Agroforestry Network
FOUNDED BY VI-SKOGEN

SCALING UP AGROFORESTRY

Potential, Challenges and Barriers

A review of environmental, social and economic aspects at the farmer, community and landscape levels

Loransi Mukarutagwenda and Domitila Mukanyirigira from Gasabo District, Rwanda are members in a farmers' cooperative. Together with the other members they run a tree nursery. They are preparing seedlings to be planted on their neighbours´ farms. Loransi and Domitila are two of many farmers that have been trained in agroforestry around Lake Victoria.

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agroforestry-network@viskogen.se
www.agroforestrynetwork.org

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Reviewed by: Amos Wekesa (Vi Agroforestry/Vi-skogen), Anders Malmer (SLU Global), Christina Schaffer (Agroforestry Sverige), Elizabeth Mwiyeria (Vi Agroforestry/Vi-skogen), Gert Nyberg (Swedish University of Agricultural Sciences), Henrik Brundin (Vi Agroforestry/Vi-skogen), Ingrid Öborn (International Centre for Research in Agroforestry, also known as the World Agroforestry Centre), Jenny Friman (Forest, climate & livelihood research network, Focali), Johanna Björklund (Agroforestry Sverige), Karin Höök (NIRAS), Linda Andersson (Vi Agroforestry/Vi-skogen), Linda Hansson (Focali), Maria Schultz (We Effect), Madeleine Fogde (Swedish International Agricultural Network Initiative, SIANI), Sara Elfstrand (SwedBio, Stockholm Resilience Centre).

Review prepared by: Linus Karlsson

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Front cover: Vi-skogen

Contact information: agroforestry-network@viskogen.se

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ABOUT AGROFORESTRY NETWORK

Agroforestry Network was founded to make agroforestry more recognised among development aid stakeholders and to share knowledge with other agroforestry experts. It is a network based in Sweden for international agroforestry practice, bringing together agroforestry experts from different organisations and institutions in Sweden and abroad. It was founded by the Swedish NGO Vi Agroforestry (in Swedish: Vi-skogen). This review has been commissioned by the Agroforestry Network and its partners Agroforestry Sverige, Focali, NIRAS, SIANI, SLU Global, SwedBio at Stockholm Resilience Centre and Vi Agroforestry (Vi-skogen).

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EXECUTIVE SUMMARY

Ecosystem services from trees contribute to food security and sustainable development. Increasingly, organisations and institutions are recognising the value of ecosystem services from trees on farms and in agricultural landscapes for food security and to sustain productivity. For smallholder farmers these services can be important for securing livelihood strategies, especially for farmers living in poverty, as trees provide fodder, food, fuelwood, finance and soil fertility. Smallholder farmers with less than 5 ha of land, produce around half of the world's food, but many of them are living in poverty and suffer from food insecurity and malnutrition. Unsustainable land management and climate change is degrading the environments these farmers live in and depend on. As the remaining forests in the world are threatened by a growing demand for food, feed, fibre and fuel, these farmers will face additional challenges, especially in a changing climate.

Agroforestry supports farmers' livelihoods while reducing pressure on forests. Agroforestry, i.e. to combine crops, trees and livestock, is a promising land management system that can improve farmers' livelihoods while reducing pressure on forests. In this report, the commonly reported positive and negative effects of agroforestry have been compiled in a thorough review that shows that agroforestry can provide many tree-related ecosystem services such as biodiversity and increased soil fertility, and can contribute to water management. Agroforestry also contributes to reduced erosion, a common environmental problem in tropical regions, and carbon sequestration thus reducing the net global emissions of greenhouse gases. Fuelwood from trees is essential for about 2.4 billion people by providing energy to cook food, and agroforestry has potential to support large parts of the rural population with fuelwood. However, most of these positive effects are dependent on a proper management and use of suitable tree species for the purpose and context ('the right tree for the right place'). If done correctly, agroforestry increases agricultural yields and improves the food and nutrition security of farmers living in poverty, while helping them adapt to more variable and extreme weather. Climate adaptation is particularly important for female farmers as they often have less access to resources compared to their male counterparts. Female farmers produce a major part of the food in many regions but generally do not have the same possibilities as men do to improve their livelihoods. Agroforestry can be a suitable land management system to reduce gender inequalities related to natural resource access, while contributing to increased control of their benefits.

Agroforestry is not commonly promoted as a viable sustainable agricultural system. Most countries with a large portion of their population engaged in agriculture have not included agroforestry in policies, land management strategies, development plans, or extension services. The paradigm is instead to separate agriculture for food production, while forestry if focused on timber production and for providing ecosystem services. This paradigm has created numerous barriers preventing a scaling-up of agroforestry. In this report, the most important barriers are analysed and actions presented for how these can be removed. The analysis shows that farmers are facing challenges when practicing agroforestry as there are few value chains developed for agroforestry products and for connecting them to consumers and the market. The long return on investment in agroforestry is also problematic, as many farmers do not have access to capital, credit or secure tenure for their land. This is especially the case for female farmers. Other barriers are found in research and higher education institutions dealing with agriculture or forestry, preventing agroforestry from being scaled-up efficiently.

This report concludes that if the current barriers are addressed, farmers can fully benefit from agroforestry practices. Promoting value chains for agroforestry products and services is an important action to take. It is also essential to strengthen the agroforestry capacity of national extension services, combined with the use of new technologies such as drones and mobile phones. Stronger farmer groups or cooperatives can also provide extension services for their members and connect them to markets. Promoting participatory research and identifying drivers of change in different contexts can further serve the purpose of a scaling-up process. Exchange and cross-fertilisation between local knowledge and agroforestry research can generate innovations to be disseminated widely, with potential to increase yields and support adaptation of agriculture to a changing climate while preserving the environment and mitigating greenhouse gas emissions.

ABBREVIATIONS AND ACRONYMS

CBD	Convention on Biological Diversity
CDM	Clean Development Mechanism
GDP	Gross Domestic Product
GHGs	Greenhouse Gases
HDI	Human Development Index
ICRAF	International Centre for Research in Agroforestry, also known as the World Agroforestry Centre
IPCC	Intergovernmental Panel on Climate Change
KACP	Kenya Agricultural Carbon Project
(I)NGO	(International) Non-Governmental Organisation
NTFP	Non-Timber Forest Products
SALM	Sustainable Agricultural Land Management
SDGs	Sustainable Development Goals
Sida	Swedish International Development Cooperation Agency
UNFCCC	United Nations Framework Convention on Climate Change
VCS	Verified Carbon Standard
WUE	Water Use Efficiency

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1 BACKGROUND

Throughout human history, mixing trees and crops has been a common way to produce food. However, during the past centuries, food and timber production have been separated into two different disciplines, with different and sometimes conflicting objectives. The development of the two sectors has been focused on high-yielding monocultures, with large amounts of agro-chemical inputs. During the past decades, the negative environmental and social effects of these systems have been recognised and their sustainability questioned.

More and more organisations, institutions and countries such as the United Nations Framework Convention on Climate Change (UNFCCC), the Convention on Biological Diversity (CBD), the Food and Agriculture Organisation of the United Nations (FAO) and the World Bank, have started to acknowledge the importance of trees for a sustainable food production because trees contribute to essential ecosystem services that are difficult to replace with chemicals or machinery (FAO, 2013; Agroforestry Network, 2017).

Agroforestry can be described as systems and technologies where trees are deliberately used on the same land management units as agricultural crops and/or animals, in some form of spatial arrangement or temporal sequence. In spite of their diversity, all these systems share the common characteristic of trees being closely linked to agriculture and food production activities (HLPE 2017).

Small-holder farmers with less than 2 ha produce 30-34% of the world's food, and farms with less than 5 ha between 44–48% (Ricciardi et al, 2018). Meanwhile, many smallholders are living in poverty, suffer from food and nutrition insecurity, and do not have access to machinery or agro-chemicals, making them even more dependent on ecosystem services (CFS, 2016). In 2010, 750 million of the world's population living in extreme poverty were smallholder farmers (FAO, 2016a).

Poverty and food insecurity makes smallholder farmers vulnerable to climate change and their production is compromised if adaptation and mitigation measures are not taken. At the same time, the demand for food is expected to increase as the global population is growing and consumption patterns are changing. This will put additional pressure on the remaining forest reserves in the world. Addressing these challenges is central in order to eradicate poverty and reach the Global Goals set by the global community in the 2030 Agenda for Sustainable Development (FAO, 2016a).

Agroforestry, where trees are integrated with crops and/or livestock, is a promising land management system that can address many of the challenges farmers are facing (Lundgren & Raintree, 1982). Agroforestry has the potential to mitigate climate change, adapt resource-poor smallholder farms to extreme and variable weather and increase tree-related essential ecosystem services, while increasing farm productivity without reliance on large amounts of external inputs such as inorganic fertilisers and chemicals for pest management.

However, initiatives to scale-up agroforestry are facing obstacles and the literature review for this report indicates that there is no publication systematically addressing these and summarising the known positive and negative impact of agroforestry. Regionally, a White Paper has been published by Catacutan et al., 2017 on Agroforestry: Contribution to food security and climate-change adaptation and mitigation in Southeast Asia. To help fill this research gap, this review will increase the scope and review environmental, social and economic aspects on the farmer, community and landscape levels. It will review research and agroforestry projects, and identify current barriers that prevent effective scale-up processes.

2 PURPOSE AND LIMITATIONS

The purpose of this work is to provide communicative evidence about the potential of agroforestry, based on research and reported case studies. Environmental, social and economic aspects are dealt with and when possible, proven effects are presented along with comparisons with other land management systems. This report also contains an analysis of how to address barriers and challenges that are preventing agroforestry from being scaled up.

The report focuses on agroforestry practised by small-scale food producers. Globally, the number of farms smaller than 2 ha has been estimated at 475 million (Lowder, Skoet and Raney, 2016). These smallholdings provide livelihoods for almost 2 billion people and, in Asia and sub-Saharan Africa, produce about 80 per cent of food consumed (HLPE, 2013). Yet, the access of small farmers to land, innovations, technology, knowledge and information that are needed to enhance productivity and incomes remains limited. Female farmers' access to knowledge of agriculture and nutrition is essential for achieving the SDG number 2 of eradicating hunger and achieving food security and sustainable agriculture. (GFRAS, 2015). In sub-Saharan Africa, small-scale agriculture is a significant driver of forest loss. (FAO, 2017b). The world's nearly 500 million smallholder farmers risk being left behind in structural and rural transformations. However, to avoid introducing agroforestry practices only suitable for small-scale food production for a local market, this report contains information on impacts and cases from projects involving larger actors. The geographical focus in the report is on regions dominated by smallholder farmers. In the analysis of barriers and challenges, most of the topics raised relate to development cooperation, but other pathways for a scale-up of agroforestry are also identified and addressed.

3 METHODOLOGY

This report is based on an extensive literature review of scientific publications and reports from implemented agroforestry and agricultural development projects. To guarantee the quality of the material, scientific reviews and publications have been chosen based on the number of citations and the credibility of the journal in which they are published. Academic search engines such as LUBScience, Web of Science, Biosis etc., have been used to identify relevant material along with discussions with agroforestry researchers.

Result reports from rural land management projects have been used to illustrate and consolidate information retrieved from academic studies. As project reports in general are not reviewed by a third party, due diligence has been exercised to assure the quality of the reviewed material. The process of due diligence involves interviews and research, e.g. mapping of how a project receives funding and reviewing external reporting of the work.

From the literature review, barriers and challenges that are preventing a scale-up of agroforestry have been identified. To further identify potential obstacles and find ways to address these, interviews have been conducted with agroforestry experts from academia, the private sector, and organisations working with environment and development cooperation. The interviews were done in a semi-structured way with a focus on each interviewee's expertise in the sector (see Appendix 1). Common topics that came out of the interviews were summarised and, when possible, confirmed by findings in the literature review.

