Fruit trees plantation

Farming households growing selected fruit tree portfolios on their farms, to gain year-round supply of nutritious fruits to eat, for diverse diets and improved health. The fruit tree portfolio approach is designed to tackle the problem of micronutrient deficiencies, also known as 'hidden hunger'.

Photo: World Agroforestry

Suggested citation:

van Noordwijk M, Zomer RJ, Xu J, Bayala J, Dewi S, Miccolis A, Cornelius JP, Robiglio V, Nayak D, Rizvi J. 2019. Agroforestry options, issues and progress in pantropical contexts. In: van Noordwijk M, ed. *Sustainable development through trees on farms: agroforestry in its fifth decade*. Bogor, Indonesia: World Agroforestry (ICRAF) Southeast Asia Regional Program. pp 113–138.

CHAPTER SIX

Agroforestry options, issues and progress in pantropical contexts

Meine van Noordwijk, Robert J Zomer, Jianchu Xu, Jules Bayala, Sonya Dewi, Andrew Miccolis, Jonathan P Cornelius, Valentina Robiglio, Devashree Nayak, Javed Rizvi

Highlights

- Tree cover on agricultural land is strongly related to climate zone, with some regional variation
- Agroforestry allows for a gradual transition from subsistence to market-oriented land use
- Tropical commodity production is highly concentrated, with the top 1, top 3 and top 10 countries accounting for about one-third, two-thirds or 90%, respectively, of global production
- Agroforestry farmers face different and changing forest-policy and property-right regimes in countries and regions
- Progress in developing land-use policies supportive of agroforestry is uneven, with opportunities for inspiration and learning from frontrunner countries
- Upscaling agroforestry practices requires developing options tailored to varying, local, socio-ecological contexts and enabling environments

1.1 Introduction

There are many ways to classify and describe agroforestry practices based on the spatial and temporal arrangement of trees, the type of trees in relation to economic value, the non-tree components (crops, livestock, fish) or the balance between retained, spontaneous and planted trees (compare with Chapter 2). The simplest way that is compatible with existing global data sets may well be the classification of tree canopy cover on agricultural land[1,2] because it allows a direct comparison across regions and countries. In this chapter, we present data, experience and lessons from the six regions in which World Agroforestry is currently active. Together, they cover 66.8% of global agricultural land and 72.9% and 78.8% of such land with at least 10% and 30% tree cover, respectively. Across all regions, tree cover on agricultural land is positively related to rainfall (scaled by potential evapotranspiration in Figure 6.1). Central

America stands out as the region with the highest, relative, on-farm tree cover in any climatic zone, with relatively small differences between other regions, once climate is accounted for. From existing data, it appears that increases in soil carbon storage in agroforestry systems relative to open-field cropping (on average 19% for the 0–100 cm depth layer) are only partially related to aboveground carbon storage in trees across four different agroforestry practices (homegardens, alley cropping, windbreaks, silvopastoral systems), but do correlate with tree age[3].

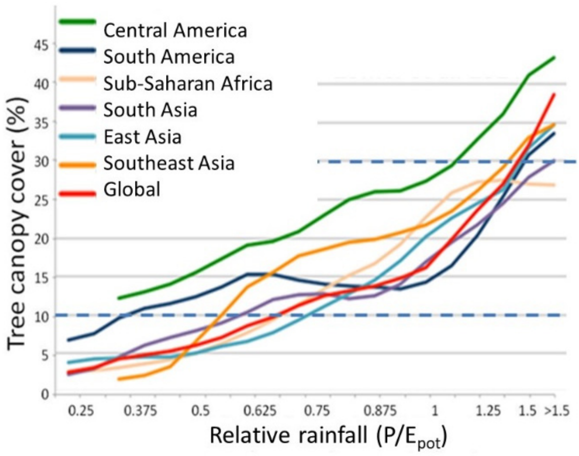

Figure 6.1 Relationship[1] between tree canopy cover in agricultural land and relative precipitation (P), scaled by potential evapotranspiration E_{pot}

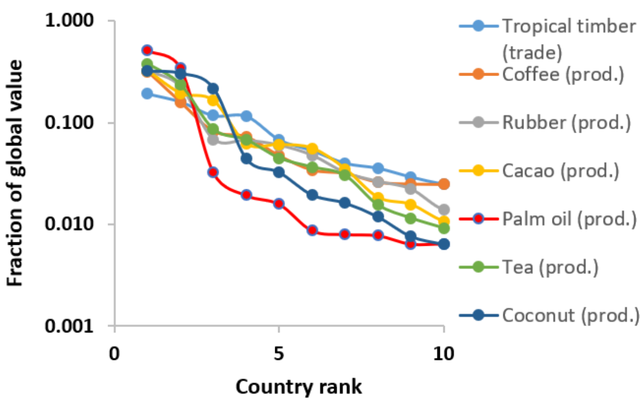

Figure 6.2 Frequency-rank relationship for tropical commodities

Source: FAO Stat data for 2014

Agroforestry is an important mode of production for some of the tropical commodities but has in others been replaced by monocultures. For these commodities, the top 1, top 3 and top 10 countries account for about 33%, 66% and 90% of global production, respectively.

However, there are some differences, with oil palm and coconut most concentrated, and coffee and tropical timber least geographically concentrated[a].

We will here give a brief characterization of the tree-cover data at country scale, the main development issues that agroforestry can contribute to, and the types of agroforestry research and development of the past four decades, with a focus on research performed by World Agroforestry and partners. Each of the six regions is 'represented' by single case studies in subsequent chapters (8–13), therefore, we will contextualize the examples here. As a generic group of settings with special consequences for agroforestry, Chapter 14 will focus on 'small islands' around the world.

6.2 Eastern and Southern Africa

The Eastern and Southern Africa region, covering 9.5% of global agricultural land, represents 6.7% and 2.5% of such land with at least 10% and 30% tree cover, respectively. This relatively low tree cover is linked to climate (most of the area has P/E_{pot} ratios below 0.62. See Figure 6.1), dominant food crops (maize, with little shade tolerance and little microclimatic benefit from shading as has been documented for other cereals[4]), and the classification of most 'rangelands' (extensive grazing in savanna landscapes with trees) as outside of 'agriculture'. Higher rainfall areas are found on the various mountain ranges, in what have locally been recognized as 'water tower' configurations[5]. Some of the earliest agroforestry descriptions of the diverse Chagga gardens[6] on the slopes of Mount Kilimanjaro are on such a water tower. As the climate at higher elevations is conducive to temperate vegetables and/or tea, these areas have attracted settlements in colonial and post-colonial periods. Within this region, Madagascar, Uganda, Burundi, Kenya, Ethiopia, Angola and South Sudan have the largest fractions of agricultural land with at least 10% tree cover.

East Africa is not a major player in tropical commodity trade but Kenya is the worlds' third-largest tea producer (9% of total) and Ethiopia the worlds' fifth-largest producer of coffee (5% of global production) while the region is the centre of origin of the main coffee species used and, thus, relevant for genetic diversity (including wild relatives). Research on the coffee agroforests of Ethiopia and some of the Eastern Arc mountains has considered the balance of local wellbeing and global value of conserving genetic diversity[7].

East Africa is the source area of the Nile, with current understanding of the atmospheric moisture transfer between the White Nile (originating in the Lake Victoria Basin) and the Blue Nile (in Ethiopia)[8] calling for a more integrated 'precipitationshed' approach[9,10] beyond current water-sharing agreements.

[a] Top producer: Highest for oil palm at 50.9% and lowest for tropical timber 19.2%; Top 3: highest for oil palm at 88.3%, coconut at 83.7%, tea at 70.3%, and lowest for tropical timber at 46.9%; Top 10: highest for coconut at 97.5%, oil palm at 95.5%, cocoa at 93.7% and tea at 91.9%, lowest for tropical timber at 83.4% and coffee at 81.5%

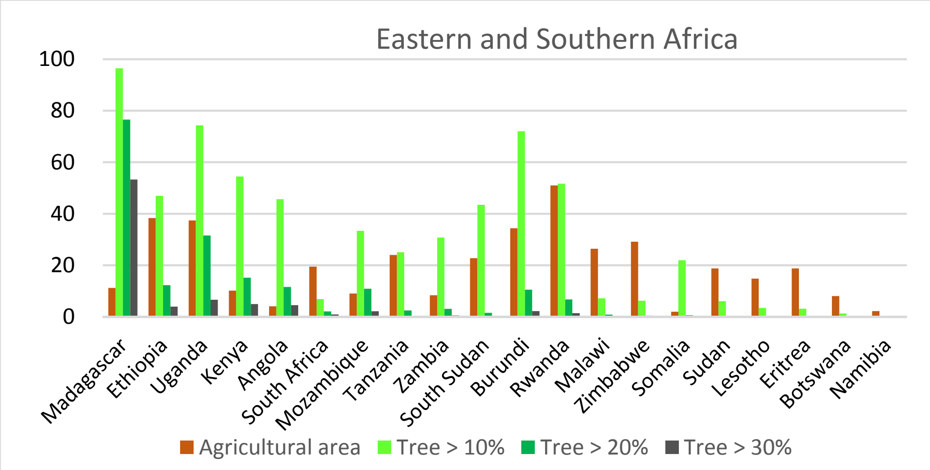

Figure 6.3. Agricultural land fraction and fractions of that with >10, >20 or >30% tree cover for countries in eastern and southern Africa

The Eastern and Southern Africa region has been afflicted by chronic poverty and food shortages, which are caused or exacerbated by a complex interplay between agroecological (declining soil fertility and crop yields, droughts, floods, environmental degradation), social (illiteracy, class and ethnic disparities), and politico-economic (unfavourable domestic policies, massive debt burdens, corruption, distorted international trade policies and skewed terms for development aid) factors.

While agriculture is the main source of livelihoods for approximately 80% of the rural population in the region, agricultural production is constrained by unaffordable inputs, especially fertilizers, lack of access to credit, and minimum involvement of smallholders in the market economy. Declining soil fertility is one of the root causes of low crop productivity and consequently of deforestation, with natural forests (of variable ages as 'fallow') being cleared for the expansion of farmland. In the wetter parts (the water towers), profitable understorey species, such as cardamom[11], lead to a gradual replacement of forest species. Owing to rapid population growth and inequitable land distribution, farmers now are forced to cultivate the same piece of land more frequently and, in some cases, continuously every year, thereby exhausting the soils. Given the small farm sizes (often under 1 hectare), many farm families cannot produce enough to feed themselves even during years of favourable rainfall. Most smallholders face food deficits during the periodic droughts affecting the region.

