover is likely to continue, as a result of multiple international initiatives to upscale on-farm natural regeneration and tree planting, particularly those related to forest landscape restoration (Minasny *et al*., 2017; Reij and Garrity, 2016).

Latin America
In Peru, the Forest and Wildlife Law of 2011[4] recognizes and provides an official definition of agroforestry, and created the Agroforestry Concessions mechanism (Robiglio and Reyes, 2016), for which guidelines were issued in 2017.[5] This measure aims to formalize hitherto illegal occupation of state forestland, based on the scaling-up of sustainable management (including agroforestry) on about 1.2 million ha of land in the country's Amazon region. In Brazil, the Forest Law of 2012[6] established the principle that agroforestry serves both social and environmental functions in protected areas, allowing farmers to restore Permanent Preservation Areas (riparian zones, springs, hillsides and ridge tops) and conservation set-asides (known as Legal Reserves), which are required on all rural lands, through agroforestry (for which a legal definition is provided). In these cases, farmers may include short-cycle crops, legumes and some exotic species provided they are intercropped with native trees and maintain basic ecological functions (Miccolis *et al*., 2016).

Southeast Asia
Many countries in Southeast Asia have mainstreamed agroforestry into agriculture, watershed management and social-forestry programmes. For example, the Government of the Philippines has been implementing an upland-agroforestry programme since 2000. Viet Nam is revising its Forestry Law, introducing provisions that allow agroforestry to be practised in allocated forestlands, which will pave the way for agroforestry to become an official forest land-use type. At the regional level, the 2016–2025 Vision and Strategic Plan of the Food, Agriculture and Forestry Sector of ASEAN (Association of Southeast Asian Nations) has a specific action programme aimed at agroforestry expansion (Strategic Thrust 4, Action Programme 5). In 2017, the ASEAN Working Group on Social Forestry agreed to the preparation of ASEAN-level guidelines on agroforestry development for Member States (Finlayson, 2017).

(Cont.)

[1] Agriculture (Farm Forestry) Rules (available at http://www.fao.org/faolex/results/details/en/?details=LEX-FAOC101360).
[2] http://www.bonnchallenge.org/content/challenge
[3] http://www.afr100.org
[4] Ley N° 29763 - Ley Forestal y de Fauna Silvestre. El Peruano, 22 de julio de 2011 (available, in Spanish, at http://www.fao.org/faolex/results/details/en/c/LEX-FAOC104648/).
[5] Resolución N° 081-2017-SERFOR – Lineamientos para el otorgamiento de contratos de cesión en uso para sistemas agroforestales. El Peruano, 31 de marzo de 2017 (available, in Spanish, at http://www.fao.org/faolex/results/details/en/c/LEX-FAOC171777/).
[6] Lei de Proteção da Vegetação Nativa n. 12.727, de 17 de Outubro de 2012 (available, in Portuguese, at http://www.planalto.gov.br/ccivil_03/_ato2011-2014/2012/lei/l12727.htm).

Box 5.11 *(Cont.)*
Policy and legislative frameworks promoting agroforestry – examples from around the world

South Asia
In 2014, India promulgated its National Agroforestry Policy, backed with a capital outlay of USD 450 million for four years (2016/17 to 2019/20) (Chavan *et al*., 2015). The policy has been an effective instrument for promoting agroforestry, has created an institutional "home" for agroforestry (the Ministry of Agriculture) and constitutes a negotiation platform for agroforestry in the country (Singh *et al*., 2016). Its effect on sustainable utilization of India's vast stock of trees on farms (1.5 million m^3) has been notable, particularly the relaxation of tree-felling and transit regulations, deregulation of sawmill opening and inclusion of agroforestry in many central government agricultural schemes. Twenty of 29 states have excluded at least 20 tree species from felling and transit regulations. Prior to approval and implementation of the agroforestry policy, felling and transport of the majority of tree species were prohibited through regulatory laws that discouraged farmers from growing trees on farms.

Box 5.12
France's Agroforestry Development Plan 2015–2020

In 2015, the French Ministry of Agriculture launched the Agroecological Project, a policy aimed at rendering production systems more effective with respect to their economic, environmental and social dimensions.[1] Sustainable use and conservation of biodiversity are key elements of agroecology. One element of this policy initiative is the Agroforestry Development Plan,[2] which consists of five axes:

- gaining better understanding of the diversity of agroforestry systems and their functioning;
- improving the legal framework and strengthening financial support;
- developing extension, training and promotion of agroforestry;
- increasing the economic valuation of agroforestry production in a sustainable way; and
- promoting and disseminating agroforestry internationally.