The development of this review included a broad review process among the Agroforestry Network partners. However, the field of agroforestry is wide and complex, with new studies and results developing continuously. The Agroforestry Network welcomes feedback on this report and complementary perspectives in a dialogue with our network and partners.

3.1 How to read this report

This report starts with an introduction to agroforestry in Chapter 4: historical trends, a definition of agroforestry, and the global distribution of the land management system. This is followed by Chapter 5 that covers an extensive scientific review, summarising positive and negative impacts of agroforestry seen from a farmer perspective. From this review, technical, social and economic barriers that are preventing a scale-up of agroforestry are identified on the farm level. These are presented together with institutional and policy barriers in Chapter 6. In Chapter 7, the barriers are analysed and solutions that would allow a sustainable scale-up of agroforestry are presented.

4 WHAT IS AGROFORESTRY?

4.1 Definition

Agroforestry is often described as a land management system or management practices, where trees are deliberately intercropped with agricultural crops or animal pastures (or other feeding ground for animals). The intercropping is done in a spatial arrangement or a temporal sequence. An illustration of different systems is seen in Figure 4.1. Within this definition there is a significant diversity but all agroforestry systems have in common the link between trees, agricultural activities and food production (HLPE, 2017). The definition in this report is based on FAO's definition in HLPE, 2017: *Agroforestry is a collective name for land-use systems and technologies where woody perennials (trees, shrubs, palms, bamboos, etc.) are deliberately used on the same land management units as agricultural crops and/or animals, in some form of spatial arrangement or temporal sequence.* As the reviewed material originates from different sources, some of the references might have used a broader or more restricted definition. When this has been identified it is explained in the text. When estimating areas with agroforestry through remote sensing, i.e. satellite or other aerial photography, agricultural land with more than 10% tree cover is defined as agroforestry (Zomer et al., 2014).

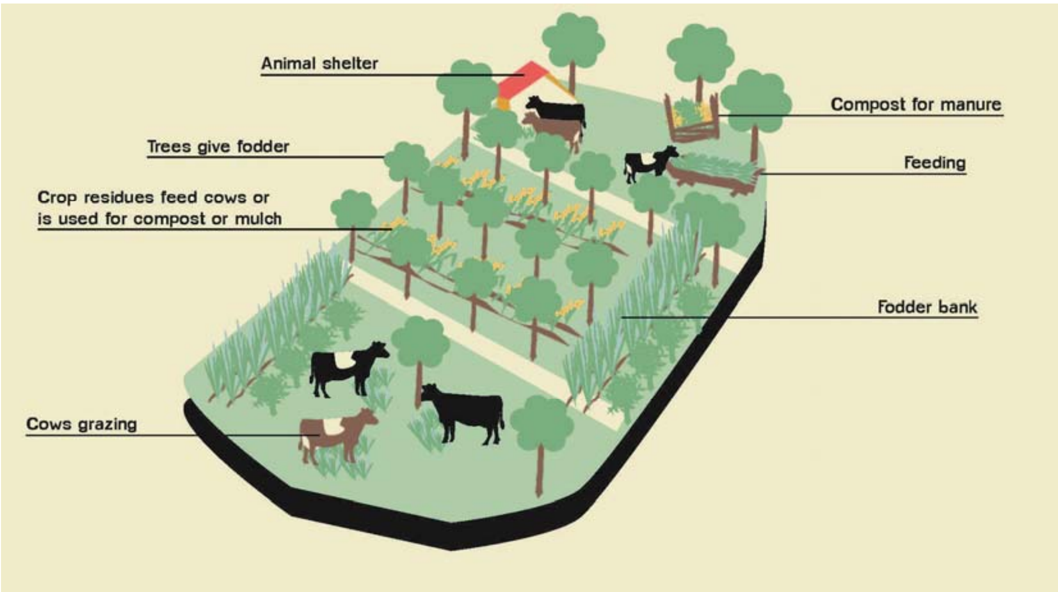

Figure 4.1. An illustration of different agroforestry systems (Wekesa & Jönsson, 2014).

Agroforestry systems can be divided into five different categories: (i) agro-silviculture, where annual or perennial crops are integrated with trees, (ii) silvopastoral systems, that integrate livestock and trees, (iii) agrosilvopastoral systems, where livestock, trees and crops are combined, (iv) entomo-silvicultural systems, combining insects with trees, and (v) aquasilviculture, where fish are combined with trees (Wekesa & Jönsson, 2014). The combination of trees and crops can be done in different temporal and spatial sequences, e.g. alley cropping, intercropping, hedgerow systems and improved fallows (Sharma, 2016). A conceptual map of different agroforestry practices is shown in Figure 4.2. Many other terms such as polycultures, forest gardens and permaculture, are also commonly used to describe agroforestry.

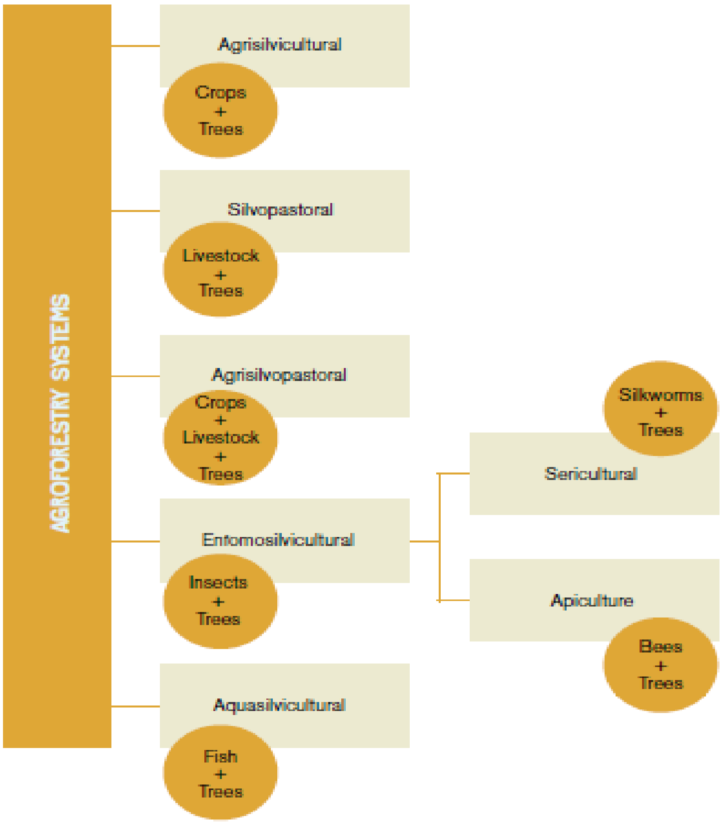

Figure 4.2. Example of a conceptual map showing five different ways to classify agroforestry practices (Wekesa & Jönsson, 2014).

4.2 History

Agroforestry has been practised throughout the world for a major part of the agricultural history. For example, shifting cultivation was popular in Europe until the Middle Ages (Nair, 1993). In the tropics, agroforestry has been practised for thousands of years. The Brazilian nut was cultivated in the Amazonian rainforest before the European colonisation and bananas have been cultivated in African rainforests for at least 3000 years (Bhagwat et al., 2008).

Multi-layered systems, i.e. systems with crops, bushes and trees, have been the common way to produce food in many tropical societies around the world. However, by the end of the 19th century, a new agroforestry practice spread with the primary objective to produce timber. The new method was developed by the British Empire and landless workers were paid with the right to grow crops between the rows of trees before the canopy closed (Nair, 1993).

In the 20th century, the development of the forestry sector in many lower income countries was questioned, as this development did not support the basic needs of rural populations. Awareness of the need to conserve tropical forests also increased and the strong focus on annual food crop production during the Green Revolution, i.e. the technological leap in agriculture that followed the Second World War, recognized the need for diversification of diets and thus of smallholder farming. Raising awareness of environmental and social aspects of the prevailing forestry and farming practices, triggered a number of international organisations, e.g. the World Bank and FAO, to introduce new or additional objectives for the forest sector and to recognise agroforestry as a sustainable land management system. To support the new development paradigm, several research institutes were established to address ecological degradation and the inefficient systems used to produce food in lower income countries. For example, the International Centre for Research in Agroforestry (ICRAF) was founded in 1978. This led to the re-introduction of agroforestry as a sustainable system for food and tree production (Nair, 1993).

4.3 Global distribution

Globally, almost 50% of the land surface suitable for vegetation has been converted to agricultural land (Zomer et al., 2016). In 2015, agricultural land covered almost 50 million km^2 of which about two-thirds were used for grazing and fodder production and one-third as crop land. Agricultural land today covers 37% of all land surface (FAOSTAT, 2017). Most of the current expansion of agricultural land occurs in the tropics, where 80% of all new agricultural land previously has been forested (Zomer et al., 2016). There are no reliable statistics on the distribution of agroforestry but researchers at the World Agroforestry Centre (ICRAF) have made estimates using remote sensing data (HLPE, 2017). They found that more than 43% of all agricultural land has a tree cover exceeding 10%. Globally, this accounts for more than 1 billion ha (10 million km^2). The agricultural area with more than 20% and 30% tree cover, covers 23% and 15% respectively of the global agricultural area. The global tree cover on agricultural land is illustrated in Figure 4.3 (Zomer et al., 2014).

Agroforestry is especially widespread in Southeast Asia, Central America and South America, where agroforestry is practised on more than 50% of the agricultural land. Globally, 1.8 billion people live on agricultural land and around 46% of these, i.e. 837 million people, live on land where the tree cover is larger than 10% (Zomer et al., 2014). The World Bank (2004) estimated the number of people dependent on agroforestry systems to be 1.2 billion. In sub-Saharan Africa, the proportion of agroforestry has been estimated to be 29% of the agricultural land, accommodating 70 million people. During the first decade of the 21st century, the tree cover on agricultural land increased globally with 3%. The corresponding increase in sub-Saharan Africa was around 1% (Zomer et al., 2014).

In general, tree cover correlates well with the aridity index, i.e. precipitation compared to the standard potential evapotranspiration, and the abundance of trees has been shown to increase with humidity. Zomer et al. (2014) also compared population density with tree cover, but did not find any clear correlation.

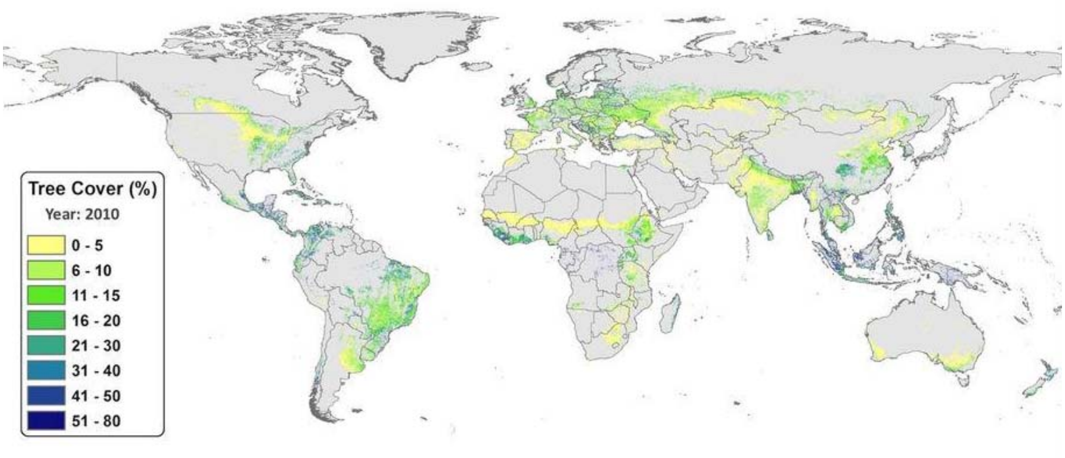

Figure 4.3. Global tree cover on agricultural land in 2010. (Zomer et al., 2016).