In this context, current agroforestry research is focussed on:

- Supplying farmers with high-quality germplasm for trees that provide fruit[12], energy[13] and fodder[14,15];
- Improving on-farm tree management[16,17];
- Disseminating science-based evidence and otherwise demonstrating the effectiveness of agroforestry systems at scale to encourage the uptake of these systems[18,19];
- Developing ecological services[20,21], particularly, water management services under agroforestry systems[22]; and

- Strengthening the capacities of government counterparts[23,24], research organizations and communities[25].

The landscape case study in Chapter 7, Shinyanga in Tanzania, represents the challenges in large areas where past development efforts in crop and livestock production did not include attention on trees or even saw them as the source of tsetse flies preventing livestock raising. Restoration and recovery of the landscape's potential to function in current and changing climates had to rely on a combination of institutional (reviving old natural management concepts), technical, social and economic interventions. The relevance and response to these options depends on context; any specific landscape example can provide inspiration but no 'blueprint'.

A farmer in Toben Gaa reducing vulnerability of smallholder farmer in western Kenya to the effects of climate change by improving their livelihood and environments. Photo credit: World Agroforestry/Joseph Gachoka.

6.3 West and Central Africa

The West and Central Africa region, covering 8.5% of global agricultural land, represents 6.1% and 8.5% of such land with at least 10% and 30% tree cover, respectively. Country-level data (Figure 6.4) show that 10 countries in the region have at least 30% tree cover on at least 80% of their agricultural land (mostly in the Congo Basin and humid West Africa); a small group (Ghana, Cameroon, Togo, Cape Verde) has intermediate tree cover; and the remaining countries, in the drier zones, have hardly any. More detailed data for this zone give a more nuanced perspective (increasing tree cover on farms while closed forest stands continue to lose out)[26] will be discussed in Chapter 8.

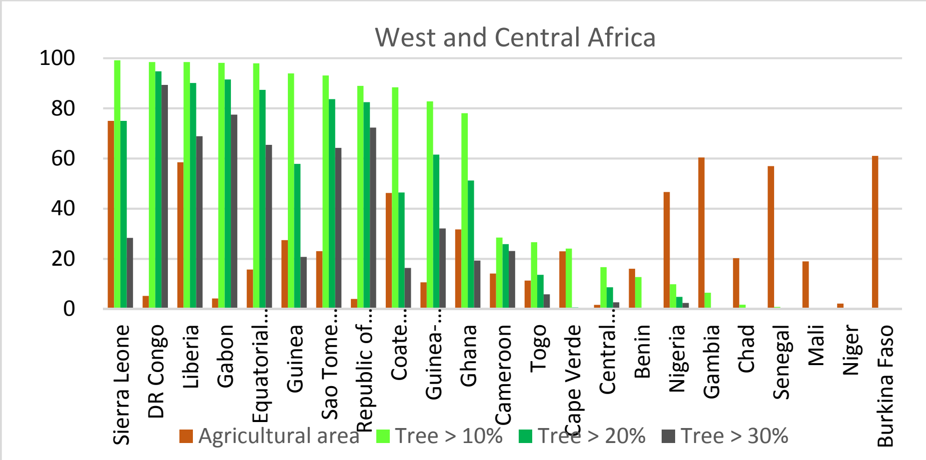

Figure 6.4 Agricultural land fraction and fractions of that with >10%, >20% or >30% tree cover for countries in western and central Africa

The West and Central African region covers approximately 1200 million hectares spanning 21 countries with a total population of more than 330 million people. It includes arid, semi-arid, sub-humid and humid ecological zones, with clearly differentiated types of agroforestry.

West and Central Africa features the worlds' primary production of cocoa (Ivory Coast in first place at 32%, Ghana second with 19%, Cameroon fifth with 6%, Nigeria sixth with 6%) and still plays some role in oil palm (Nigeria in fifth place at 2%) while it is the centre of origin of both oil palm and some of the coffee species used and, thus, relevant for genetic diversity (including wild relatives).

The Congo Basin contains the world's second-largest continuous area of rainforest and is home to more than 20 million people, most of whom depend on the use of natural resources for their livelihoods. In the humid tropics zone of Central Africa, early agroforestry research on improved fallows[27] has been transformed into interest in the direct value of trees for the local economy. Fruit tree domestication[28,29] became closely linked to processing and marketing of tree products[30,31,32,33], rural resource centres and marketing arrangements[34,35], jointly understanding adoption[36]. Technical efforts to develop new value chains for *Allanblackia*[37,38] still require a stronger economic embedding. Legal frameworks for tree management proved to be essential across the various zones and legal traditions[39,40] while what so far has been seen as 'community forest management' needs to connect agroforestry and local business development[41,42]. On the policy side, REDD+ and emerging climate policies also have a richer meaning when linked to agroforestry[43,44].

About 70% of the world's production is sourced from West and Central Africa. However, cocoa farming developed over time to the detriment of food crops and caused shortages of major food commodities not only in cocoa-farming households but also in food markets. A mapping of malnutrition in the major cocoa-producing areas of Côte d'Ivoire[45] and Ghana[46] revealed stunting rates varying respectively from 25% to 34% and from 25% to 38%. These high rates were linked to a very low dietary diversity, axed on consumption of energy-dense and nutrient-poor foods, such as fats and oils, white roots and tubers, excluding vitamin A-rich fruits or vegetables. While some positive relationship has been established between cocoa production and food security in cocoa-producing households, it is not clear how this happens. Also, cases of food insecurity are frequently reported by cocoa-farming families in West and Central Africa and the factors causing this are also not well known[47].

In general, food security is influenced by many structural factors like price fluctuation of commodities, low edible crop productivity, low level of incomes, lack of access to agricultural inputs and credit markets and, consequently, poor investment in the agricultural sector. Climate change also has direct effects on food security through abnormal changes in temperature, rainfall and extreme weather events[48]. Higher temperatures are affecting cocoa production, calling for more vigorous forms of agroforestry, associating trees for shade or other crops for diversification.

In the Sahel region, conventional approaches to reforestation have involved the use of expensive, environmentally destructive inputs and the propagation of exotic species, often with need for water that strains available resources. Owing to low survival rates of planted trees, farmer-managed natural regeneration (FMNR) has been developed over the three last decades as an alternative. FMNR can be combined with planting to broaden the portfolio of tree products and services. For planting, seedling production and propagation methods to shorten the juvenile phase and improve the quality of the products have been developed in a domestication effort[49,50]. Parkland agroforestry[51,52] and its role in supporting food production[53,54] has seen a revival after changes in forest policy (see Chapter 8). Clarifying tenure was essential to give efforts in dryland tree improvement[55,56] a chance of success. Tree products from the parklands contain vitamins and micro-nutrients that complement the starch-based (cereals) diet of the Sahel region. There are also sources of income and creation of jobs for women, who are the most active in processing tree products[57,58,59].

The main focus of the research in the region is on domesticating trees for high-quality germplasm to produce fruit and fodder, restoring cocoa orchards, managing tree–crop interactions to optimize parkland performance, developing tree-based land restoration, developing value chain and public–private partnerships, analysing regulations and supporting the development of conducive environments for the promotion of trees and agroforestry[60,61,62].

6.4 Southeast Asia

The Southeast Asia region, covering 7.9% of global agricultural land, represents 14.7% and 28.9% of such land with at least 10% and 30% tree cover, respectively. The region includes Indonesia with 6.3% and 13.8% of global agricultural land with >10 and >30%, respectively, as a champion of agroforestry. Myanmar and Cambodia have the lowest fraction of agricultural land with at least 10% tree cover but would still be in the high tree-cover frequency class if they were part of Africa or the rest of Asia.

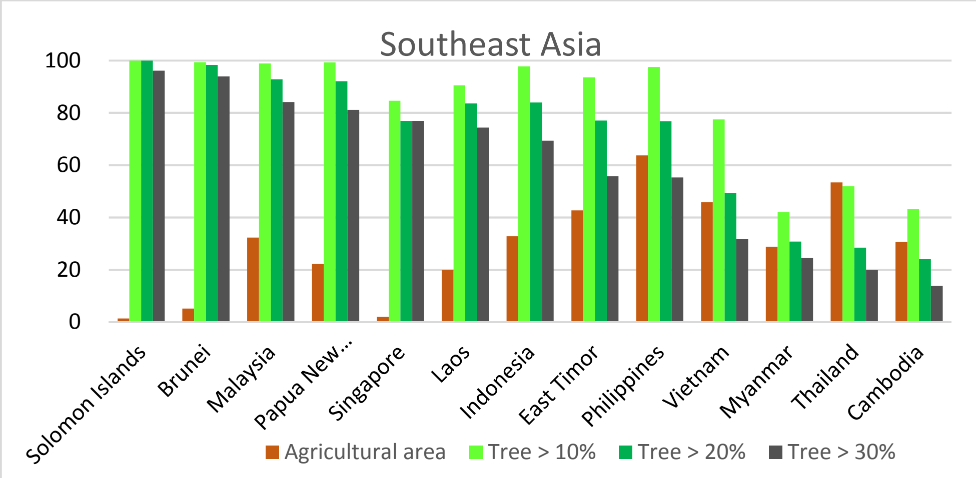

Figure 6.5 Agricultural land fraction and fractions of that with >10, >20 or >30% tree cover for countries in southeast Asia

Southeast Asia dominates tropical commodity production and trade in oil palm (Indonesia is in first place at 51% of global production in 2014, Malaysia is second at 34%, Thailand third at 3%, Papua New Guinea is sixth at 1%); rubber (Thailand in first place at 32%, Indonesia second at 22%, Viet Nam third at 7%, Malaysia sixth at 5%, Philippines seventh at 3%); and coconut (Philippines in first place at 32%, Indonesia second at 30%, Thailand fifth at 3%, Viet Nam sixth at 2% and Malaysia seventh at 2%); while being also relevant in coffee (Viet Nam in global second place at 16%, Indonesia fourth at 7%); cocoa (Indonesia globally third at 16%); and tea (Viet Nam sixth at 4%, Indonesia seventh at 3%).