The axes comprise 23 actions that are coordinated by the Ministry of Agriculture and implemented with a dozen partners, including the National Institute for Agricultural Research (INRA), the Ministry of the Environment, the associations involved in the territories, and the network of Chambers of Agriculture.

The objective of the Agroforestry Development Plan is to develop existing agroforestry systems such as hedgerows (about 1 million ha in France, but decreasing), tree intercropping (about 5 000 ha), fruit-tree silvopasture and silvopastoralism.

[1] http://agriculture.gouv.fr/le-projet-agro-ecologique-pour-la-france
[2] http://agriculture.gouv.fr/un-plan-national-de-developpement-pour-lagroforesterie

Source: Provided by Patricia Larbouret, Christophe Pinard and Pierre Velge.

Approaches to agroforestry development

Agroforestry innovations often encounter problems in scaling up (Coe, Sinclair and Barrios, 2014; Shiferaw, Okello and Reddy, 2009). A diverse range of factors may be responsible. For example, Porro (2009) lists 46 causes of failure in adoption of agroforestry systems in the Amazon. Three specific areas stand out.

First, rural advisory services, where they exist, often struggle to address some forms of agroforestry, which can be knowledge intensive, context specific and provide benefits in the long term rather than the short term. Rural resource centres (Degrande *et al.*, 2015) – training and demonstration hubs that are managed by grassroots organizations and may operate outside the formal extension model – are one promising approach. The exchange of knowledge and experiences between farmers should also be facilitated and supported (Martini, Roshetko and Paramita, 2017).

Second, special attention needs to be paid to gender differences in access to agroforestry resources and potential to benefit from them. Men and women often play different roles in production and along value chains, which means that they have different knowledge about species and management practices, and different perceptions of the value of the potential benefits of agroforestry practices (Colfer *et al.*, 2016; Kiptot, Franzel and Degrande, 2014; Mulyoutami *et al.*, 2015).

Third, support to agroforestry often tends to neglect marketing, business practices and financial incentives such as credit (Blare and Donovan, 2016). This can apply to agroforestry commodities (e.g. the principal beverage crops) (Donovan, Blare and Poole, 2017), to companion crops grown in agroforestry systems (e.g. Sears *et al.*, 2018) and to farmer-produced timber (Holding-Anyonge and Roshetko, 2003; Perdana, Roshetko and Kurniawan, 2012). When markets are considered, the focus has often been on export markets rather than on establishing more stable local and regional demand (Blare and Donovan, 2016). A more integrated vision is needed, in which promotion of agroforestry includes efforts to identify markets for the mix of crop and tree species cultivated.

These and many other factors are part of a general failure to adequately consider local contexts (Coe, Sinclair and Barrios, 2014). The latter authors propose an "options-by-context", co-learning approach in which different agroforestry interventions (potentially including innovation in policy, advisory services, institutions and value chains, as well as in production systems) are considered in relation to local social, economic, biophysical and political contexts.

Germplasm

The availability of germplasm has long been considered a constraint to the scaling-up of tree-planting by smallholders (Caveness and Kurtz, 1993; Franzel *et al.*, 2001; Kakuru, Doreen and Wilson, 2014; Koffa and Roshetko, 1999; Roshetko, Mulawarman and Dianarto, 2008; Walters *et al.*, 2005). Expansion of restoration initiatives implies significantly higher demand for germplasm (Broadhurst *et al.*, 2016). For example, if half of the area currently pledged to the Bonn Challenge (140 million ha) (see Section 5.4) were to be subject to relatively low-density planting averaging 100 trees per ha over a period of ten years, the demand for seed would be around 1.4 billon seeds per year.[51] The quantities of seeds and the institutional frameworks required would be beyond the current capacities of most, if not all, developing countries (e.g. Atkinson *et al.*, 2017).