5 ENVIRONMENTAL, SOCIAL AND ECONOMIC IMPACTS OF AGROFORESTRY

This chapter is structured thematically. Each part describes an aspect that affects a farmer's daily work and the connection to a sustainable development. Environmental, social and economic aspects are described and the varied lengths of the sections reflect the availability of published scientific studies and different kinds of project reports addressing the subject.

5.1 Climate change

Agriculture, forestry and other land uses are globally large emitters of greenhouse gases and stand for 21% of the world's total emissions. The major pathways of emissions are through deforestation, livestock production, and soil and nutrient management (FAO, 2016a). Many of the countries expected to be severely affected by climate change are located in the tropics, with large parts of their populations dependent on agriculture (Hertel & Rosch, 2010). The Intergovernmental Panel on Climate Change (IPCC) has estimated that Africa is especially vulnerable to climate change. Agriculture engages 70% of the work force on the continent and contributes with 25% of the Gross Domestic Product (GDP). In Africa, agricultural production has stagnated the past decades (Pereira, 2017) and many studies, summarised in the Fifth Assessment Report by the IPCC, predict that agricultural yields will decrease during the 21st century due to climate change. This while the population numbers are expected to increase significantly (Niang et al., 2014). Farmers living in poverty, and especially women, bear the heaviest burden of a changing climate, as they often depend on rain-fed agriculture without any systems for irrigation and lack resources to rely on in times of hardship. For example, 80% of the arable land in California is covered with irrigation systems and although the climate is much dryer in Niger, Chad and Burkina Faso, the corresponding figure for this region is less than 1%. Furthermore, 91% of the farmers in USA are insured against extreme weather but such insurance-schemes are basically absent in lower-income countries (Oxfam, 2015). Climate change also has a disproportionate impact on women and children, who are 14 times as likely as men to die during a disaster (UN Women, 2017).

5.1.1 Mitigation of greenhouse gas emissions

Agricultural land covers 37% of the global land surface (FAOSTAT, 2017) and the agricultural sector is globally the largest emitter of non-CO_2 GHGs. These are mainly methane and nitrous oxid, which in 2010 was estimated to 5.2-5.8 billion tons of CO_{2eq}, or 10-12 % of the global emissions of GHGs (Smith et al., 2014). The flux of carbon dioxide from agricultural land can be either positive or negative, but the global average is close to zero (Smith et al., 2007; Smith et al., 2014). The potential of agroforestry to mitigate climate change was recognized in 2001 when the land management system was allowed for greenhouse gas sequestration under the Kyoto Protocol (Nair et al., 2009). Though trees on agricultural land are still not accounted for when global and national carbon budgets are determined (Zomer et al., 2016), they are accepted as a Clean Development Mechanism (CDM) used to offset emissions from higher income countries.

After 2001, the number of academic studies estimating the above- and belowground carbon storage in agroforestry systems increased greatly. Unfortunately, this increase was also accompanied by large differences in methodologies and concepts, making it difficult to consolidate data. The scientific approach to belowground carbon storage is especially rudimentary as few research projects have addressed this specifically (Nair et al., 2009; Kumar & Nair, 2011; Lorenz & Lal, 2014).

All the same, agroforestry increases carbon storage aboveground in biomass and belowground through litter fall and enhanced root production, rhizodeposition, i.e. the organic material from roots incorporated into the soil. How the different mechanisms contribute to carbon sequestration varies significantly between different agroforestry systems and climates. On average, aboveground biomass stands for about half of all sequestrated carbon, belowground biomass for one sixth, and soil organic carbon for one third of the storage potential (Kim et al., 2016). Agroforestry stores more carbon than pastures and fields with annual crops, but less than forested areas. The storage potential varies significantly between different systems but is, for the part stored in vegetation, in general higher in regions with a humid climate compared to semi-arid and arid areas. Vegetation also stores more carbon in tropical regions compared to temperate areas. When it comes to carbon stored in the soil, no such generalisations can be made due to lack of methodological standards (Nair et al., 2009). There is also no comprehensive understanding of how agroforestry affects fluxes of nitrous oxide and methane. On the one hand, the use of nitrogen-fixing trees increases the soil emissions of nitrous oxide, but on the other hand, such practices are likely to reduce the need for inorganic fertilisers, a large contributor to the global emissions of nitrous oxide (Kim et al., 2016). An illustration of different land use management systems and their potential to store carbon in the tropics is seen in Figure 5.1.

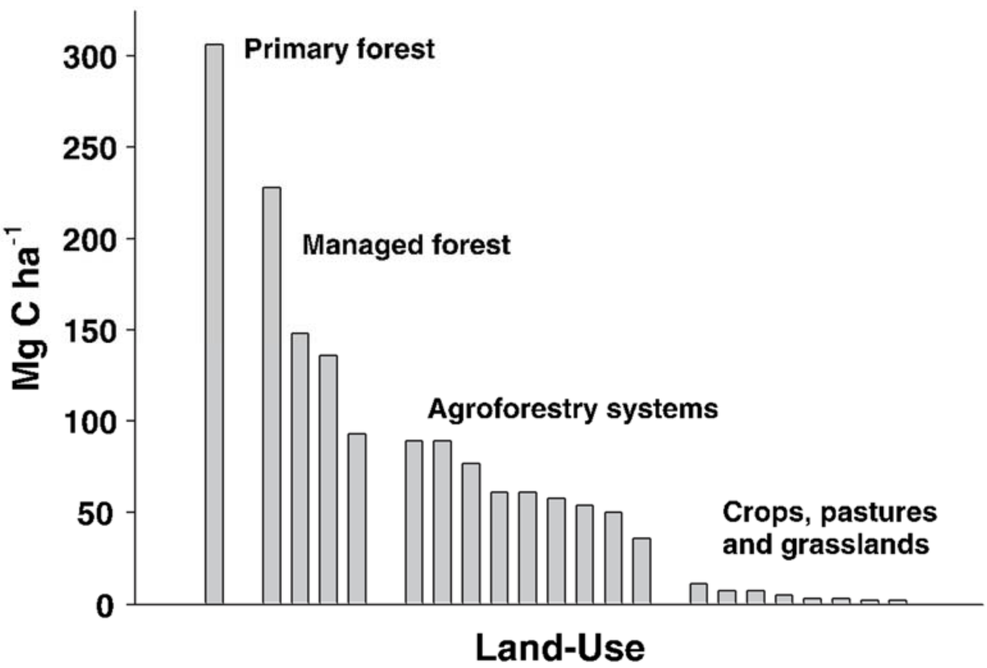

Figure 5.1. A schematic illustration of the storage potential of carbon in different ecosystems in the tropics (Verchot et al, 2007).

For non-rotational agroforestry practices, i.e. systems with a constant spatial arrangement of trees and crops, the annual carbon sequestration potential has been estimated to be 7.2 ± 2.8 tons C per ha (average derived from 59 peer-reviewed papers). Home gardens, i.e. complex smaller plots often near the house, where trees, cattle, vegetables and crops are combined, have shown to sequester more carbon than any other agroforestry system above ground. Few studies have measured the belowground storage. Carbon sequestration rates are also likely higher in silvopastures (pastures with isolated trees) than in other non-rotational agroforestry systems with crops, such as alley cropping where crops are grown in between rows of trees. When trees are planted and other agroforestry practices implemented, the sequestration rates are high and decrease when a system reaches equilibrium, i.e. the trees have grown tall and high activity of microorganisms degrade added carbon (Kim et al., 2016).

If fluxes of other GHGs are included, agricultural land converted to agroforestry has the potential to annually sequester 27.2 ± 13.5 tons CO_{2eq} q per ha, at least for the first 14 years after establishment. The global mitigation potential, based on the assumption that 20% of the world's 630 million ha of unproductive agricultural land is suitable for agroforestry, then becomes 3.4 ± 1.7 billion tons CO_{2eq} per year (Kim et al., 2016). This can be compared with the annual GHG emissions, including those from land use, land use change and forestry (LULUCF), which have been estimated to about 51.9 billion tons CO_{2eq} in 2016 (UNEP, 2017). The above numbers should be used with care as the scientific understanding of GHG-sequestration in agroforestry systems is still rudimentary.

Kenya Agricultural Carbon Project (KACP): Adaptation, mitigation and livelihood improvement

Prisca Mayende in Bungoma is one of the farmers participating in KACP. "Before, there were no trees on my farm and productivity was low. After getting trainings from Vi Agroforestry, I started planting trees, doing mulching and using sustainable farming practices. This has improved the maize yields from 3 to 8 bags, and I now have firewood and fodder from the trees. I am proud of my farming today!"

On 16 January 2014, the Kenya Agricultural Carbon Project (KACP) received its first carbon credits certified under the Verified Carbon Standard (VCS, today Verra). The project started as a partnership between the Swedish NGO Vi-skogen (Vi Agroforestry), the World Bank's Bio-Carbon Fund and UNIQUE forestry and land use. It is implemented by Vi Agroforestry and feeds off the synergies between climate mitigation, adaptation and increased productivity created by the use of Sustainable Agricultural Land Management (SALM) practices. In total, the project involves 1,730 farmer groups with 29,497 smallholder farmers on 21,965 ha of land in western Kenya.

The farmers in the area have seen their yields decline and the environment degrade after years of unsustainable agricultural practices. Vi Agroforestry trains the farmers involved in the KACP-project in different SALM-practices, e.g. agroforestry, mulching, use of cover crops, and use of green manure, to increase the organic content in the soil. Increased content of organic matter improves yields, provides resilience to droughts and heavy rains, limits erosion, and stores carbon, which the farmers receive payments for. The main economic incentive for the farmers is though the increasing yields and the project has shown that by using SALM-practices yields increase with over 150% in all agro-ecological zones in 8 years, resulting in increased food security. Savings among farmer families have also increased along with a greater resilience to shocks and changes. Other results include increased knowledge on climate change and increased access to firewood, fruits and fodder from trees.

The project formed the basis for the development of a new carbon methodology, Verified Carbon Standard methodology Vm0017, based on an approach of accounting for carbon sequestration in the soil from the adoption of SALM practices. When the methodology was certified in 2011, the project became the first one in Africa to implement soil carbon sequestration. The generated carbon credits are partly purchased by the World Bank's BioCarbon Fund and partly sold by Vi Agroforestry to private companies internationally. The BioCarbon fund has paid US$580,000 for carbon credits, funds that partly have gone directly to the contracted farmer groups and partly used for project development costs and marketing of credits.

In 2017, the project was able to verify that 329,049 tons of CO_{2eq} had been sequestered and stored in the soil between 2009-2017. The project ends in 2030 and then the sequestrated amount of carbon is expected to be 2 million tons. The main reason for the success of the project is that farmers have seen their yields increase when implementing SALM practices. With this incentive, the project has gained momentum and interest. Payments for carbon credits have only been a secondary motivation. When the project matures, carbon credits will no longer be delivered but the main incentive for the farmers to continue will still be there. The main challenges in the project have been to effectively reach a large number of farmers and to develop a monitoring and evaluation system that is effective and precise. This has been achieved by a farmers-based activity monitoring system with an online platform and SMS-based reporting.

Sources: Tennigket et al. (2013), BioCarbon Fund (2017), World Bank (2017), World Bank (2014), Vi Agroforestry (2016), Vi-skogen (2017), Oborn et al (2017), Linda Andersson, Vi-skogen (Personal Communication, 2018). Photo: Vi-skogen (Linda Andersson).