Farmers tending a pepper garden in Southeast Sulawesi to improve rural livelihoods by raising on-farm productivity, encouraging better environmental management, and improving governance. The initial focus has been on South and Southeast Sulawesi, two provinces which suffer from high levels of poverty and still possess significant tracts of natural forest. So far, several thousand people have benefited from training sessions on marketing, establishing demonstration trials, participatory governance and development of land-use models. Photo: World Agroforestry/Yusuf Ahmad

The region has more than 200 million hectares of forested land, covering nearly half of its total land area. These forests contain some of the highest levels of biological diversity in the world. Indonesia's rainforests alone, while covering only 1% of the Earth's land area, contain 10% of the known plant species, 12% of mammal species (including endangered orangutans and critically endangered Sumatran tigers and rhinos) and 17% of bird species.

It is estimated that forest cover in the region is reduced by an average of almost 1.4 million hectares a year. The main drivers of this forest (and agroforest) loss are conversion to agriculture, with a continuing proliferation of monocultural rubber, oil palm[63], and pulp-and-paper plantations. As a result of land conversion and other factors, the region has lost almost 15% of its original forest cover over the past fifteen years, with some areas, including parts of Indonesia, projected to lose up to 98% of their forests by 2022.

Within this context, some agroforestry research has documented two pathways of 'swidden intensification': one focussed on crops that can grow with shorter or ultimately without fallows (but may still have trees between upland rice paddies[64]), another in which the fallow became agroforest and as such was prolonged[65,66]. Such agroforests[67,68] have been shown to reduce pressure on remaining forests[69]. They used to harbour as much tree diversity as secondary forests as long as the surrounding forest matrix and its 'seed rain' was intact (Chapter 2) but where the landscape crossed a 'diversity tipping point' they lost species, except those that were allowed to mature and reproduce in agroforests[70,71].

In response to the agricultural-intensification (or Borlaug) hypothesis, a deeper understanding has emerged of relative advantages for the combined targets of productivity and conservation in both segregated and integrated land-use arrangements[72]. Efforts to introduce more productive rubber clones into agroforest management practices proved to be remarkably complex[73].

Early work on quantifying the prevalence of *Imperata* grasslands in the region has shown that such symptoms of land degradation can be transient if tenure regimes allow smallholders to restore multifunctionality[24,74]. Smallholders' timber production has become an important component of agroforestry in the region[75,76,77].

Part of the regional fire incidents stem from land-right conflicts[78]; addressing such[79,80] conflicts at their roots goes a long way toward facilitating agroforestry-based, sustainable land use. In the case of tropical peatlands[81], however, the current range of tree species usable in 'paludiculture' is limited.

Two decades of research on incentive and reward systems that support environmental-service-friendly land uses has shown the relevance of co-investment[82,83] paradigms, rather than 'payments'.

Along with the high diversity of languages, ethnic identities and a complex historical pathway of political change, gender-based role differentiation varies within the region but is in many instances relevant for the ways agroforestry can contribute to transforming lives and landscapes[84]. The landscape case study of Chapter 9, Sumber Jaya in Indonesia, represents one of the main open-air social-ecological system laboratories where 'negotiation support' systems emerged in interactions between farmers, foresters, local government authorities and agroforestry researchers. In the Philippines, the Landcare[85,86] movement allowed forms of collective action and actively supported learning to emerge, partly in the specific post-land-reform era.

The region is rich in 'small islands', in which agroforestry has a specific meaning and contribution to make (Chapter 13). The region is, unfortunately, also a global leader in 'natural disasters' and the loss of ecological buffering that increases human impacts of extreme events (Chapter 14). In the region, climate resilience[87] has a specific meaning. Tropical deforestation and its various drivers at multiple scales have made the region a frontrunner in the climate-change policies aimed at reducing emissions from deforestation and forest degradation (REDD$^+$), with some progress in clarifying the solutions an agroforestry approach can bring[88,89,90,91]. From a focus on 'opportunity costs', the agroforestry agenda has transformed into one of supporting 'green growth'[92,93]. Long-term impacts of agroforestry research in the region can be seen in the high-level policy support for agroforestry that the *ASEAN Guidelines for Agroforestry Development* (Chapter 18).

6.5 East and Central Asia

The East and Central Asia region, covering 11.5% of global agricultural land, represents 8.5% and 5.3% of such land with at least 10% and 30% tree cover, respectively. It includes China with 8% and 5.1% of global agricultural land with >10 and >30%, respectively. Tree cover on agricultural land is generally low in East and very low in Central Asia. The size of China, however, masks the considerable variation in tree cover and agroforestry[94] within the country, which is highest in the wettest southern part, especially in Yunnan Province, where it coincides with high ethnic diversity and strong agroforestry traditions. Agroforestry in China includes the well-studied *Paulownia* and wheat systems in the north[95] and sacred forests[96].

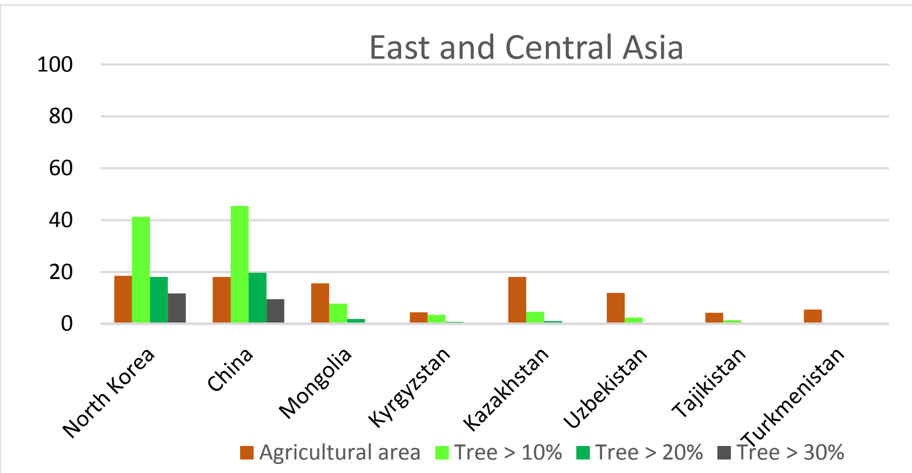

Figure 6.6 Agricultural land fraction and fractions of that with >10%, >20% or >30% tree cover for countries in East and Central Asia

East and Central Asia plays a modest role in tropical commodity production but China is the worlds' fifth-largest rubber producer (6% of global total), world's largest tea producer (38%) and is the centre of origin of tea (*Camellia sinensis*). Rubber expansion in the mountainous parts of Yunnan is causing problems[97] although a recent study of hydrological impacts showed that it matters what land cover rubber replaces and where in the landscape the conversion occurs[98]. Water flows from the higher mountains (including the cascading effects of a warming Himalaya[99]) are a major concern for land-cover management in Yunnan[100].

Since 1998, following the devastating impact of floods caused or exacerbated by deforestation, China has implemented a massive initiative to restore and conserve forests. The landscape case study of Chapter 10 represents the challenges and opportunities created at local level by the top–down Sloping Land Conversion Program, also known as 'grain to green'. China was one of the first countries in Asia to report an increase in forest cover, after decades of decline[101]. Such 'forest transition', however, masks qualitative changes in the type of tree cover that is included in 'forest' statistics. Government statistics indicate that China's programs have achieved significant success, with gains of 434,000 km^2 of forested land from 2000 to 2010. However, these figures hide the fact that the term 'forested land' is loosely defined, including both low-density monocultural plantations and areas of dense, high tree cover[102]. A large proportion of land classified as 'forested land' includes scattered, immature or stunted plantations often consisting of a single species or even single clones, which are unlikely to provide the same benefits as large areas of dense and tall forest[103]. If only land with tall, relatively dense tree cover is included[104] then the expansion of China's forests is much less impressive than that claimed by official statistics, increasing by only 33,000 km^2.

A remarkable agroforestry success has been reported from the Democratic People's Republic of Korea[105,106], where new ways of local food production alongside reforestation of sloping land emerged as an opportunity for local initiative in an otherwise strongly regulated landscape.

6.6 South Asia

The South Asia region, covering 9.3 % of global agricultural, represents 5.2% and 1.8% of such land with at least 10% and 30% tree cover, respectively (Figure 6.7). Relatively high tree cover is found in Bhutan, Sri Lanka, Nepal and Bangladesh. South Asia plays a modest role in tropical commodity production but India is the world's second-largest tea producer (24% of global total), third-largest coconut producer (22%), fourth-largest rubber producer (7%) and sixth-largest coffee producer (3%). Sri Lanka is the world's fourth-largest tea (7%) and fourth-largest (4%) coconut producer.

The eight countries of South Asia occupy no more than 4.5 million km^2 but are home to more than 1.6 billion people, more than a fifth of the global population, making South Asia one of the most densely populated regions. This population is growing at the alarming rate of 1.5–1.8% annually. Agriculture accounts for a quarter of the region's GDP and half of all jobs as well as providing industrial raw material for domestic consumption and export. In India, agriculture contributes just 15% to GDP but supports the livelihoods of over half of the population. Thus, the health and resilience of the region's ecosystems is vital for the region's social and economic well-being.

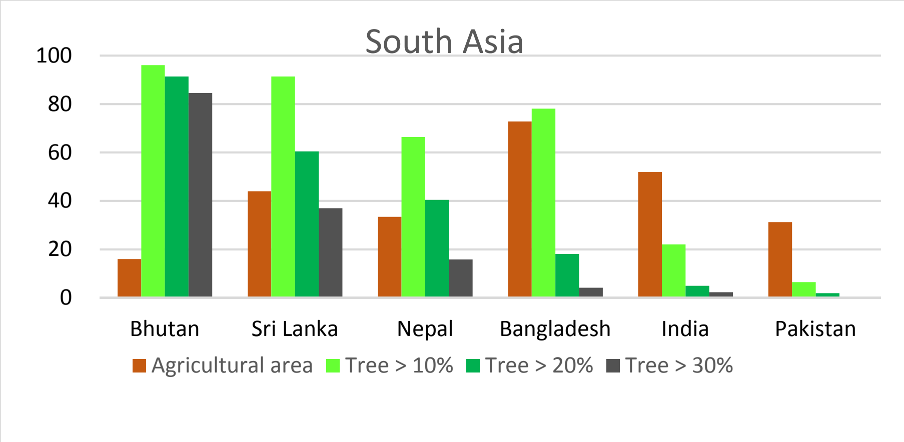

Figure 6.7 Agricultural land fraction and fractions of that with >10, >20 or >30% tree cover for countries in South Asia

The region includes four major agroecological environments:

- The mountainous regions of Afghanistan, Bangladesh, Bhutan, northeast India and Nepal
- The Indo-Gangetic Plains of Bangladesh, India, Nepal and Pakistan
- The humid coastal areas of Bangladesh, India, Maldives and Sri Lanka
- The semi-arid lands of India, Pakistan and Sri Lanka

The landscape case study of Chapter 11, Bundelkhand Jaya in India, represents the semi-arid lands where seasonal water shortages can, in part, be tackled by restoration of traditional water harvesting and retention techniques ('haveli'). The watershed rehabilitation program in the dry landscape around Jhansi (India) as initiated in 2012 in the Parasai-Sindh watershed inhabited by 3000 people in three villages covering 1246 ha. Co-investment of public funds with support of local community, scientific expertise and Government machinery in such a critical ecosystem had a substantial social welfare multipliers[107]. The program restored the traditional water reservoir structures, 'haveli' for recharging the groundwater, slowing the streamflow in check dams, thereby making water available for second growing season plus a year-round domestic water supply. For success of such endeavours, clear responsibilities and common understanding for resource management at landscape scale are key. For landscape management, the land-use rights in the area which is to be utilized for rainwater reservoir structure need proper care and handling, so that all stakeholders are engaged and see benefits of participation. With a water reservoir upstream, the downstream reservoirs benefit from less sediment deposition, but also face lower annual water yields. The community gained from the water availability as they could take two crops annually, and shift to the use of perennials, including fruit trees such as guava, citrus, and pomegranate as well as timber species. The landscape serves as an excellent opportunity to assess the working of National Agroforestry Policy of India, as the policy could serve as a basis to assign water use rights to trees in the restored sub catchment areas of such landscapes.