In some cases, the market may respond adequately to increased demand. However, profit-seeking nursery producers will tend to concentrate on the most profitable species, meaning that germplasm-supply systems based purely on the market are unlikely to offer the diversity that tree planters seek (Cornelius and Miccolis, 2018). Lillesø *et al.* (2018) have argued for legislation that favours public–private partnerships, with small-scale entrepreneurs becoming the major producers and distributors of quality tree-planting materials. Low income may prevent resource-poor farmers from purchasing planting stock (Harrison, Gregorio and Herbohn, 2008; Murray and Bannister, 2004; Osemeobo, 1987), and distribution of free or subsidized seedlings is an option in such cases. Although there is a risk of undermining private nurseries (Graudal and Lillesø, 2007), development agencies that distribute free or low-cost planting material can avoid this problem if they themselves purchase from private nurseries (Cornelius and Miccolis, 2018). In this way, they can strengthen emerging germplasm-supply systems by acting as intermediaries between nurseries and farmers that are too poor or too distant to purchase from them.

Research

Enumerating the full range of research needs in agroforestry research is beyond the scope of this

[51] 7 million ha per year, 100 seedlings per ha, 2 seeds per seedling produced.

overview. It is important, however, to stress that the agroforestry research agenda must reflect the full scope of agroforestry, i.e. from landscape-level effects (e.g. relationships between trees and water supply, or optimum configurations for biodiversity objectives) to plot-level, and including social-science research as well as the hitherto more dominant biophysical research.

Integration of research into development is essential to the scaling up of agroforestry. As noted above, potential agroforestry interventions need to be adapted to specific local contexts. This may require formal planned comparisons nested within development activities (Coe *et al.*, 2017).

5.5.4 Diversification practices in aquaculture

Introduction

Recent decades have seen a general upward trend in the share of aquaculture production in total fish production across all continents (FAO, 2018a). Aquaculture accounted for 47 percent of total world fish production in 2016, up from 42 percent in 2012 and 31 percent in 2004 (FAO, 2016k, 2018a). Given that production from capture fisheries is fairly stable (FAO, 2018a), it is likely that aquaculture will be the main source of future growth in the fisheries sector.

Aquaculture is very diverse in terms of the range of species, environments and production systems utilized.[52] It also includes a range of diversification practices. The country-reporting guidelines invited countries to provide information both on "diversity-based practices" in aquaculture, including specifically on polyculture and aquaponics, and on "mixed systems", including integrated aquaculture, i.e. systems in which aquaculture is integrated with crop or livestock production. The first three subsections below present an overview of such practices. The first two cover systems that involve combining aquaculture with other components (integrated aquaculture and the specialized case of aquaponics) and the third covers the use of multiple aquatic species (polyculture) in the context of aquaculture itself. The final subsection discusses trends in the use of diversification practices in aquaculture and presents findings from the country reports on the levels of (and trends in) the use of polyculture and aquaponics practices.

Integrated aquaculture

Much of modern aquaculture operates in relative isolation from other types of food and agricultural production and with little attention to its impacts on, or interactions with, surrounding ecosystems and biodiversity (see Chapter 3 for further discussion of the impacts on BFA). Traditional aquaculture, in contrast, is not an isolated operation but rather an integral component of local farming systems, and is managed in accordance with farmers' overall strategies for the use of their labour capacity, land and other resources (Dabbadie and Mikolasek, 2015). Such systems are often referred to as "integrated aquaculture" (Edwards, Little and Demaine, 2002; FAO, IIRR and WorldFish Center, 2001; Nhan *et al.*, 2007; van der Zijpp *et al.*, eds., 2007).

A 2001 review of integrated agriculture–aquaculture (FAO, IIRR and WorldFish Center, 2001) identified a wide range of systems within this category:

- grass–fish and embankment–fish systems – fish ponds integrated with vegetable crops and grass. Grass, plant wastes and vegetable cuttings are fed to grass carp (*Ctenopharyngodon idella*) or other herbivorous fish species;
- seasonal ponds and ditches – components of other farming systems that become inundated for a period of the year, allowing fish stocking and culture;
- livestock–fish integration systems featuring chickens, ducks or pigs – typically involving the placement of a livestock pen or cage over or next to a fish pond so that waste feed and manure drop into the pond, directly feeding the fish or fertilizing the water to increase primary productivity;

[52] FAO estimates that about 598 aquatic species are currently farmed around the world, including seaweeds, molluscs, crustaceans, fish and other groups (FAO, 2018a). This number is increasing very fast, as there were only 472 aquatic species reportedly farmed in 2006 (ibid.).