5.1.2 Resilience including adaptive capacity

Agroforestry provides an opportunity for farmers to diversify their farms and thus increase sustainability and resilience to shocks by reducing the consequences of crop-failure. Trees also provide a number of ecosystem services such as erosion control, flood control and pest control, all important for resilience to climate change (Verchot et al., 2007; Mbow et al., 2014). Furthermore, trees improve the microclimate by shading crops and cooling the surrounding air by increasing the transpiration, an energy consuming process (Ellison et al., 2017). Agroforestry can thus buffer climate extremes, expected to become more common in the future (Mbow et al., 2014).

Re-greening in Niger

With a poverty rate of 44%, Niger is one of the world's poorest nations. In 2016, it ranked second to last (187th out of 188 countries) on the United Nations Human Development Index (HDI). During the past 20 years, two regions on the southern fringes of Sahara have seen an astonishing development as around 5 million ha of degraded farmland have been covered with trees and bushes, restoring the environment and the welfare of the farmers. Studies have shown that yields in the area have increased significantly and that farmers with a longer experience in agroforestry are coping better with climate change than farmers that are new to the system. The trees provide a number of useful products such as medicinal plants and firewood. The access to firewood is especially important for women, who often has the responsibility to provide fuel for cooking. Trees on farm has reduced the time spent on collecting firewood to a minimum. Furthermore, women benefit from the trees by picking fruits and other products, earning extra cash. In total, the value of tree products harvested each year has been estimated to around US$1000 per farm. The value of fuelwood alone was estimated to around US$250 per household.

The driver of change has been identified as a complex combination of improved livelihoods, a mentality shift among farmers, policy changes and successful interventions by an NGO. The approach by the NGO was bottom-up, which has created many local institutions and committees now responsible for extension services, wood sales and surveillance of farmer activities.

Source: Pye-Smith (2013), World Bank, (2017b).

The current research on how tree-based systems perform in a more variable climate is still not very advanced (Verchot et al., 2007), but some conclusions can be drawn from a few studies. In an extensive review about crop-tree interactions in sub-Saharan Africa, Kuyah et al. (2016) showed that trees created a more favourable microclimate in 61% of the assessed agroforestry systems. The rest of the systems were negatively altered. Furthermore, to combine crops with nitrogen-fixing trees has been shown to stabilise yields during dry years (Sileshi et al., 2008; Sileshi et al., 2011, Sileshi et al., 2012). Nguyen et al. (2013) also showed that agroforestry provided several opportunities for adaptation in Vietnam as tree-based systems were less affected by climate shocks than rice and rain-fed crops. Rice and rain-fed crops without any trees lost over 40% of the yield during years with extreme droughts or floods compared to "normal" years.

Several studies have also confirmed that rural farmers use tree products such as fruits and nuts, as a coping mechanism (Ong et al., 2015). As the forest cover is decreasing in many parts of the world, this adaptive measure needs to be integrated with agriculture through domestication of wild tree species. However, except for a few tree species, domestication of wild trees useful in agroforestry systems is lagging far behind domestication of agricultural crops, which has been ongoing for thousands of years. There is thus a large potential to further improve the resilience and yields from agroforestry systems by investing in tree domestication (Dawson et al., 2012).

Summary: Agroforestry & Climate Change

- Small-scale farmers and especially women in tropical regions, are the ones bearing the heaviest burden of climate change.
- Agriculture is globally one of the largest emitters of greenhouse gases. However, intercropping trees with crops can transform agriculture to become a net sink of GHGs. How much greenhouse gases agroforestry can store in biomass and in the soil is regarded as difficult to estimate, as scientific models for this are still rather simple. However, one estimate is that the global mitigation potential is 3.4 ± 1.7 billion tons CO_{2eq} per year (Kim et al., 2016). This can be compared with the annual GHG emissions, which have been estimated to be about 51.9 billion tons CO_{2eq} in 2016 (UNEP, 2017).
- Agroforestry, with the use of nitrogen-fixing trees, increases the soil emissions of nitrous oxide. However also reduces the need for inorganic fertilisers, a large contributor to global emissions of nitrous oxide.
- The potential of agroforestry to store carbon in vegetation is greater in a humid climate compared to areas with semi-arid and arid climates. The same is also true when comparing tropical to temperate regions. No such generalisation can be done for carbon stored in the soil.
- An agroforestry farm with a diverse production can be more resilient to climate change than a farm without trees. Trees also contribute with several different ecosystem services that are important to sustain yields in a more variable and extreme climate. To combine crops with nitrogen-fixing trees has shown to stabilise yields during dry years.

5.2 Water

Rain-fed agriculture without any infrastructure for irrigation covers 80% of the global area under cultivation and generates 60-70% of the world's staple food. This figure is much higher in sub-Saharan Africa and South Asia, where 95% and 90%, respectively, of all farmland is rain-fed. The Water Use Efficiency (WUE), i.e. the crop per drop, tends to be low in rain-fed systems as the onset and duration of rain is not possible to control. Increasing the WUE in rain-fed systems is important in order to improve global food security, especially in regions with a semi-dry and sub-humid hydro-climate where many "hot spots" for malnourishment are found. In these regions, water is a key limiting factor for food production and low yields are interlinked with land-degradation in a cause and effect relationship. Furthermore, land degradation damages water resources since eroded soil ends up in ponds and lakes and causes eutrophication. Degraded land is also more prone to flooding because the infiltration capacity of degraded soil is low and water therefore runs off the surface instead of infiltrating (Wani, et al., 2009). The frequency and severity of floods and droughts will likely increase in many areas due to changing precipitation patterns. This is a major challenge for the millions of small-scale farmers practising rain-fed agriculture around the world (Verchot, et al., 2007).

5.2.1 Water use efficiency in agroforestry systems

Trees can utilise a large soil volume to withdraw water and can thus grow and produce food even during long lasting droughts that affect crops (Verchot et al., 2007). Since an agroforestry system occupies more ecological niches, it has the potential to use the available water more efficiently. Compared to annual crop systems, agroforestry reduces surface runoff and evaporation. Studies from India show that agroforestry systems can double the rainwater utilisation, mainly because the trees use water unavailable for the crops in between growth seasons (Pandey, 2007). Studies from southern Africa confirm that the WUE is higher in agroforestry systems with maize and pigeon pea compared to corresponding monocultures (Akinnifesi et al., 2010).

It must also be mentioned however that trees can also increase the water consumption and therefore compete for water during dry conditions. In several studies it is concluded that trees decrease the soil moisture content and cause yield reductions (Odhiambo et al., 2001; Livesley et al., 2004; Radersma & Ong, 2004), thoughothers have shown positive effects (Sinare & Gordon, 2015; Radersma & Ong, 2004; Siriri et al., 2013). Fast growing trees seem to be more prone to compete for water resources (Pandey, 2007; Radersma & Ong, 2004). In an extensive review about crop-tree interactions in sub-Saharan Africa, Kuyah et al. (2016) showed that competition was more likely to occur when the density of trees was high and during dry years. They found that trees had positive effects on water availability in 51% and negative effects in 35% of the studies. They concluded that the positive effects were a result of improved infiltration and reduced evapotranspiration, i.e. water vapour leaving the soil and the plants. Furthermore, Kuyah et al. (2016) found many studies confirming that competition between trees and crops could be minimised by selecting non-competitive species and pruning the roots and the canopy.

5.2.2 Water distribution on a farm

How trees affect the water dynamics on a farm is complex as trees can increase the evapotranspiration but also change the soil properties, and thus the water distribution in the soil. This field of research is at present largely neglected and the scientific community lacks several important pieces of knowledge to fully understand how different agroforestry practices affect water availability (Bargues Tobella, 2014; Everson et al., 2009; Ilstedt et al., 2007; Lozano-Parra et al., 2016). Trees have been shown to increase the soil macro-porosity, i.e.

the larger soil structures, in agroforestry systems (Ilstedt et al., 2016; Bargues Tobella et al., 2014; Benegas et al., 2014). Macro-structures can increase the infiltration capacity, which several studies of agroforestry systems have confirmed. This ecosystem service is especially important for soils rich in clay, where water is infiltrating very slowly (low hydraulic conductivity) as it can reduce surface runoff during intense precipitation events (Cannavo et al., 2011; Benegas et al., 2014; Bargues Tobella et al., 2014).

5.2.3 Effects of trees on landscape, regional and continental scales

On the regional and continental scale, trees are important for the formation of rain as landscapes with forests produce more water vapour and increase the relative humidity. Trees also affect the albedo, i.e. the reflective property of the ground, and release aerosols, small particles on which droplets can form. Climate modellers predict that large-scale deforestation could decrease rainfall with as much as 30% in some regions (Ellison et al., 2017). The tree distribution in the landscape also affects the formation of groundwater. Several scientists are currently challenging the paradigm claiming that an increase in tree cover reduces groundwater formation. These scientists are presenting new models where an "optimum" tree distribution, somewhere in between a forest and a pasture or agricultural field, actually increases the groundwater formation. A conceptual illustration of the "optimum tree cover" is seen in Figure 5.2. According to the theory, an "optimum" tree cover would result in less surface runoff and fewer floods (Ilstedt et al., 2016). A study done in 46 countries in Africa, Latin America and Asia showed that a 10% increase in deforestation could increase the flood frequency with 4-28% (Bradshaw et l., 2007).

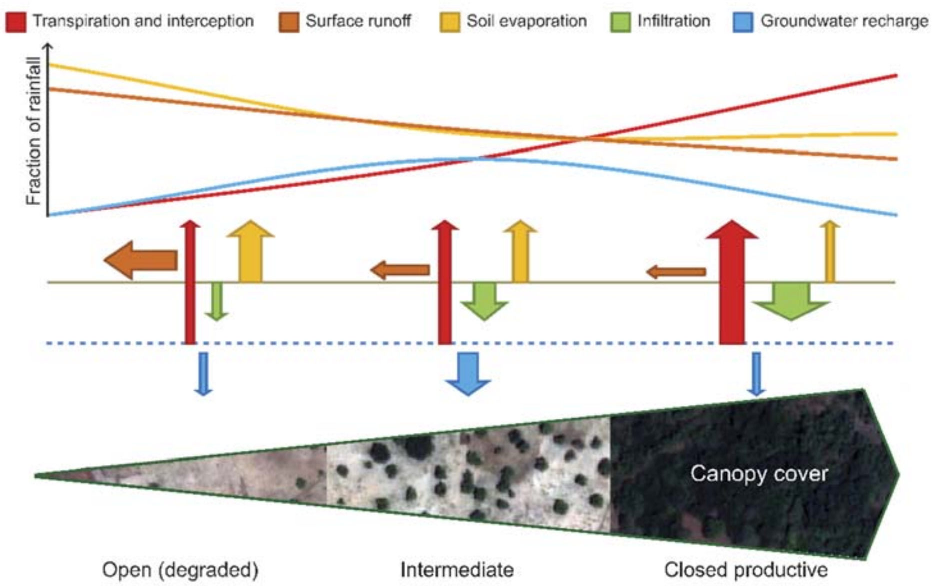

Figure 5.2. A conceptual drawing of the "optimum tree cover"-theory proposing that groundwater recharge will be greatest under an intermediate tree cover (Ilstedt et al., 2016).

The optimum tree cover theory

There have been many studies on the net impacts of changes in tree cover on water yields, and the general conclusion is that increasing tree cover leads to reduced water yields (i.e. streamflow and groundwater recharge), while reducing tree cover boosts water supplies (Farley et al., 2005; Bosch & Hewlett, 1982; Andreassian, 2004). This is usually attributed to the fact that trees use more water than shorter vegetation types such as grasses or agricultural crops. Thus, a *trade-off theory*, in which more trees means less water, has become the dominant paradigm in forest hydrology.