Since early 1990s, the Forest Survey of India (FSI) has been estimating the number of stems along with wood volume of Trees Outside Forest (TOF) at state and national level. FSI is reporting the information on National level estimates of growing stocks, both inside and outside the forest area in the biennial reports, India State of Forest Report (ISFR) since 2003. Although the agroforestry systems constitute an important component of TOF, information on available tree resources in agroforestry system has not been separately reported until 2013. The ISFR 2013,[108] reported 11.2 million ha area as total tree green cover under agroforestry system in the country, which is 3.39 per cent of the country's geographical area of 328.7 M ha. For this agroforestry estimation, only rural TOF inventory has been taken into consideration by FSI. The Central Agroforestry Research Institute (CAFRI), under the umbrella of Indian Council for Agricultural Research (ICAR) has mapped 16.6 million ha under agroforestry area in 2018[109], through GIS mapping that covered 208 M ha geographical area of the country. In the recent ISFR 2017[110], the growing stock of wood in the country is estimated to be 5 822 million m^3, which comprises of 1 604 million m^3 outside recorded forest (TOF). The annual production of timber from TOF for the year 2017, has been estimated to be 74.51 million m^3, an increase of 5.47 million m^3 as compared to updated estimates of ISFR 2011. Successful agroforestry practices, better conservation of forests, improvement of scrub areas to forest areas, increase in mangrove cover, conservation and protection activities have led to increase in the forest and tree cover by 8,021 km^2 as compared to assessment of 2015 (ISFR 2017). Moreover, by using agroforestry technologies developed by the research institutions, forest departments, non-governmental organizations (NGOs), National Wasteland Development Board (NWDB), and other developmental agencies in India have rehabilitated more than 1 million ha of salt-affected soils, particularly the village level community lands, areas along road side, canals, and railway tracts[111].

Throughout Asia home-gardens are a tradition[112,113], and though small in extent at individual level, collectively they occupy substantial area, as much as 36% of the arable land in Matara District of Sri Lanka, for example. Tropical homegardens cover about 8 million hectares in south and southeast Asia[114]. The homestead agroforestry in Bangladesh, Kandy homegardens in Sri Lanka, Kerala homegardens in India, and alnus-cardamom systems in Nepal and north eastern India are some of the examples of the classical homegardens. The main factors affecting the appearance, function, structure and composition of home gardens are environmental conditions, geographic location, socioeconomic and house hold needs, cash income opportunities and the cultural specificity.

In Bangladesh, majority of the agroforestry area is dominated by homestead agroforestry, which is the integrated production of crops, trees, and/or livestock in the household’s residence and its surrounding areas. It contributes about 70% fruit, 40% vegetable, 70% timber, and 90% firewood and bamboo requirement of the country[115]. Homestead agroforestry or home gardens combines all farming components and forms a highly intensive and multi-strata integrated production system depending on household needs, preferences and knowledge.

In Sri Lanka, home gardens are one of the oldest and major land use forms[116,117] that covered 858,100 ha in 1995, representing 13.1 per cent of the total land area of the country[118,119,120]. They are an integral part of the landscape and culture for centuries in the country. There are 196 fruit species recorded in Sri Lanka, and more than half of these species are recorded from

17 per cent of the home garden area of Kandy and adjacent districts, such as Badulla, Kegalle, Kurunegala, Matale, Nuwara Eliya and Rathnapura, which are defined and popularly known as Kandyan home gardens or Kandyan forest gardens[121]. This land use system that maintains, enhances and conserve the diverse crop genetic diversity, over time and space, and hence they can be regarded as a good practice for maintaining diversity[122]. Year-round production of a wide range of products required by householders, new business ventures through value addition, provision of many ecosystem services and easing pressure on natural forests have been identified as key elements of these Homegardens (or agroforests).

The Government of India formulated the National Agroforestry Policy[123] in 2014, to address the vulnerability in agriculture caused by climate change[124]. The policy recommends for setting up of a Mission or Board to address development of agroforestry sector in an organised manner. The Sub Mission on Agroforestry was formulated in 2016-17 under the National Mission for Sustainable Agriculture (NMSA) with a capital outlay of USD 450 million for 4 years (2016-17 to 2019-20)[125]. The policy has been an effective instrument in providing an overarching positive trend, an official home of agroforestry at the Ministry of Agriculture, and a negotiation platform for agroforestry produce in the country. The policy has been effective in relaxing the tree felling and transit regulations, de-regularization of saw mills opening, and inclusion of agroforestry in many of the central government agricultural schemes. As of 2018, 21 states, out of a total 29 states, had de-notified at least 20 tree species from felling and transit regulations. Further, there is relaxation of ban on setting up of new saw mills, especially in places having less than 5% forest area.

Intercropping of Napier grass in coconut-based agroforestry system in Tumkur, Karnataka, India. Photo: World Agroforestry/SK Dalal

Some of the significant successes which can be attributed to effective implementation of the agroforestry policy in India are: Establishment of the Central Agroforestry Research Institute

(CAFRI) by ICAR through upgradation of its National Research Centre for Agroforestry (NRCAF); inclusion of agroforestry in the eligible activities for CSR funding, and initiation of a dialogue through Finance Commission of India that Federal Government provides more funding to state having more green cover. The Indian policy has also created ripple effect in the region and has inspired Nepal to work with ICRAF on its own agroforestry policy. The Ministry of Agriculture and Livestock Development & the Ministry of Forest and Environment with ICRAF have completed the development of the Nepal agroforestry policy which is now due for approval by the Cabinet of Ministers of Nepal.

6.7 Latin America

The Latin America region, covering 20% of global agricultural land, represents 31.6% and 30.8% of such land with at least 10% and 30% tree cover, respectively. Brazil alone has 18.3% and 11.4% of global agricultural land with >10 and >30% tree cover, respectively. In Central America and the Caribbean, nearly all agricultural land has at least 10% tree cover (Figure 6.8).

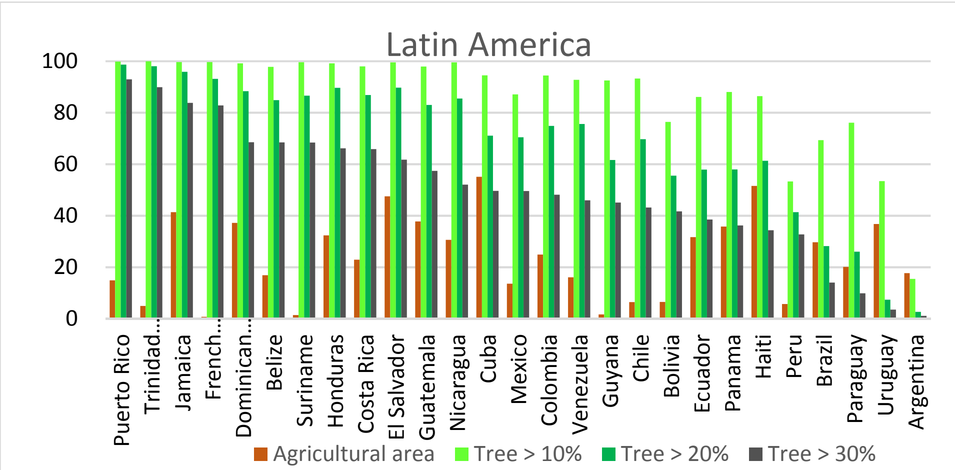

Figure 6.8 Agricultural land fraction and fractions of that with >10, >20 or >30% tree cover for countries in Central and South America

Latin American countries are major producers of several tree commodity crops: coffee (Brazil first in the world at 32%, Colombia third at 8%, Honduras seventh at 3%); cocoa (Brazil fourth at 6%, Ecuador seventh at 4%) avocado (Mexico first, Dominican Republic second, Peru third, Colombia fourth); and oil palm (Colombia fourth at 2%). The region is also the centre of origin of cocoa, avocado, rubber, cassava, and numerous globally cultivated agroforestry species (fruit, nut, timber and agroecological-service trees), thus, an important source of genetic diversity (including wild relatives).

Latin America is comprised of a wide range of ecoregions, including the Amazon rainforest and the Guyana shield; the Caatinga, the dry forests and shrublands of Northeast Brazil; the Mata Atlântica, or the Brazilian Atlantic Rainforest; the Cerrado, a vast woody savanna located to the south and east of the Amazon Basin; the Pantanal, a large wetland area forming the floodplain of the Rio Paraguay; the Chiquitano dry forests located in north-eastern Bolivia; and the Tropical Andes montane forests, Mesoamerica dry and tropical pine forests.

Agroforestry in Latin America began with the indigenous peoples that inhabited the region well before European conquest[126] and has since been taken up by other social actors, predominantly, family farmers and traditional communities of both indigenous and colonial origins. Common practices across ecoregions and social groups include tree fallows (improved or predominantly based on natural secondary succession processes) in slash-and-burn and swidden[127,128]; and trees and shrubs along boundaries, watercourses and contours in the Andes[129] and in the upper and low-lying floodplains; trees associated with both annual and permanent crops, including commodities such as cocoa[130] and coffee systems, silvopasture[131], and home gardens[132]. Use of both natural regeneration — particularly timber and shade species — stem coppicing, seed dispersal and planted trees is common as well as preservation of useful species[133] . The acronym SAF (from the Portuguese and Spanish words for 'agroforestry system') is widely used and usually means multi-storey systems. Agroforestry has assumed a prominent role in prevention, mitigation and reversal of land degradation as the region has taken on international initiatives (for example, the Bonn Challenge) to translate commitments into action (https://initiative20x20.org), and many national and sub-national governments have followed suit by establishing ambitious restoration targets.

In Brazil, successional or biodiverse agroforestry, usually combining short-cycle crops, fruits, fertilizer species and native trees, has become widely disseminated throughout its ecoregions. Research on agroforestry-based restoration has shown that such systems are the most suitable for reconciling environmental and social functions associated with restoration of conservation set-asides on all rural land (Permanent Preservation Areas and Legal Reserves)[134]. Key constraints to upscaling these relatively complex systems, which vary considerably according to local context, most commonly include access to knowledge (training and extension), labour, credit, markets, and germplasm[135] (Chapter 12).

World Agroforestry research in the region revolves around livelihoods, design and implementation of agroforestry practices tailored to local socio-ecological contexts in the framework of climate-change mitigation and adaptation, restoration and reforestation, biofuels and renewable energy, and tree functional diversity and its role in reducing vulnerability to climate change. Moreover, research has supported the development of restoration practices that further family farmers' productive objectives (Chapter 12) and has delved into cocoa[136,137], coffee[138] and oil-palm agroforestry[139], silvopastoral systems, and the contribution of local knowledge to smallholders' tree-based adaptation strategies. The Amazon, with its history of uncontrolled forest conversion and wealth of traditional communities, has long been the subject of research on agroforestry, its social and ecological benefits and key constraints to upscaling[140]. Farmer-based domestication of local timber species in the Peruvian Amazon has contributed to global understanding of how such processes work[141,142,143]. Cocoa-based agroforestry systems, oftentimes intercropped with native Amazon palms, fruits and timber species, are one example of an Amazon agroforestry option that can both improve livelihoods and produce deforestation-free commodities while restoring environmental functions. Restoration and conservation have become major themes of agroforestry policies and initiatives in the region.

In Brazil, the 2012 Forest Code laid out opportunities and incentives for farmers to perform mandatory restoration of privately-owned land using agroforestry systems, provided they maintained basic ecological functions (Chapter 12). A host of innovative rural credit and procurement policies favouring the adoption of agroforestry[144] may also serve as examples for other countries.

Similarly, in Peru, work on agroforestry concessions, a legal mechanism provided by the last forestry law of Peru approved in 2011, has shown promising results by mingling direct and indirect incentives. The scheme is considered crucial as it enables the granting of a 40-year, renewable lease to farmers who had encroached on public forestland, conditional to the commitment to conserve forest remnants, to maintain or establish sustainably managed agroforestry systems on 20% of the designated area, and to implement soil and water conservation measures. A recent study of the extent to which smallholders were participating in the scheme identified weaknesses in its current design and made recommendations for its improvement[145].

References

[1] Zomer RJ, Trabucco A, Coe R, Place F, van Noordwijk M, Xu J 2014. *Trees on farms: an update and reanalysis of agroforestry's global extent and socio-ecological characteristics.* Working Paper 179. Bogor, Indonesia: World Agroforestry Centre (ICRAF) Southeast Asia Regional Program.

[2] Zomer RJ, Neufeldt H, Xu J, Ahrends A, Bossio D, Trabucco A, van Noordwijk M, Wang M. 2016. Global tree cover and biomass carbon on agricultural land: the contribution of agroforestry to global and national carbon budgets. *Scientific Reports* 6:29987.

[3] Shi L, Feng W, Xu J, Kuzyakov Y. 2018. Agroforestry systems: meta-analysis of soil carbon stocks, sequestration processes, and future potentials. *Land Degradation Development* 29:3886–3897.

[4] Sida TS, Baudron F, Kim H, Giller KE. 2018. Climate-smart agroforestry: *Faidherbia albida* trees buffer wheat against climatic extremes in the Central Rift Valley of Ethiopia. *Agricultural and Forest Meteorology* 248:339–347.

[5] Dewi S, van Noordwijk M, Zulkarnain MT, Dwiputra A, Prabhu R, Hyman G, Gitz V, Nasi R. 2017. Tropical forest-transition landscapes: a portfolio for studying people, tree crops and agro-ecological change in context. *International Journal of Biodiversity Science, Ecosystem Services, and Management* 13(1):312–329.

[6] Fernandes EC, Oktingati A, Maghembe J. 1985. The Chagga homegardens: a multistoried agroforestry cropping system on Mt Kilimanjaro (Northern Tanzania). *Agroforestry Systems* 2(2):73–86.

[7] Jemal O, Callo-Concha D, van Noordwijk M. 2018. Local agroforestry practices for food and nutrition security of smallholder farm households in southwestern Ethiopia. *Sustainability* 0(8):2722.

[8] Mokria M, Gebrekirstos A, Abiyu A, van Noordwijk M, Bräuning A. 2017. Multi-century tree-ring precipitation record reveals increasing frequency of extreme dry events in the upper Blue Nile River catchment. *Global Change Biology* 23(12):5436–5454.

[9] Gebrehiwot SG, Ellison D, Bewket W, Seleshi Y, Inogwabini BI, Bishop K. 2019. The Nile Basin waters and the West African rainforest: rethinking the boundaries. *WIREs Water* 6:e1317.

[10] Van Noordwijk M, Namirembe S, Catacutan D, Williamson D, Gebrekirstos A. 2014. Pricing rainbow, green, blue and grey water: tree cover and geopolitics of climatic teleconnections. *Current Opinion in Environmental Sustainability* 6:41–47.

[11] Mpanda M, Munjuga M, Reyes T, Said A, Rutatina F, Kimaro A, van Noordwijk M. 2014. Allanblackia, butterflies and cardamom: sustaining livelihoods alongside biodiversity conservation on the forest-agroforestry interface in the East Usambara Mountains, Tanzania. *Trees Livelihoods* 23:127–142.

[12] Akinnifesi FK, Mng'omba SA, Sileshi G, Chilanga TG, Mhango J, Ajayi OC, Chakeredza S, Nyoka BI, Condwe MTF. 2009. Propagule type effects growth and fruiting of *Uapaca kirkiana* a priority indigenous fruit tree of Southern Africa. *Journal of Horticultural Science* 44:1662–1667.

[13] Njenga M, Karanja N, Munster C, Iiyama M, Neufeldt H, Kithinji J, Jamnadass R. 2013. Charcoal production and strategies to enhance its sustainability in Kenya. *Development in Practice* 23(3):359–371.

[14] Franzel S, Arimi H, Karanja J, Mureithi F. 1996. Boosting milk production and income for farm families: the adoption of *Calliandra calothyrsus* as a fodder tree in Embu District, Kenya. *East African Agricultural and Forestry Journal* 62(1–2):235–251.

[15] Roothaert RL, Franzel S. 2001. Farmers' preferences and use of local fodder trees and shrubs in Kenya. *Agroforest Systems* 52(3):239–252.

[16] Kiptot E, Franzel S, Hebinck P, Richards P. 2006. Sharing seed and knowledge: farmer to farmer dissemination of agroforestry technologies in western Kenya. *Agroforestry Systems* 68(3):167–179.

[17] Nyaga J, Barrios E, Muthuri CW, Öborn I, Matiru V, Sinclair FL. 2015. Evaluating factors influencing heterogeneity in agroforestry adoption and practices within smallholder farms in Rift Valley, Kenya. *Agriculture, Ecosystems and Environment* 212:106–118.

[18] Akinnifesi F, Ajayi O, Sileshi G, Chirwa P, Chianu J. 2010. Fertilizer tree systems for sustainable food security in the maize based production systems of East and Southern Africa Region: a review. *Agronomy for Sustainable Development* 30:615–629.

[19] Sileshi G, Akinnifesi FK, Ajayi OC, Place F. 2008. Meta-analysis of maize yield response to planted fallow and green manure legumes in sub-Saharan Africa. *Plant and Soil* 307:1–19.

[20] Sileshi G, Akinnifesi FK, Ajayi OC, Chakeredza S, Kaonga M, Matakala PW. 2007. Contributions of agroforestry to ecosystem services in the Miombo eco-region of eastern and southern Africa. *African Journal of Environmental Science and Technology* 1(4):68–80.

[21] Iiyama M, Mukuralinda A, Ndayambaje J, Musana B, Ndoli A, Mowo J, Garrity DP, Ling S, Ruganzu V. 2018. Tree-Based Ecosystem Approaches (TBEAs) as multi-functional land management strategies: evidence from Rwanda. *Sustainability* 10(5):1360.

[22] Swallow BM, Sang JK, Nyabenge M, Bundotich DK, Duraiappah AK, Yatich TB. 2009. Tradeoffs, synergies and traps among ecosystem services in the Lake Victoria basin of East Africa. *Environmental Science and Policy* 12(4):504–519.

[23] German LA, Mowo J, Amede T, Masuki K, eds. 2013. *Integrated natural resource management in the highlands of eastern Africa: from concept to practice*. London, UK: Earthscan; Ottawa, Canada: International Development Research Centre.

[24] Ajayi OC, Place F. 2012. Policy support for large-scale adoption of agroforestry practices: experience from Africa and Asia. in: Nair PKR and Garrity DP,Eds. *Agroforestry: The Future of Global Landuse*. Dordrecht, The Netherlands: Springer.

[25] Mowo J, Masuki K, Lyamchai C, Tanui J, Adimassu Z, Kamugisha R. 2016. By-laws formulation and enforcement in natural resource management: lessons from the highlands of eastern Africa. *Forests, Trees and Livelihoods* 25(2):120–131.

[26] Brandt M, Rasmussen K, Hiernaux P, Herrmann S, Tucker CJ, Tong X, Tian F, Mertz O, Kergoat L, Mbow C, David JL, Melocik KA, Dendoncker M, Vincke C, Fensholt R. 2018. Reduction of tree cover in West African woodlands and promotion in semi-arid farmlands. *Nature Geoscience* 328(11):328–333.

[27] Degrande A, Asaah E, Tchoundjeu Z, Kanmegne J, Duguma B, Franzel S. 2007. Opportunities for and constraints to adoption of improved fallows: ICRAF's experience in the humid tropics of Cameroon. In: Bationo A, Waswa B, Kihara J, Kimetu J, eds. *Advances in integrated soil fertility management in Sub-Saharan Africa: challenges and opportunities*. Dordrecht, The Netherlands: Springer. pp 901–910.