Based on this paradigm, many scientists have raised concerns and warned against forestation and tree-based restoration programs in drylands, as increasing tree cover in these regions may put at risk already scarce water resources (Jackson et al., 2005).

But the available scientific evidence for the trade-off theory has several limitations (Malmer et al., 2010). First, there is a strong bias of studies towards humid temperate areas, while studies in the tropics are scarce, especially in drylands (Locatelli & Vignola, 2009; Hamilton & King, 1983). Second, the impacts of forestation of degraded lands have not been investigated (Scott et al., 2005; Bruijnzeel, 2004). Third, almost all studies focus on the impact of young, fast growing plantations of either eucalypts or pines. And fourth, the available studies compare extremes; they focus on open land versus closed forest and thereby neglect areas with intermediate levels of tree cover such as agroforestry parklands. Thus, it is not possible to draw any sound conclusions about the net impact of tree cover on water yields from the current scientific evidence.

In 2010, a group of scientists from SLU, ICRAF and INERA started a project with the aim to gain a better understanding of the impact of tree cover on water resources, and more specifically on groundwater recharge, in the seasonally-dry tropics by studying an agroforestry parkland in semiarid Burkina Faso, West Africa. A new, alternative theory to the *trade-off theory* was proposed, namely that under conditions that prevail across the seasonally-dry tropics, groundwater recharge is maximised at an intermediate level of tree cover. This new theory, named the *optimum tree cover theory*, was then tested in the study site. Evidence from this project showed that groundwater recharge in the agroforestry parkland was indeed maximsed at an intermediate, non-zero, tree cover, thus confirming the optimum tree cover theory (Ilstedt, et al., 2016). At tree covers below the optimum, more trees resulted in more groundwater recharge, as the benefits gained from more trees through enhanced soil infiltration capacity and preferential flow (Bargués Tobella et al., 2014) outweighed the additional transpiration and interception losses from trees. Above the optimum, the contrary happened and more trees led to reduced groundwater recharge.

To date, evidence for the *optimum tree cover theory* comes from a single location, but it is likely that groundwater recharge is maximised at an intermediate tree cover over widespread areas in the seasonally-dry tropics. Management practices that improve soil infiltration and reduce tree water use such as tree pruning, selection of tree species and livestock control, can further enhance groundwater recharge. That more trees can lead to improved water resources offers opportunities for renewed tree protection and tree-based restoration of degraded lands in the seasonally-dry tropics, at the same time improving the livelihoods of millions of people in this region and contributing to environmental benefits.

Sources: Aida Bargues Tobella, SLU, and above references.

Summary: Agroforestry & Water

- Most of the farmers in the world depend on rain-fed agriculture and do not have access to irrigation infrastructure. To reduce global food insecurity, it is essential to improve their use of available rainwater, especially in a changing climate.
- Agroforestry can improve the use of rainwater and produce more "crop per drop" compared to monocultures. However, trees can also compete with crops for water and reduce yields, especially in dry climates. Choosing the right tree species and managing these correctly can minimise and eliminate this competition.
- Trees affect the water distribution on a farm, in the landscape and on a regional scale. They can be essential to reduce surface runoff by improving infiltration. The can also help increase groundwater formation, and on the continental scale they are important for the formation of rain.

5.3 Soil

Soil resources are degrading globally with the loss of important ecosystem services as a result. One main reason for degradation is the continuous withdrawal of nutrients and organic material. In some areas such as Central America, Africa and Eastern Europe, the primary reason for low yields is lack of nutrients. In other areas, too much nutrients are used, causing eutrophication of aquatic environments and greenhouse gas emissions. All over the world the loss of soil biodiversity (decline in the diversity of organisms present in the soil) and decrease of soil organic matter content is a challenge together with erosion (FAO & ITPS, 2015).

In many regions that suffer from soil nutrient deficiency, farmers have limited access to inorganic nutrients. For example, a farmer in sub-Saharan Africa typically uses less than 10 kg of mineral nitrogen per ha and year compared to farmers in some European countries that use more than 100 kg of mineral nitrogen per ha and year (Rosenstock et al., 2014; Eurostat, 2017). In Figure 5.3, estimates of the annual nutrient depletion from agricultural land in Africa are shown. It is not possible to solve soil nutrient deficiency by just adding mineral fertilisers though - nutrient restoration must be accompanied with the addition of large amounts of organic material (FAO & ITPS, 2015).

To increase the soil organic matter content is crucial. It can be done through growing more perennial crops such as trees and grass, or through recycling crop, animal and household residues, e.g. in the form of compost.

A vital benefit of agroforestry is the input of organic material from trees. If nitrogen-fixing trees and plants are used, in e.g. improved fallows, high amounts of nitrogen are added together with the organic material (Rosenstock et al., 2014). This is especially relevant for female farmers as they in general have smaller plots, less access to expensive agricultural inputs such as inorganic fertilisers and manure, and less time to collect organic material from outside their farms (Kiptot & Franzel, 2011). Globally, women make up just 13% of agricultural land holders (UN Women, 2017b).

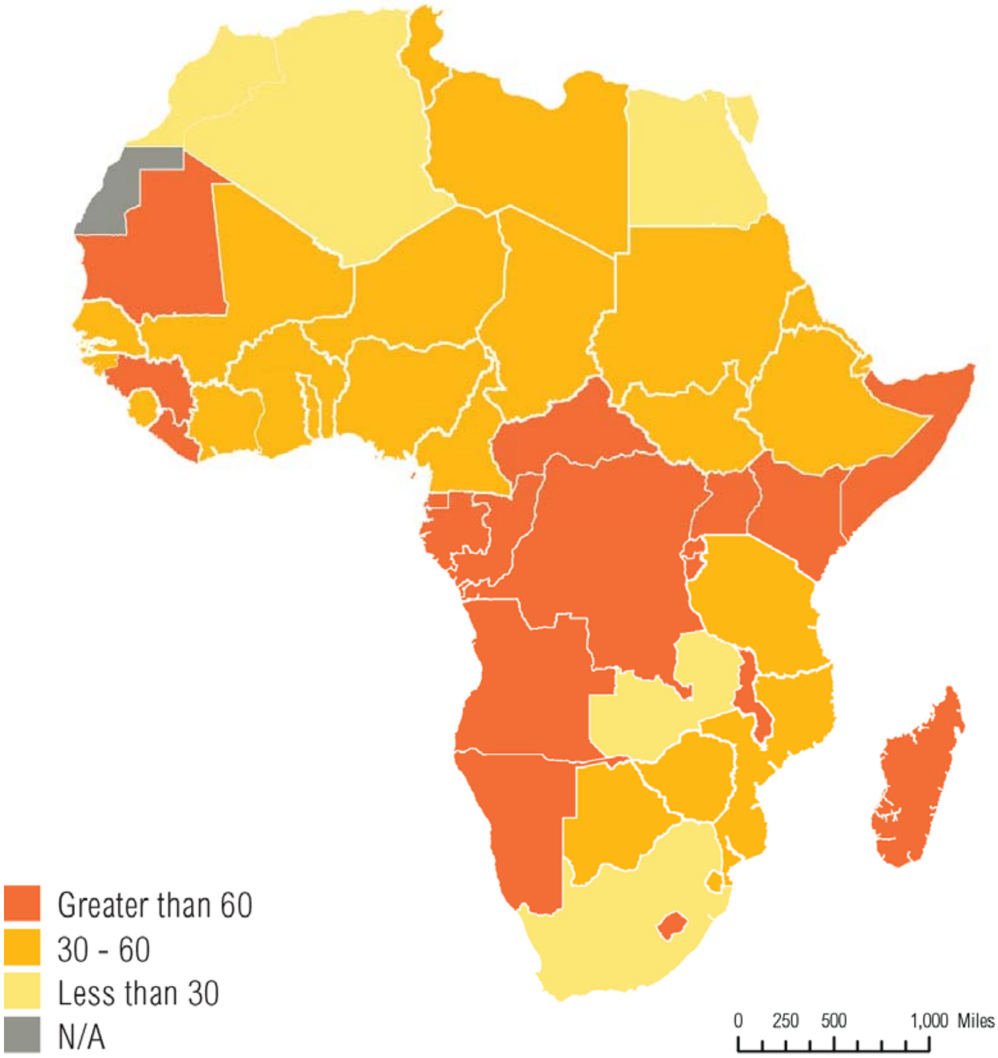

Figure 5.3. Annual nutrient depletion from agricultural soils in Africa. Figures are given in kg NPK per ha and year (Winterbottom, 2013).

5.3.1 Soil nutrient content and circulation

Nitrogen-fixing plants live in symbiosis with rhizobia-bacteria. The bacteria establish inside the roots and capture atmospheric dinitrogen (N_2) as a by-product when producing ammonium. The ammonium is then converted into different amino acids before being transferred to the plants in exchange of carbohydrates. Trees can also utilise nutrients from deeper soil layers and accumulate them into biomass. When farmers recycle this biomass through mulching, more nutrients are made available for the crops. The scientific evidence that crop yields substantially increase when intercropped with nitrogen-fixing trees is strong. This increase can be several hundred per cent and significantly improve food security as shown in a summary of 94 studies from sub-Saharan Africa. In that summary, it is shown that nitrogen-fixing trees could add more than 60 kg of nitrogen per ha and year and reduce the requirements of inorganic nitrogen fertilisers with 75% while still achieving optimal yields (Akinnifesi et al., 2010). Another review (meta-analysis of many studies), showed that planting nitrogen-fixing trees had positive effects on maize yields and that the trees stabilised yields during droughts and other extreme weather events as well as improved the water use efficiency (Sileshi et al., 2008; Sileshi et al., 2011, Sileshi et al., 2012).

The Malawi miracle?

To tackle food insecurity in Africa through soil enrichment has long been a standing objective of governments and organisations. How to do this has been debated for decades. The World Bank together with other international financial institutions and donors helped to subsidise fertilisers in sub-Saharan Africa in the 1970s and 1980s. As they saw these subsidies holding the private sector back, they stopped and pushed many countries to do the same.

In 2005, when Malawi faced a major food crisis, the president reintroduced subsidies for fertilisers and improved seeds. This resulted in the so-called Malawi miracle. Maize yields almost tripled according to government sources, but to a great cost for the government that spent 13.5% of the national budget on subsidies in 2009. The great success made the World Bank soften its stance on subsidies and some other countries adopted similar strategies as Malawi. The programme induced many initiatives to improve the use of fertilisers in sub-Saharan Africa, but as the economy in Malawi started to collapse in 2010 with many big bilateral donors and investors reducing their support, the fertiliser programme fell apart.

Seeing the downsides of the expensive fertiliser programme at the mercy of international politics, many experts, donors and investors have instead started to promote green solutions with nitrogen-fixing crops and trees. An example of such initiative is the multimillion participatory research project N2Africa. N2Africa is developing and distributing food grain legumes (different types of beans and peas) that produce high yields and have good nitrogen-fixing abilities. The project shows that focusing on and improving multifunctional indigenous species seems to be the best option for small-scale farmers in sub-Saharan Africa and the most sustainable solution to soil enrichment.

Sources: Gilbert (2012) and N2Africa (2017)

5.3.2 Soil structure

Soil structure describes how large soil elements such as soil aggregates, are arranged and form voids (macro-pores). Soil texture describes the arrangement of soil particles (silt, sand and clay) that are not aggregated. Trees affect the soil structure by adding organic material and improving the conditions for microorganisms and soil fauna. In general, more organic material and biological activity in the soil means that the macro-porosity will increase, i.e. the presence of large pores. When the macro-porosity increases the water infiltration capacity of the soil also improves, especially in soils rich in clay and silt, i.e. small particles. The scientific evidence, proving that trees increase the macro-porosity in the topsoil, is strong. This results in reduced surface runoff and erosion, and decreases the risk of waterlogging, further discussed in chapter 5.2 (Akinnifesi et al., 2010; Bayala et al., 2015).