[28] Asaah EK, Tchoundjeu Z, Leakey RRB, Takousting B, Njong J, Edang I. 2011. Trees, agroforestry and multifunctional agriculture in Cameroon. *International Journal of Agricultural Sustainability* 9:110–119.

[29] Tchoundjeu Z, Degrande A, Leakey RRB, Simons AJ, Nimino G, Kemajou E, Asaah E, Facheux C, Mbile P, Mbosso C, Sado T, Tsobeng A. 2010. Impact of participatory tree domestication on farmer livelihoods in west and central Africa. *Forests, Trees and Livelihoods* 19(3):219–234.

[30] Ayuk ET, Duguma B, Franzel S, Kengue J, Mollet M, Tiki-Manga T, Zenkeng P. 1999. Uses, management and economic potentials of *Garcinia kola* and *Ricinodendron heudelotii* in the humid lowlands of Cameroon. *Journal of Tropical Forest Science* 11(4):746–761.

[31] Degrande A, Schreckenberg K, Mbosso C, Anegbeh PO, Okafor J, Kanmegne J. 2006. Farmers' fruit tree growing strategies in the humid forest zone of Cameroon and Nigeria. *Agroforestry Systems* 67:159–175.

[32] Degrande A, Gyau A, Foundjem-Tita D, Tollens E. 2014. Improving smallholders' participation in tree product value chains: experiences from the Congo Basin. *Forests, Trees and Livelihoods* 23:102–115.

[33] Foundjem-Tita D, Degrande A, D'Haese M, van Damme P, Tchoundjeu Z, Gyau A, Facheux C, Mbosso C. 2012a. Building long-term relationships between producers and trader groups in the non-timber forest product sector in Cameroon. *African Journal of Agricultural Research* 7:230–239.

[34] Foundjem-Tita D, d'Haese M, Degrande A, Tchoundjeu Z, van Damme P. 2011. Farmers' satisfaction with group market arrangements as a measure of group market performance: a transaction cost analysis of non-timber forest products' producer groups in Cameroon. *Forestry Policy and Economics* 13:545–553.

[35] Degrande A, Franzel S, Yeptiep YS, Asaah E, Tsobeng A, Tchoundjeu Z. 2012. Effectiveness of grassroots organisations in the dissemination of agroforestry innovations. In: Kaonga ML, ed. *Agroforestry for biodiversity and ecosystem services: science and practice*. London, UK: Elsevier.

[36] Mbosso C, Degrande A, Villamor GB, van Damme P, Tchoundjeu Z, Tsafack S. 2015. Factors affecting the adoption of agricultural innovation: the case of *Ricinodendron heudelotii* kernel extraction machine in southern Cameroon. *Agroforestry Systems* 89:799–811.

[37] Atangana AR, van der Vlis E, Khasa DP, van Houten D, Beaulieu J, Hendrickx H. 2011. Tree-to-tree variation in stearic and oleic acid content in seed fat from *Allanblackia floribunda* from wild stands: potential for tree breeding. *Food Chemistry* 126:1579–1585.

[38] Jamnadass R, Dawson IK, Anegbeh P, Asaah E, Atangana A, Cordeiro NJ, Hendrickx H, Henneh S, Kadu CAC, Kattah C, Misbah M, Muchugi A, Munjuga M, Mwaura L, Ndangalasi HJ, Njau CS, Nyame SK, Ofori D, Peprah T, Russell J, Rutatina F, Sawe C, Schmidt L, Tchoundjeu Z, Simons T. 2010. Allanblackia, a new tree crop in Africa for the global food industry: market development, smallholder cultivation and biodiversity management. *Forests, Trees and Livelihoods* 19(3):251–268.

[39] Yatich T, Kalinganire A, Weber JC, Alinon K, Dakouo JM, Samaké O, Sangaré S. 2012. *How do forestry codes affect access, use and management of protected indigenous tree species: evidence from West African Sahel*. Occasional Paper no. 15. Nairobi, Kenya: World Agroforestry Centre (ICRAF).

[40] Foundjem-Tita D, Tchoundjeu Z, Speelman S, D'Haese M, Degrande A, Asaah E, van Huylenbroeck G, van Damme P, Ndoye O. 2012b. Policy and legal frameworks governing trees: incentives or disincentives for smallholder tree planting decisions in Cameroon? *Small-scale forestry* 12:489–505. https ://doi.org/10.1007/s1184 2-012-9225-z

[41] Minang P, Duguma L, Bernard F, Foundjem-Tita D, Tchoundjeu Z. 2019. Evolution of community forestry in Cameroon: an innovation ecosystems perspective. *Ecology and Society* 24(1).

[42] Piabuo S, Foundjem-Tita D, Minang P. 2018. Community forest governance in Cameroon: a review. *Ecology and Society* 23(3).

[43] Bernard F, Minang P. 2019. Community forestry and REDD+ in Cameroon: what future? *Ecology and Society* 24(1).

[44] Ngum F, Alemagi D, Duguma L, Minang PA, Kehbila A, Tchoundjeu Z. 2019. Synergizing climate change mitigation and adaptation in Cameroon: an overview of multi-stakeholder efforts. *International Journal of Climate Change Strategies and Management* 11(1):118–136.

[45] Agbo AE, Kouamé C, N'Doua ND, Kouassi A, Brou K. 2017. Assessment of cocoa producers' children nutritional status in the Nawa Region, Cote d'Ivoire. *Journal of Food and Nutrition Research* 5(8):606–613.

[46] De Vries K, Mc Clafferty B, van Dorp M. 2012. *Increasing cocoa productivity through improved nutrition: a call to action.* Concept Brief. Wageningen, The Netherlands: Global Alliance for Improved Nutrition, Wageningen University.

[47] Greenberg G, Root C. 2016. *African Cocoa Initiative final performance evaluation report*. Washington DC, USA: United States Agency for International Development. https://pdf.usaid.gov/pdf_docs/pa00m2gp.pdf.

[48] Schroth G, Läderach P, Martinez-Valle A, Bunn C, Jassogne L. 2016. Vulnerability to climate change of cocoa in West Africa: patterns, opportunities and limits to adaptation. *Science of the Total Environment* 556:231–241.

[49] Sanou H, Kambou S, Teklehaimanot Z, Dembélé M, Yossi H, Sina S, Djingdia L, Bouvet JM. 2004. Vegetative propagation of *Vitellaria paradoxa* by grafting. *Agroforest Systems* 60:93–99.

[50] Teklehaimanot Z. 2004. Exploiting the potential of indigenous agroforestry trees: *Parkia biglobosa* and *Vitellaria paradoxa* in sub-Saharan Africa. *Agroforest Systems* 61:207–220.

[51] Boffa J-M. 1999. *Agroforestry parklands in Sub-Saharan Africa*. FAO Conservation Guide. Rome, Italy: Food and Agriculture Organization of the United Nations.

[52] Bayala J, Sanou J, Teklehaimanot Z, Ouedraogo SJ, Kalinganire A, van Noordwijk M. 2015. Advances in knowledge of processes in soil–tree–crop interactions in parkland systems in the West African Sahel: a review. *Agriculture, Ecosystems and Environment* 205:25–35.

[53] Garrity DP, Akinnifesi FK, Ajayi OC, Weldesemayat SG, Mowo JG, Kalinganire A, Larwanou M, Bayala J. 2010. Evergreen Agriculture: a robust approach to sustainable food security in Africa. *Food Security* 2(3):197–214.

[54] Reij C, Garrity DP. 2016. Scaling up farmer-managed natural regeneration in Africa to restore degraded landscapes. *Biotropica* 48(6):834–843.

[55] Kalinganire A, Weber JC, Coulibaly S. 2012. Improved *Ziziphus mauritiana* germplasm for Sahelian smallholder farmers: first steps toward a domestication programme. *Forests, Trees and Livelihoods* 21:128–137.

[56] Sotelo Montes C, Silva DA, Garcia RA, Muñiz GIB, Weber JC. 2011. Calorific value of *Prosopis africana* and *Balanites aegyptiaca* wood: relationships with tree growth, wood density and rainfall gradients in the West African Sahel. *Biomass Bioenergy* 35:346–353.

[57] Degrande A, Franzel S, Yeptiet Y, Asaah E, Tsobeng A, Tchoundjeu Z. 2012. Effectiveness of grassroots organisations in the dissemination of agroforestry innovations. In Kaonga M, ed*. Agroforestry for biodiversity and ecosystem services: science and practice*. London, UK: InTechOpen.

[58] Binam JN, Place F, Djalal AA, Kalinganire A. 2017. Effects of local institutions on the adoption of agroforestry innovations: evidence of farmer managed natural regeneration and its implications for rural livelihoods in the Sahel. *Agricultural and Food Economics* 5:2.

[59] Binam JN, Place F, Kalinganire A, Sigue H, Boureima M, Tougiani A, Dakouo J, Mounkoro B, Sanogo D, Badji M, Diop M, Bationo BA, Haglund E. 2015. Effects of farmer managed natural regeneration on livelihoods in semi-arid West Africa. *Environmental Economics and Policy Studies* 17(4):543–575.

[60] Kalinganire A, Weber JC, Uwamariya A, Kone B. 2008. Improving rural livelihoods through domestication of indigenous fruit trees in parklands of the Sahel. In: Akinnifesi FK, Leakey RRB, Ajayi OC, Sileshi G, Tchoundjeu Z, Matakala P, Kwesiga FR, eds. *Indigenous fruit trees in the tropics: domestication, utilization and commercialization*. Wallingford, UK: CAB International.

[61] Kouame C, Bene Y, Toure E, Berthe B, Kouassi A, Diomande S, Tchoundjeu Z. 2016. *Restoring Cote d'Ivoire cocoa orchards.* Technical Brief Series 1. Nairobi, Kenya: World Agroforestry Centre (ICRAF).

[62] Tchoundjeu Z, Degrande A, Leakey RRB, Nimino G, Kemajou E, Asaah E, Facheux C, Mbile P, Mbosso C, Sado T, Tsobeng A. 2010. Impacts of participatory tree domestication on farmer livelihoods in West and Central Africa. *Forests, Trees and Livelihoods* 19(3):217–234.

[63] Van Noordwijk M, Pacheco P, Slingerland M, Dewi S, Khasanah N 2017. *Palm oil expansion in tropical forest margins or sustainability of production? Focal issues of regulations and private standards.* Working Paper 247. Bogor, Indonesia: World Agroforestry Centre (ICRAF) Southeast Asia Regional Program.

[64] Wangpakapattanawong P, Finlayson R, Öborn I, Roshetko JM, Sinclair FL, Shono K, Borelli S, Hillbrand A, Conigliaro M. 2017. *Agroforestry in rice-production landscapes in Southeast Asia: a practical manual*. Bangkok, Thailand: FAO Regional Office for Asia and the Pacific; Bogor, Indonesia: World Agroforestry Centre (ICRAF) Southeast Asia Regional Program.

[65] Van Noordwijk M, Mulyoutami E, Sakuntaladewi N, Agus F. 2008. *Swiddens in transition: shifted perceptions on shifting cultivators in Indonesia.* Bogor, Indonesia: World Agroforestry Centre (ICRAF) Southeast Asia Regional Program.

[66] Van Noordwijk M, Bizard V, Wangkapattanawong P, Tata HL, Villamor GB, Leimona B. 2014. Tree cover transitions and food security in Southeast Asia. *Global Food Security* 3:200–208.

[67] Michon G, Mary F, Bompard J. 1986. Multistoried agroforestry garden system in West Sumatra, Indonesia. *Agroforestry Systems* 4(4):315–338.

[68] Gouyon A, de Foresta H, Levang P. 1993. Does 'jungle rubber' deserve its name? An analysis of rubber agroforestry systems in southeast Sumatra. *Agroforestry Systems* 22(3):181–206.

[69] Murniati, Garrity DP, Gintings AN. 2001. The contribution of agroforestry systems to reducing farmers' dependence on the resources of adjacent national parks: a case study from Sumatra, Indonesia. *Agroforestry Systems* 52(3):171–184.

[70] Tata HL, van Noordwijk M, Rasnovi S, Werger MJA. 2009. *Forests as provider of tree diversity in rubber agroforest in lowland Sumatra*. Paper presented at the XIII World Forestry Congress, Buenos Aires, Argentina, 18–23 October 2009. Rome, Italy: Food and Agriculture Organization of the United Nations.

[71] Michon G. 2005. *Domesticating forests: how farmers manage forest resources*. Marseille, France: Institut de Recherche pour le Développement; Bogor, Indonesia: World Agroforestry Centre (ICRAF) Southeast Asia Regional Program; Center for International Forestry Research (CIFOR).

[72] Van Noordwijk M, Tata HL, Xu J, Dewi S, Minang PA. 2012. Segregate or integrate for multifunctionality and sustained change through rubber-based agroforestry in Indonesia and China. In: Nair NPR, Garrity D. *Agroforestry: the future of global land use*. Dordrecht, The Netherlands: Springer.

[73] Williams SE, van Noordwijk M, Penot E, Healey JR, Sinclair FL, Wibawa G, Nilsson SI. 2001. On-farm evaluation of the establishment of clonal rubber in multistrata agroforests in Jambi, Indonesia. *Agroforestry Systems* 53:227–237.

[74] Garrity DP, Soekardi M, van Noordwijk M, de La Cruz R, Pathak PS, Gunasena HPM, Van So N, Huijun G, Majid NM. 1996. The Imperata grasslands of tropical Asia: area, distribution, and typology. *Agroforestry Systems* 36:3–29.

[75] Bertomeu M. 2012. Growth and yield of maize and timber trees in smallholder agroforestry systems in Claveria, northern Mindanao, Philippines. *Agroforestry Systems* 84:73–87.

[76] Rohadi D, Roshetko JM, Perdana A, Blyth M, Nuryartono N, Kusumowardani N, Pramono AA, Widyani N, Fauzi A, Sasono J, Sumardamto P. 2012. *Improving economic outcomes for smallholders growing teak in agroforestry systems in Indonesia*. Canberra, Australia: Australian Centre for International Agricultural Research.

[77] Khasanah N, Perdana A, Rahmanullah A, Manurung G, Roshetko J, van Noordwijk M. 2015. Intercropping teak (*Tectona grandis*) and maize (*Zea mays*): bioeconomic trade-off analysis of agroforestry management practices in Gunungkidul, West Java. *Agroforestry Systems* 89:1019–1033.

[78] Tomich TP, Fagi AM, de Foresta H, Michon G, Murdiyarso D, Stolle F, van Noordwijk M. 1998. Indonesia's fires: smoke as a problem, smoke as a symptom. *Agroforestry Today* 10(1):4–7.

[79] Suyanto S, Permana RP, Khususiyah N, Joshi L. 2005. Land tenure, agroforestry adoption, and reduction of fire hazard in a forest zone: A case study from Lampung, Sumatra, Indonesia. *Agroforestry Systems* 65(1):1–11.

[80] Galudra G, van Noordwijk M, Suyanto S, Sardi I, Pradhan U, Catacutan D. 2011. Hot spots of confusion: contested policies and competing carbon claims in the peatlands of Central Kalimantan (Indonesia). *International Forestry Review* 13:431–441.

[81] Van Noordwijk M, Matthews RB, Agus F, Farmer J, Verchot L, Hergoualc'h K, Persch S, Tata HL, Lusiana B, Widayati A, Dewi S, Dewi S. 2014. Mud, muddle and models in the knowledge value- chain to action on tropical peatland issues. *Mitigation and Adaptation Strategies for Global Change* 19:863–885.

[82] Van Noordwijk M, Leimona B. 2010. Principles for fairness and efficiency in enhancing environmental services in Asia: payments, compensation, or co-investment? *Ecology and Society* 15(4):17.

[83] Van Noordwijk M, Leimona B, Jindal R, Villamor GB, Vardhan M, Namirembe S, Catacutan D, Kerr J, Minang PA, Tomich TP. 2012. Payments for environmental services: evolution towards efficient and fair incentives for multifunctional landscapes. *Annual Review of Environmental Resources* 37:389–420.

[84] Catacutan D, Naz F. 2015. Gender roles, decision-making and challenges to agroforestry adoption in Northwest Vietnam. *International Forestry Review* 17(4):22–32.

[85] Garrity DP, Amoroso VB, Koffa S, Catacutan D, Buenavista G, Fay CP, Dar W. 2002. Landcare on the poverty–protection interface in an Asian watershed. *Conservation Ecology* 6(1).

[86] Catacutan D, Bertomeu M, Arbes L, Duque C, Butra N. 2008. Fluctuating fortunes of a collective enterprise: the case of the Agroforestry Tree Seeds Association of Lantapan (ATSAL) in the Philippines. *Small-Scale Forestry* 7(3–4):353–368.

[87] Nguyen Q, Hoang MH, Öborn I, van Noordwijk M. 2013. Multipurpose agroforestry as a climate change resiliency option for farmers: an example of local adaptation in Vietnam. *Climatic Change* 117:241–257.

[88] Hoang MH, Do TH, Pham MT, van Noordwijk M, Minang PA. 2013. Benefit distribution across scales to reduce emissions from deforestation and forest degradation (REDD+) in Vietnam. *Land Use Policy* 31:48–60.

[89] Agung P, Galudra G, van Noordwijk M, Maryani R. 2014. Reform or reversal: the impact of REDD+ readiness on forest governance in Indonesia. *Climate Policy* 14:748–768.

[90] Minang PA, van Noordwijk M. 2013. Design challenges for achieving reduced emissions from deforestation and forest degradation through conservation: leveraging multiple paradigms at the tropical forest margins. *Land Use Policy* 31:61–70.

[91] van Noordwijk M, Agus F, Dewi S, Purnomo H. 2014. Reducing emissions from land use in Indonesia: motivation, policy instruments and expected funding streams. *Mitigation and Adaptation Strategies* for *Global Change* 19:677–692.

[92] Leimona B, van Noordwijk M, Mithöfer D, Cerutti PO. 2018. Environmentally and socially responsible global production and trade of timber and tree crop commodities: certification as a transient issue-attention cycle response to ecological and social issues. *International Journal of Biodiversity Science, Ecosystem Services and Management* 13:497–502.

[93] Amaruzaman S, Leimona B, van Noordwijk M, Lusiana B. 2017. Discourses on the performance gap of agriculture in a green economy: a Q-methodology study in Indonesia. *International Journal of Biodiversity Science, Ecosystem Services and Management* 13(1):233–247.

[94] Zou X, Sanford RL. 1990. Agroforestry systems in China: a survey and classification. *Agroforestry Systems* 11:85–94.

[95] Yin R, He Q. 1997. The spatial and temporal effects of paulownia intercropping: the case of northern China. *Agroforestry Systems* 37:91–109.

[96] Xu J, Ma ET, Tashi D, Fu Y, Lu Z, Melick D. 2005. Integrating sacred knowledge for conservation: cultures and landscapes in southwest China. *Ecology and Society* 10(2).

[97] Ziegler AD, Fox JM, Xu J. 2009. The rubber juggernaut. *Science* 324(5930):1024–1025.

[98] Ma X, Lacombe GC, Harrison P, Xu J, van Noordwijk M. 2019. Expanding rubber plantations in Southern China: evidence for hydrological impacts. *Water* 11:651.

[99] Xu J, Grumbine RE, Shrestha A, Eriksson M, Yang X, Wang YUN, Wilkes A. 2009. The melting Himalayas: cascading effects of climate change on water, biodiversity, and livelihoods. *Conservation Biology* 23:520–530.

[100] Ma X, Xu J, van Noordwijk M. 2010. Sensitivity of streamflow from a Himalayan catchment to plausible changes in land cover and climate. *Hydrological Processes* 24(11):1379–1390.

[101] Xu J, Yang Y, Fox J, Yang X. 2007. Forest transition, its causes and environmental consequences: empirical evidence from Yunnan of Southwest China. *Tropical Ecology* 48(2):137.

[102] Hua F, Xu J, Wilcove DS. 2018. A new opportunity to recover native forests in China. *Conservation Letters* 11(2):e12396.

[103] Xu J. 2011. China's new forests aren't as green as they seem. *Nature News* 477(7365):371.

[104] Ahrends A, Hollingsworth PM, Beckschäfer P, Chen H, Zomer RJ, Zhang L, Wang M, Xu J. 2017. China's fight to halt tree cover loss. *Proceedings of the Royal Society B: Biological Sciences* 284(1854):20162559.

[105] Xu J, van Noordwijk M, He J, Kim KJ, Jo RS, Pak KG, Kye UH, Kim JS, Kim KM, Sim YN, Pak JU. 2012. Participatory agroforestry development for restoring degraded sloping land in DPR Korea. *Agroforestry Systems* 85:291–303.