5.3.3 Soil microflora and macrofauna

Microflora such as, fungi and bacteria, are decomposing organic material in the soil and release stored nutrients. A few studies have addressed the effects of agroforestry trees on the microflora composition (Akinnifesi et al., 2010). These studies indicate that the microflora concentration increases in the vicinity of trees, which is expected as trees increase the amount of organic material in the soil (Araujo et al., 2012). Soil processes are also affected by the macrofauna, i.e. termites, worms, ants and beetles. Several studies in southern Africa have shown that the density of macrofauna increases in the vicinity of trees. The composition and density of macrofauna is essential for soil formation processes and the degradation of organic material. Some of the animals living in the soil, especially termites, are still also herbivores and can damage crops. However, such damages are in general lower in agroforestry systems compared with monocultures (Akinnifesi et al., 2010). Kuyah et al. (2016) found that in most agroforestry studies the belowground biodiversity increased in sub-Saharan Africa, which correlated well with increasing crop yields and improved soil fertility.

5.3.4 Erosion control

Erosion is a major problem in humid tropical regions, mainly because of heavy rainfall. When soil is lost through erosion, land is degraded resulting in reduced crop yields. Erosion also affects off-site terrestrial and aquatic environments by causing eutrophication and increased turbidity in lakes, rivers and oceans. Soil losses in the humid tropics are greatest from bare soils, slightly lower from agricultural land with annual crops and very low in forested areas. Vegetation-related conservation strategies such as hedgerows, mulching (see Figure 5.4) and intercropping, can still decrease the erosion rate with as much as 90% compared to croplands where no conservation strategies are practised. If vegetation strategies are combined with soil-conservation methods such as no-till and contour planting without trees, the erosion rate can be reduced to basically zero (Labrière et al., 2015).

Figure 5.4. Tree biomass can be used for mulching. Mulching, in this picture, practised in a field with cabbage in Eastern Uganda. Mulching reduces erosion, and increases the amount of organic material in the soil. (Photo: Linus Karlsson).

More vertical vegetation layers, i.e. when crops on the ground are combined with bushes and tall trees, generally decrease the erosion rate. In complex agroforestry systems, e.g. in homegardens (a smaller plot often near the house, where trees, cattle, vegetables and crops are combined) the erosion rate will thus be very small (Labrière et al., 2015). Studies of steep croplands in Kenya have confirmed that planting hedges is an efficient way to reduce erosion and at the same time increase yields. Some trade-offs have though been identified, in this case, Napier grass commonly grown in agroforestry systems in Kenya competed with the crops and affected the yields (Angima et al., 2002; Mutegi et al., 2008; Janaki et al., 2006).

Summary: Agroforestry & Soil

- Increasing the organic content in soils, reducing erosion, and addressing nutrient deficiency in smallholder farms, in sub-Saharan Africa especially, is essential to halt the degradation of soil resources and improve global food security.
- Agroforestry trees and practices add organic material to the soil, which is important for many ecosystem services, contribute to reduced erosion levels and can provide nutrients that can increase yields significantly.
    - Agroforestry with nitrogen fixing trees can increase crop yields with up to several hundred per cent and substantially improve food security.
    - Nitrogen-fixing trees can reduce the requirements of inorganic nitrogen fertilisers with up to 75% and still achieve optimal yield.
    - Vegetation-related conservation strategies such as hedgerows, can decrease the erosion rate with as much as 90% compared to croplands where no conservation strategies are practiced.
- These benefits are essential for smallholder farmers, especially women who often cannot afford inorganic fertilisers, and where land competition and lack of time put a limit to the amount of organic material they can collect from forests and communal land.

5.4 Biodiversity and ecosystem services

Forests hold more than 75% of the world's terrestrial biodiversity (FAO, 2016b). The conversion of forests to agricultural land is the major reason for biodiversity losses in tropical regions where most of the world's biodiversity reserves are found. High population rates in these regions continue to drive the expansion of agricultural land (Scales & Marsden, 2008). In addition, international trade of agricultural commodities (such as beef, soy and palm oil) continue to drive the expansion of agricultural land (Sembres et al., 2017). In sub-Saharan Africa, small-scale agriculture is a significant driver of forest loss (FAO, 2017b). Biodiversity is important for a number of reasons, not to mention the food and nutrition security of rural farmers. A landscape with a high level of biodiversity allows farmers to seek other sources of food and income when crop yields are low. Furthermore, a diverse landscape is more resilient to shocks and changes, including climate change. Trees also provide shelter and habitats for species that are essential for food production, for example pollinators and natural enemies to pests. Such ecosystem services are especially important for small-scale farmers that use no or low amounts of agro-chemicals (HLPE, 2017). Between 2010 and 2015, the world lost 3.3 million hectares of forest areas. Rural women living in poverty often depend on common pool resources and are especially affected by their depletion (UN Women, 2017b).

5.4.1 Biodiversity conservation

Agroforestry can reduce deforestation and pressure on protected forests by providing bioenergy, timber and other forest products from farmers' fields. Agroforestry also provides a range of ecosystem services such as erosion control and flood mitigation, that benefit the surrounding landscape and thus prevent habitat degradation. Apart from having indirect effects, agroforestry production systems host a significant part of the biodiversity found in tropical forests reserves, as the species richness in agroforestry systems is higher compared to agricultural fields with annual crops (Jose, 2012). Many of the species living in forest reserves are also better protected if agroforestry buffer zones are created around the forests. On a landscape level, agroforestry farms function as ecological corridors allowing species to move between different habitats (Scales & Marsden, 2008). Such corridors are very important in a fragmented landscape as the vitality and survival of a population of species is often dependent on genetic exchange between subpopulations. As the tropical landscape is becoming increasingly fragmented, conservationists need to put more focus on the agricultural land and the farmers surrounding forest reserves (Perfecto & Vandermeer, 2008).

Agroforestry systems with a high canopy cover that are less intensively managed have a higher biodiversity than systems with open canopies (Bhagwat et al., 2008, Jose, 2012). This trend was also shown by de Beenhouver et al. (2013) in a global meta-analysis on biodiversity and ecosystem services in cocoa and coffee agroforestry systems. However, promoting agroforestry with minimum management and a high canopy cover can be a trade-off to increasing crop yields on a farm as unmanaged trees can increase competition (Jose, 2012; Kuyah et al., 2016).

Some species are better suited to adapt to agroforestry landscapes than others. In general, agroforestry favours generalist species (that can live in a wide range of environmental conditions), and species thriving in an open landscape. Other species, however, tend to disappear such as endemic species (only found in one geographical location), restricted-range species (only found on a limited area in the world), and understory vertebrate species (species with a backbone living in the space between the forest floor and the canopy).

As expected, the presence of forest specialists (the opposite of generalists) decreases when forests are converted to agroforests (Scales & Marsden, 2008). The biodiversity in agroforestry systems also depends on the tree composition. As forest plantations often use exotic fast-growing trees, many farmers tend to plant these on their farms. Lack of non-native trees in agroforestry systems compromises the positive effects on biodiversity and several scientific studies have called out for an extended domestication of native trees and use of indigenous knowledge to promote native species. Contrary to the popular opinion in many tropical regions, many native trees have been shown to grow as fast as exotic species when domesticated (Jose, 2012).

Ecological initiatives in Brazil

The Brazilian organisation Centro Ecológico was founded in 1985 in the southern province Rio Grande do Sul as a reaction to the widespread agro-chemical intensive agriculture. The organisation started on a small experimental farm and has since its inception grown to become a national centre that promotes organic and social development of the Brazilian agriculture.

Centro Ecológico supports farmers with extension services in organic farming and agroforestry. The centre also helps to develop local value chains for organic and agroforestry products and linking farmers with markets in the cities. By reducing the number of intermediaries, farmers can compete with larger inorganic farms and get higher profit. By making their products available on the local market, the public interest in organic food has increased significantly.

Many farmers also choose to plant trees among their crops to shade sensitive plants and become less dependent on one specific crop. The agroforestry farms in the region produce banana, papaya, acai, acerola cherries, maize, vegetables, and palmiteiro from which the delicacy hearts of palm is produced. The agroforestry systems in Rio Grande do Sul are very important for the conservation and restoration of the threatened Atlantic Forests by providing habitats and food for the local fauna.

Centro Ecologico also works with domestication of indigenous trees together with an agriculture institute as well as developing value chains for fruits from indigenous trees. One example is "rainforest ice cream" produced with fruits from several indigenous trees, such as guabiroba, acai, butiá, jabuticaba, and araçá, among others.

Source: SSNC (2009) and personal communication André Goncalves, Instituto Federal Catarinese (IFC) and member of Centro Ecológico (2018). Photo: Centro Ecológico.

5.4.2 Pest control

In mechanised and rationalised agricultural systems, pest control is commonly done with chemical pesticides with negative effects on the surrounding environment and human health. However, there are examples of mechanised organic farming practices applied where markets for these products have been established. As a majority of rural farmers in sub-Saharan Africa are resource poor, pest control with agro-chemicals is usually not an option and instead, pests and diseases are controlled by disturbing the environment frequently, i.e. with rotational cropping, burning the land, tilling, etc. Many of these practices are not possible in an agroforestry system and traded for the increased potential of self-regulation within the system (Schroth et al., 2000). The high vegetational diversity in an agroforestry system can increase the abundance of natural predators to pests and reduce the density of the target crop, thus reducing the likelihood that a destructive insect or herbivore will find it. As insects transmit the majority of viruses, these are therefore rarer in polycultures than in monocultures (Pumariño et al., 2015; Ratnadass et al., 2012). Furthermore, the susceptibility to pests and diseases increases with nutrient deficiency and other stresses. As described earlier, these stresses are reduced in a well-managed agroforestry systems (Schroth et al., 2000).

Several studies have confirmed that the effects of pests and diseases on crops are reduced in agroforestry systems, especially for perennials. Some studies have though shown that the risk of pests and diseases can increase when the wrong combination of trees and crops is chosen and the trees become pest-hosts in between growing seasons. To determine suitable combinations is not always easy and requires extensive experience, knowledge and research (Pumariño et al., 2015; Ratnadass et al., 2012). In an extensive review of tree-crop interactions in sub-Saharan Africa, pest control was found to be positive in 68%, negative in 15%, and not affected in 26% of the studied agroforestry systems (Kuyah et al., 2016).

5.4.3 Pollination

Pollination has been estimated to contribute with benefits of about US$200 billion for domesticated and wild plants (Jose, 2012) and corresponding to an annual market value of $235 billion to $577 billion worldwide directly attributable to pollination (IPBES, 2016). Thirty-five per cent of the global food production is dependent on insect pollination (HLPE, 2017) and in a recent study by Garibaldi et al. (2016) they showed that a diversity of pollinators was especially important for vulnerable small-scale farmers in the tropics and increased yields significantly.

Today, colonies of managed honey bees are declining and high seasonal colony loss has been reported in some regions, and the interest in other native wild species has increased. Forests are essential for providing habitats for wild bees and other pollinators, and studies have shown a negative correlation between the distance to a forest and pollination rates. In a fragmented landscape, forest strips and forest fragments are therefore important habitats for pollinators (HLPE, 2017).

Summary: Agroforestry & Biodiversity

- Conservation of biodiversity is essential for a number of ecosystem services, necessary for global food production and important in building resilience to e.g. climate change.
- Agroforestry production systems host a significant part of the biodiversity found in tropical forests reserves, as the species richness in agroforestry systems is higher compared to agricultural fields with annual crops. On a landscape level, agroforestry farms function as ecological corridors allowing species to move between different habitats as well as provide important habitats for pollinators.
- A growing demand for food and biofuels risks reducing the terrestrial biodiversity further. However, agroforestry is a promising land management system to slow down this trend by conserving more biodiversity than agricultural systems with annual crops. To fully take advantage of the positive effects, it is important to use indigenous trees in agroforestry systems.
- Agroforestry can also reduce the negative effects from pests and diseases on yields but the increased vegetational diversity in an agroforestry system does not per se mean better pest and disease management. Therefore, thorough design of agroforestry systems is essential to avoid combining trees that can host pests and diseases in between growth seasons.

5.5 Food security, nutrition and household economy

In 2017, the number of undernourished people in the world increased to 821 million. For the third year in a row, there has been a rise in world hunger. The highest prevalence is found in sub-Saharan Africa and especially in Eastern Africa, where one third of the population does not have access to sufficient amounts of calories (FAO et al., 2018). Globally, around two billion people also suffer from so called “hidden hunger”, i.e. they are lacking one or many micronutrients. Lack of iron, vitamin A, zinc and iodine are the most common micronutrient deficiencies causing serious health problems (Sunderland et al., 2013). Malnutrition and undernourishment cause stunting, i.e. when a child is too short for his or her age, and is affecting 23% of all children. Most of these children live in Southern Asia and sub-Saharan Africa (UNICEF et al., 2017). Another common syndrome caused by malnutrition and undernourishment is anaemia, affecting one-third of all women in reproductive age, with the highest prevalence in sub-Saharan Africa (39%) and Southern Asia (49%) (FAO et al., 2018). Women and girls are also overrepresented among those who are food-insecure, accounting for around 60% of the all undernourished people (WFP, 2009). In nearly two thirds of countries, women are more likely than men to report food insecurity (UN Women, 2017).

To be food secure, food should be available, accessible and safe to eat while also meeting the physiological requirements of each individual (World Food Programme, 2018). Poverty and food security are closely interlinked and according to the most recent figures from 2013, 770 million people in the world live below the poverty line. Half of these are found in sub-Saharan Africa. A vast majority of the global population living in poverty is employed in the agricultural sector in rural areas (World Bank, 2016). Without money, farmers cannot access food even if it is available. Food affordability, i.e. income compared to the relative price of food, is lower in sub-Saharan Africa than in any other region of the world (FAO, 2017). During periods with low yields, many farmers and especially women therefore rely on forest products for food and additional income. Forest products are also important to reduce malnutrition, as they are rich in nutrients, fibres and proteins. However, deforestation and increasing pressure on forests have limited the availability of these important products (FAO, 2013).

5.5.1 Agricultural yields

In general, crop yields increase when different soil and water conservation practices, including agroforestry, are implemented on a farm. A large meta-study by Branca et al. (2013) on cereal production in Asia and sub-Saharan Africa, measured how different management strategies increased agricultural yields. The study divided different strategies into: agronomic practices (e.g. use of cover crops and crop rotation), organic fertilization (e.g. compost and use of animal manure), minimum soil disturbance (e.g. reduced tillage combined with mulching), water management (e.g. terraces, contour farming and in-situ water harvesting), and agroforestry (a range of activities where trees with different functions are intercropped with the crops). The review found that the increase in yields was in the range of 100% for all the different strategies and that the increase in general was more pronounced in sub-Saharan Africa than in Asia (Branca et al., 2013).

Another review by Reed et al. (2017), addressing production and productivity in the tropics, found that trees increased or had no effect on yields in a majority of the studies. The increase was positive in 47%, neutral in 5% and negative in the 48% of the studies. The positive trend was stronger in Africa and the Americas, while in Asia trees actually decreased crop yields in 48% of the studies. Many of the studies that showed a negative correlation between vicinity of trees and crop yields explained this with competition for resources, but showed that other benefits from trees often compensated yield losses. The study also made an effort to estimate the effects from trees on livelihoods and found net negative effects only in 15, 25, and 8% of the studies in Africa, Asia, and the Americas respectively. Most of the reviewed studies were originally done on agroforestry systems practising e.g. alley cropping (Reed et al., 2017). Kuyah et al. (2016) showed that tree-based systems in general increased the yields in sub-Saharan Africa. The extensive review found that crop yields increased in 68%, were unaffected in 14%, and decreased in 18% of the studied systems. They found that nitrogen-fixing trees increased yields in improved fallows and that tree management and climatic conditions in general determined yields in non-rotational systems. A high density of trees could decrease yields by competing with crops for nutrients, light and water.

In a review summary of 94 studies from Sub-Saharan Africa, Akinnifesi et al. (2010) also concluded that using nitrogen-fixing trees increased yields up to several hundred per cent and significantly improved food security.

Successful rural development project around Mount Meru, Tanzania

Between 1989 and 2000, Sida, the Swedish International Development Cooperation Agency, funded the Soil and Water Conservation Project in Arusha (SCAPA) to address the severe land degradation around Mount Meru. The objective of the project was to develop the land management skills among rural farmers. This was done by integrating soil and water conservation packages into extension services in agriculture, forestry and livestock husbandry.

By introducing improved land management practices that also focused on increased production and improvement of food security, the project succeeded where previous projects had failed. Among the techniques that were promoted in the project, various soil and water conservation practices and agroforestry were the core activities.

The project had significant effects on the food production and the evaluation estimated that the combined effects of the extension services increased the yields of maize and beans with 50-150%, though requiring more inputs in terms of labour and technical resources.

Source: Celander et al. (2003).

5.5.2 Income generation

Few studies have tried to estimate the effects of agroforestry on farmer income but Miller et al. (2016) compared the economic situation of tree growing farmers with farmers without trees. The study was extensive and more than 20,000 rural households were assessed in Ethiopia, Malawi, Nigeria, Tanzania and Uganda. In three of the five countries (Ethiopia, Nigeria and Tanzania), farmers growing trees for cash-crops were significantly better off. Positive effects on the purchasing power were also found among farmers in Ethiopia, Nigeria and Uganda that had fruit trees on their farms. However, no difference in purchasing power was found for farmers growing trees for timber compared to farmers without trees. As the study did not include a time-aspect it was difficult to determine why farmers with trees had more money.

Maroyi (2009) studied how the use of homegardens (a smaller plot often near the house where trees, cattle, vegetables and crops are combined) in Zimbabwe affected rural livelihoods. He found that most of the products from the homegardens were consumed by the farmers themselves and contributed to the food security, especially important for vulnerable farmers in times of hardship. However, some of the harvest was sold on a local market and provided a small additional income. Quinion et al. (2010) assessed how different agroforestry practices affected rural livelihoods in Malawi. They saw that intercropping with nitrogen-fixing trees increased yields and provided an additional income for the farmers, mainly from sales of agroforestry tree seeds and fuelwood. Tougiani et al. (2008) studied how food security and income generation in rural communities changed after agroforestry practices were implemented in Niger. They found that trees on the farms had increased the domestic consumption and that the sale of tree products, especially fuelwood, was an important contributor to farmer income. Some farmers in Niger have also adopted more complex agroforestry systems, which has further diversified and increased their incomes.

In many areas of sub-Saharan Africa, exotic trees are planted on farms, as they are perceived as more productive compared to indigenous trees and very few indigenous tree species have been domesticated. Contrary to this preference for exotic species, a two-fold improvement or more in quality or yield is possible for many wild tree species through genetic selection (Jamnadass et al., 2011; Dawson et al., 2013). For example, Waruhiu et al. (2004) showed that local selection of safou stands could increase the economic value of the produced material with 400%. This shows an underutilised potential and that domesticated indigenous trees can effectively produce high quality timber and other products (Dawson et al., 2013).

5.5.3 Livestock and milk production

Access to quality fodder is limited in sub-Saharan Africa and together with animal health issues, this led to low livestock productivity (reproduction and growth) and low milk production per animal. The use of fodder shrubs is a suitable agroforestry practice to improve livestock production as these compete only marginally with crops (Kiptot et al., 2014). In East Africa, the most common fodder shrub is *Calliandra calothrysus* and studies have shown that 2 kg of dry Calliandra leaves can increase milk production from a cow with 0.6-1.3 kg per day. One kg of dried leaves corresponds to 3 kg of fresh leaves and the plant is fast growing and matures in 9-12 months and then ready to be cut periodically (Place et al., 2009). In East Africa, 200,000 smallholder dairy farmers grow fodder shrubs to increase their milk production. This activity is estimated to increase the revenues from milk sales with around US$100 per year and cow (FAO, 2013). Paterson et al. (1998) reviewed the effects of planting fodder shrubs such as Calliandra, on milk production in Kenya. They concluded that fodder shrubs were more resilient to drought compared to grasses as they have deeper roots. The study showed that 160-250 metres of Calliandra bushes could replace the farmers use of commercial dairy meal. In another study, Place et al. (2009) estimated the effects from fodder shrubs by reviewing previous research in East Africa. They found that 205,000 smallholder dairy farmers, of which almost half were women, had adopted the agroforestry practice in 2005. On-farm field trials showed that feeding a cow with 2 kg of dry Calliandra per day in addition to grass increased the milk production with 10%, i.e. 450 kg per year. One kg of dry Calliandra thus resulted in 0.6-0.8 kg of milk. Place et al. (2009) also developed several scenarios for the adoption of fodder shrubs on farms in East Africa and estimated the economic impacts from these. They found that if a farmer planted 500 bushes of Calliandra, he or she could increase the net income with US$101-US$122 per year in the beginning of the second year after plantation. For most farmers, daily incomes from milk sales and manure are very important for their livelihoods as these provide a steady stream of money.

An innovative investment model to improve milk production around Mount Elgon, Kenya

Margaret Muchange in Kiminini, Kenya is one of the farmers participating in the project. She receives trainings and advice through the dairy cooperative where she is a member.

Around Mount Elgon in Kenya, deforestation, uncontrolled grazing and unsustainable agricultural practices such as burning of residues have led to land degradation, loss of biodiversity and soil erosion. Yields are low in the area along with a variable milk production. A new project running since 2015, aims to halt this development by strengthening 15 cooperatives to become professional hubs for business, providing extension services to farmers, connect them to the dairy market and create a secure supply chain of milk for the dairy. The project is a partnership between three parties: The Livelihoods Fund provides the upfront financing for the project implementation and in return generates carbon credits to its investment partners; the development organisation Vi Agroforestry implements and monitors the project, and the company Brookside Dairy co-invests by guaranteeing to buy quality raw milk from farmers over a period of 10 years.

Around Mount Elgon, 30,000 farmers will be trained in sustainable farming practices of which agroforestry is an important component. The farmers are reached through 1,200 farmer groups and the 15 cooperatives. The cooperatives are supported to improve the supply chain of milk, including quality assurance. Furthermore, the cooperatives are strengthened to better reach their members with veterinary services and artificial insemination. The project aims to double or triple the milk productivity from today's 3 litres per cow and day. This will be possible by promoting fodder crops on the farms, for example through agroforestry fodder trees, and introduce improved breeds through artificial insemination. The project aims to increase revenues and improve livelihoods of 30,000 farmers. By farmers adopting sustainable agriculture on 35,000 hectares of land, crop yields are expected to increase by 30%. The project aims to sequester 1 million tonnes of CO_2 over 10 years.

Source: Livelihoods Fund et al. (2016). Photo: Livelihoods Fund (Laurent Joffrion).