[106] He J, Xu J. 2017. Is there decentralization in North Korea? Evidence and lessons from the sloping land management program 2004–2014. *Land Use Policy* 61:113–125.

[107] Singh R, van Noordwijk M, Chaturvedi OP, Garg KK, Dev I, Wani SP, Rizvi J. 2017. Public co-investment in groundwater recharge in Bundelkhand, Uttar Pradesh, India. In: Namirembe S, Leimona B, van Noordwijk M, Minang P, eds. C*o –investment in ecosystem services: global lessons from payment and incentive schemes*. Nairobi, Kenya: World Agroforestry Centre (ICRAF)

[108] Forest Survey of India. 2013. *Chapter 7: Trees in agroforestry systems in India. India State of Forest Report*. Ministry of Environment and Forest, Government of India.

[109] Newaj R, Rizvi RH, Prasad R, Handa AK, Dhiraj K, Chavan, Alam SB, Bhaskar S, Prabhakar M. 2018. *Agroforestry in Mitigation of Climate Change: Current Status*. Technical Brief-1/2018. Jhansi, India: ICAR-CAFRI.

[110] Forest Survey of India. 2017.*India State of Forest Report*. , Ministry of Environment and Forest, Government of India. 396p

[111] Puri S, Nair PKR. 2004. Agroforestry research for development in India: 25 years of experiences of a national program. *Agrofor Syst* 61:437–452

[112] Das T, Das AK. 2005. Inventorying plant biodiversity in homegardens: A case study in Barak Valley, Assam, North East India. *Current Science* 89*:* 155-163.

[113] Kumar BM, Nair PKR. 2004. The enigma of tropical homegardens. *Agroforestry Syst*, *61*(1-3):135-152.

[114] Kumar BM. 2006). Carbon sequestration potential of tropical homegardens. In: Kumar BM, Nair PKR, eds. *Tropical homegardens: A time-tested example of sustainable agroforestry.* Dordrecht, The Netherlands: Springer.

[115] Miah MG, Hussain MJ. 2010. Homestead Agroforestry: a Potential Resource in Bangladesh. In: Lichtfouse E, ed. *Sociology, Organic Farming, Climate Change and Soil Science*. Sustainable Agriculture Reviews, vol 3. Dordrecht, The Netherlands: Springer.

[116] Mahawamsa. 2007. The Great Chronicle of the History of Sri Lanka. www.mahawamsa.org.

[117] De Silva KM. 1981. *A History of Sri Lanka*. London, UK: C. Hurst & Company

[118] Forestry Planning Unit, Forest Department. 1995. Forestry Sector Master Plan (Sri Lanka). Colombo, Sri Lanka: Ministry of Agriculture, Lands and Forestry

[119] MFE. 1999. *Biodiversity Conservation in Sri Lanka: A Framework for Action*. Battaramulla, Sri Lanka: Ministry of Forestry and Environment

[120] Pushpakumara DKNG, Wijesekara A, Hunter DG. 2010. Kandyan home gardens: A promising land management system in Sri Lanka', in: C. Belair, K. Ichikawa, BYL. Wong, KJ. Mulongoy, eds. *Sustainable Use of Biological Diversity in Socio-ecological Production Landscapes: Background to the 'Satoyama Initiative for the Benefit of Biodiversity and Human Well-being*. Technical Series no 52. Montreal, Canada: Secretariat of the Convention on Biological Diversity

[121] Jacob VJ, Alles WS. 1987. The Kandyan gardens of Sri Lanka, *Agroforestry Systems* 5: 123–137

[122] Pushpakumara DKNG, Heenkenda HMS, Marambe B, Ranil RHG, Punyawardena BVR, Weerahewa J, Silva GLLP, Hunter D, Rizvi J. 2016. Kandyan home gardens: a time-tested good practice from Sri Lanka for conserving tropical fruit tree diversity. In: Bhuwon Sthapit, Hugo AH Lamers, V Ramanatha Rao and Arwen Bailey, eds. *Tropical fruit tree biodiversity: good practices for in situ and on-farm conservation*. Routledge, New York: EarthScan.

[123] Department of Agriculture Cooperation and Farmers Welfare (DAC&FW), Ministry of Agriculture and Farmers' Welfare (MoA&FW), Government of India, Delhi. 2014. *National Agroforestry Policy*.

[124] Singh VP, Sinha RB, Nayak D, Neufeldt H, Van Noordwijk M, Rizvi J. 2016. *The national agroforestry policy of India: experiential learning in development and delivery phases*. Working paper 240. Nairobi, Kenya: World Agroforestry Centre (ICRAF).

[125] Sub-Mission on Agroforestry (SMAF). 2016. *Operational Guidelines Under National Mission for Sustainable Agriculture (NMSA)*. Department of Agriculture, Cooperation and Farmers Welfare (DAC&FW), Ministry of Agriculture and Farmers Welfare, Government of India. 30p

[126] Miller RP, Nair PKR. Indigenous agroforestry systems in Amazonia: from prehistory to today. *Agroforestry Systems* 66(2):151.

[127] Cotta JN. 2017. Revisiting bora fallow agroforestry in the Peruvian Amazon: enriching ethnobotanical appraisals of non-timber products through household income quantification. *Agroforestry Systems* 9:17–36.

[128] Coomes OT, Barham BL. 1997. Rain forest extraction and conservation in Amazonia. *Geographical Journal* 163:180–188.

[129] Mathez-Stiefel SL. 2016. *Agroforestería para la adaptación al cambio climático En Los Andes: aprendiendo de los conocimientos locales*. Policy Brief 36. Lima, Peru: World Agroforestry Centre (ICRAF).

[130] Somarriba E, Suárez-Islas A, Calero-Borge W, Villota A, Castillo C, Vílchez S, Deheuvels O, Cerda R. 2014. Cocoa–timber agroforestry systems: *Theobroma cacao–Cordia alliodora* in Central America. *Agroforestry Systems* 88(6):1001–1019.

[131] Montagnini F, Ibrahim M, Murgueitio E. 2013. Silvopastoral Systems and Climate Change Mitigation in Latin America. *Bois et Forets des Tropiques* 67(316):3–16.

[132] Padoch C, de Jong W. 1991. The House Gardens of Santa Rosa: diversity and variability in an Amazonian agricultural system. *Economic Botany* 45(2): 166–75.

[133] Padoch C, Pinedo-Vasquez M. 2006. Concurrent activities and invisible technologies: an example of timber management in Amazonia. In: Posey DA, Balick MJ, eds. *Human impacts on the Amazon: the role of traditional ecological knowledge in conservation and development.* New York City NY, USA: Columbia University Press.

[134] Miccolis A, Peneireiro FM, Marques HR, Vieira DM, Arco-Verde MF, Hoffmann MR, Rehder T, Pereira AVB. 2016. *Restauração ecológica com sistemas agroflorestais: como conciliar conservação com produção: opções para Cerrado e Caatinga*. Brasilia, Brazil: World Agroforestry Centre (ICRAF).

[135] Miccolis A, Peneireiro F, Vieira D, Marques HR, Hoffmann M. 2017. Restoration through agroforestry: options for reconciling livelihoods with conservation in the Cerrado and Caatinga Biomes in Brazil. *Experimental Agriculture* 1:18. https://doi.org/10.1017/S0014479717000138.

[136] Deheuvels O, Saj S, Xavier-Rousseau G, Valverde J, Robiglio V. 2017. *Cocoa-based agroforestry vs fallow: what option for soil quality regeneration in the Peruvian Amazon?* Booklet of abstracts of the first International Symposium on Cocoa Research ISCR 2017: Promoting Advances in Research to Enhance the Profitability of Cocoa Farming. Lima, Peru, 13 November 2017. Lima, Peru: International Cocoa Organization.

[137] Somarriba E, *Orozco*-Aguilar L, Cerda R, López-Sampson A. 2018. Analysis and design of the shade canopy of cocoa-based agroforestry systems. In: Umaharan P, ed. *Achieving sustainable cultivation of cocoa*.Cambridge, UK: Burleigh Dodds Science Publishing.

[138] Robiglio V, Baca MG, Donovan J, Bunn C, Reyes M, Gonzáles D, Sánchez C. 2017*. Impacto del cambio climático sobre la cadena de valor del café en el Perú*. CCAFS report. Wageningen, The Netherlands: CGIAR Research Program on Climate Change, Agriculture and Food Security.

[139] Miccolis A, Robiglio V, Cornelius JP, Blare T, Castellani D. 2019. Oil palm agroforestry: fostering socially inclusive and sustainable production in Brazil. In: Jezeer R, Pasiecznik N, eds. *Exploring inclusive palm oil production.* EFTERN News 59. http://www.etfrn.org/publications/exploring+inclusive+palm+oil+production

[140] Porro R, Serrão A, Cornelius JP. 2005. The Amazon Initiative: a multidisciplinary, international consortium for prevention, mitigation and reduction of resource degradation. *The Forestry Chronicle* 81: 337–341.

[141] Sotelo Montes C, Hernández RE, Beaulieu J, Weber JC. 2008. Genetic variation in wood color and its correlations with tree growth and wood density of *Calycophyllum spruceanum* at an early age in the Peruvian Amazon. *New Forests* 35:57–73.

[142] Cornelius JP, Mesén F, Ohashi ST, Leão N, Silva CE, Ugarte-Guerra J, Wightman KE. 2010. Smallholder production of agroforestry germplasm: experiences and lessons from Brazil, Costa Rica, Mexico and Peru. *Forests, Trees and Livelihoods* 19: 201–216.

[143] Cornelius JP, Pinedo-Ramírez R, Sotelo Montes C, Ugarte-Guerra LJ, Weber JC. 2018. Efficiency of early selection in *Calycophyllum spruceanum* and *Guazuma crinita*, two fast-growing timber species of the Peruvian Amazon. *Canadian Journal of Forest Research 48*:517–523.

[144] Porro R, Miccolis A. 2011. *Políticas públicas para o desenvolvimento agroflorestal no Brasil*. Belém PA, Brazil: World Agroforestry Centre (ICRAF). http://www.fao.org/forestry/36079-020ee9893d541ea176f0df22301c7ef99.pdf.

[145] Robiglio V, Reyes M. 2016. Restoration through formalization? Assessing the potential of Peru's Agroforestry Concessions scheme to contribute to restoration in agricultural frontiers in the Amazon region. *World Development Perspectives* 3:42–46.