5.5.4 Nutritious products and access to food

In East Africa, the daily fruit consumption is only 35 g compared to the recommended consumption of 400 g per day (Kiptot et al., 2014). Agroforestry contributes with important nutritional security as the diversification provides the farmers with a more varied diet, if for example trees providing fruit or nuts are used. Many of the fruit and nut trees used in farms are exotic (Nyaga et al., 2015), but there are also examples of traditional indigenous tree species. Fruits and nuts are often rich in vitamins, micronutrients, fibres and proteins. Such products have historically been collected from the forests, but as forest reserves are decreasing and becoming degraded, trees on farms play a more important role for the nutritional security (Dawson et al., 2013).

Agroforestry has many implications for the access to food. As described in the chapter 5.6 Energy, agroforestry improves the access to bioenergy for food preparation. This allows farmers to cook crops that require a longer time on the stove but that are also rich in nutrients. Access to trees also provides an important coping mechanism when households run out of food. In a survey done in Malawi, Zambia and Zimbabwe, 26-50% of the households reported that they collect fruits and nuts from indigenous trees to deal with hunger during food scarce periods. This coping mechanism is especially important for women as they are considered to have the right to such tree products in many regions (Kiptot et al., 2014). Another example is the agroforestry system homegardens, covering 13% of Sri Lanka. For land users living in poverty, these are an insurance or safety net in times of increasing food prices or harvest failures according to a recently conducted literature review (Mattsson et.al, 2017).

Furthermore, by mixing different tree species among their crops, farmers can have access to ripe fruits and other tree-products all year around since the harvest period varies between different species. This variation is not as apparent for different staple crops that are in general harvested during the same period in a year (Dawson et al., 2013).

Agroforestry in Malawi improves food security

Three-quarters of Malawi's 13 million people are smallholder farmers of which many are considered food-insecure. Funded by Irish Aid, The World Agroforestry Centre (ICRAF) has implemented an agroforestry programme in the country to address different dimensions of food security. The project improved maize yields by promoting intercropping with fertiliser trees (nitrogen-fixing trees). Farmers were guided to plant fruit trees to improve the nutritional value of the food and get extra income. Fodder trees were also promoted to improve milk production and trees to provide fuelwood were planted to ensure a stable access to bioenergy. The project reached 180,000 farmers between 2007 and 2011 in its first phase and 179 million fertiliser trees were planted, mostly Tephrosia and Sesbania on a short term rotation in improved fallows. Furthermore 370,000 fruit trees were planted for improved nutrition, health and income among the adopters. An external review indicated that the extension programme increased maize yields for the beneficiaries and improved the food security. Farmers receiving extension services also increased their dietary diversity by consuming more fruits grown on their farms.

Source: Dawson et al. (2013) and ICRAF (2014).

Summary: Agroforestry & Food security, Nutrition, Household economy

- 770 million people today live below the poverty line and a majority of these are smallholder farmers in rural areas. Poverty and food insecurity are closely interlinked and 821 million people are undernourished in the world. Sub-Saharan Africa has the highest prevalence of both poverty and food insecurity along with the lowest food affordability.
- Agroforestry practices (e.g. improved fallows and intercropping with hedge rows) increase agricultural crop yields. However, competition can reduce yields when one or many resources, such as nutrients, light or water are scarce. It is therefore essential to use appropriate tree species and proper design and management of agroforestry systems in order to get the best possible contribution to agricultural food production.
- Few studies have estimated the economic effects of agroforestry on a farmer income. The ones that have been done indicate that farmers using agroforestry systems can earn more cash from improved yields and sales of tree products.
- Planting fodder shrubs can be done without decreasing the availability of light, nutrients and water for adjacent crops. Fodder shrubs, and especially Calliandra, are commonly planted in East Africa and can increase milk production and net farmer income, if well managed.
- Malnutrition affects billions of people around the world. Agroforestry trees, such as fruit and nut trees, are important to reduce malnutrition, as their produce are often rich in vitamins, micronutrients, proteins and fibres. To plant such types of trees on the farms will become even more important as the access to forests in food-insecure areas is decreasing.

5.6 Energy

Fuelwood and charcoal from trees have historically been given little attention even though these forest products are essential for about 2.4 billion people, providing them with energy to cook food. Of these 2.4 billion, 660 million live in Africa (HLPE, 2017) where women are the main collectors of firewood, a time-consuming and physically demanding task when wood sources are located far from the home. In Asia, women are also responsible for fuelwood collection but are helped out more by men. In Latin America, men dominate this area (Sunderland, et al. 2014).

In sub-Saharan Africa the demand for bioenergy is increasing rapidly. In 2007, the charcoal industry in the region was estimated to turn around US$8 billions (FAO, 2013) and is estimated to account for 80% of the primary energy consumption, i.e. all energy consumed within the region including losses in electricity production and transformation (Iiyama et al. 2014). Deforestation and increasing pressure on forested areas are today limiting the access to bioenergy from trees, compromising the food security in many rural regions (FAO, 2013).

5.6.1 Bioenergy access and agroforestry

The contribution from agroforestry trees to the global supply of fuelwood is difficult to determine accurately, but estimations show that agroforestry produces around 20% and 70% of the fuelwood in Africa and Asia (Sharma et al., 2016). Jama et al., (2008) studied fuelwood production on agroforestry farms in Western Kenya. The farmers in the study had 0.01-0.08 ha of improved fallows, generating fuelwood that lasted 12-125 days when harvested. The researchers showed that if the area used for improved fallows increased to 0.25 ha, which is the average area that lies fallow on farms in densely populated Western Kenya, 6 months of improved fallows would provide fuelwood for 0.7-1.5 years. Eighteen months of improved fallows would generate fuelwood for 1.9-3.2 years. Both these options would thus make the farmers self-sufficient in bioenergy and directly benefit women and children who are today tasked with the chore of supplying fuelwood (Jama et al., 2008). In Kenya, Mugo (1999) showed that women spent on average 130 hours per year collecting firewood from outside their farms, while women that harvested fuelwood on their farms spent 36 hours per year with this task. Kumar and Hotchkiss (1988) showed that deforestation increased the time women need to spend on collecting firewood in Nepal. A study from western Kenya showed that women often spend around two to five hours per day collecting firewood (IFAD & FAO, 2003) and in another study by Malmberg Calvo (1994) women spent 800 hours per year collecting firewood. The corresponding number Gambia and Tanzania was 300 hours. Njenga (Personal communication, 19 April 2018) studied how much time women that used forests for fuel provision spent collecting firewood in two Kenyan villages. On average, these women spent one working day per week collecting firewood carrying heavy loads on their backs for long distances. In Figure 5.6, cooking fuelled by branches collected from agroforestry trees on a farm is shown.

Figure 5.6a. Water is boiled on a “three-stone stove” in Uganda. (Photo: Linus Karlsson)

Figure 5.6b. Food is cooked on an energy efficient stove in Uganda, with smoke led out of the kitchen. It is fuelled by branches collected on the farm. (Poto: Vi-skogen, Ylva Johansson)

Summary: Agroforestry & Energy

- Bioenergy from trees is an important source of energy for households, especially in sub-Saharan Africa where women are the main collectors of fuelwood.
- Agroforestry has potential to support farmer self-sufficiency in bioenergy if practices such as improved fallows are expanded.

5.7 Conflicts and social stability

The global population is expected to reach between 7 (low population growth scenario) and 16 billion people (high population growth scenario) by the end of this century. The medium scenario predicts 11.2 billion people and basically all population growth takes place in Asia and Africa. The population in several countries in sub-Saharan Africa will continue to grow significantly throughout the 21st century and even multiply. For example, the population in Niger is expected to increase from 20 million people today to an astounding 209 million people by the end of the century (FAO, 2017c). A larger population together with changing consumption patterns will create a massive demand for food, feed, fuel and fiber. The demand for agricultural products (both food and non-food commodities) is expected to grow with 1.1% per year during the first half of the 21st century (different commodities have in this estimate been aggregated according to their prices). The production of cereals is expected to increase from 2 billion tons in 2005/2007 to 3 billion tons in 2050 and meat production from 258 million tons to 455 million tons for the medium population growth scenario (these estimations are based on the UN population projection from 2008 which estimates 9.15 billion people in 2050) (Alexandratos & Bruinsma, 2012). The increasing demand for agricultural products will likely lead to additional conflicts between biodiversity conservation and agricultural production, especially in sub-Saharan Africa and South America (Laurance et al., 2014). Furthermore, globalisation and competition for land will likely create conflicts as rural smallholder farmers can lose access to private and communal land due to unclear land rights. Women are particularly vulnerable in such conflicts as their rights to land and decision-making often are repressed. Conflicts between farmers are also likely to increase when competition for land and resources intensifies (Anseeuw et al., 2012).

5.7.1 Agroforestry and land conflicts

Some agroforestry practices are believed to reduce conflicts, especially in areas lacking well-defined boundaries where the competition for land is significant. In such areas, where livestock farmers compete for resources on communal land, a transition from communal land management to a more privatized land management enables diversification and intensification of land use, for example by implementing agroforestry and/or planting fodder shrubs. Live fences (or conventional fences) around "privatized" areas are a prerequisite for this type of intensified management. This transition within a community can decrease the competition for communal land and thus decrease conflicts. However, a "privatization" can favour some people within a community and thus induce conflicts and reduce the possibilities for people depending on the communal land. Private management and enclosures can also decrease the number of farmers migrating to distant grazing ground. Such migration sometimes results in conflicts with deadly outcomes (FAO, 2013; Nyberg, Personal Communication 19 April 2018).

Kirabo et al. (2011) investigated causes for conflict in western Uganda and found that land scarcity was the most important underlying source for resource-related conflicts, especially when cattle farmers were involved. The most effective measure against these conflicts was to involve the police but the study showed that there was a significant potential in using agroforestry as a sustainable option, as agroforestry could contribute to a more effective use of the land, i.e. create more resources, create boundaries and reduce land degradation. The local farmers considered many agroforestry practices as effective strategies to mitigate conflicts.

This has been tested in a development and research project in West Pokot during the past three decades. Enclosures and agroforestry were introduced to the local pastoralists to address the severe land degradation in the area. The initiative has significantly improved the land management and the living conditions for the local people (Nyberg et al, 2015; Triple L, 2015). In an interview-based study by Saxer (2014) the interviewees in general perceived that conflicts in the area had decreased. However, new conflicts had erupted over boundaries, trespassing and the land market.

Agroforestry could also be effective to reduce illegal logging in forest reserves. In the Ecomakala project near Goma in the Democratic Republic of Congo, WWF has helped farmers to establish woodlots on marginal land and agroforestry-cocoa systems to supply the growing population with fuelwood and timber. This relieves the pressure on and reduces illegal logging in the Virunga Forest, a protected biodiversity hotspot (NGP, 2017). Murniati et al. (2001) studied the same principle on the Sumatra Island in Indonesia. The study found that farmers that combined annual crops such as rice with multi-layered agroforestry gardens (gardens with multiple vertical layers of vegetation, e.g. vegetables and other cash crops, bushes and trees) were much less prone to enter the national parks in search for fuelwood, timber, fibres and game, compared to farmers that only had annual crops or agroforestry gardens. Thus, agroforestry systems combined with annual crops could help to conserve biodiversity in the national parks and stop illegal collection of timber and fuelwood. The study proposed that a stricter enforcement of park boundaries should be accompanied with agroforestry initiatives to avoid conflicts.

Summary: Agroforestry & Conflicts and Social Stability

- The global demand for food, feed, fuel and fibre will increase significantly in the future and likely create more conflicts between farmers, and between different land uses, e.g. food production, biofuel production and biodiversity conservation.
- Agroforestry could mitigate such conflicts by improving the productivity of farms, thus decreasing the pressure on communal resources.

5.8 Gender equality

In many regions around the world, women are responsible for the agricultural production. In lower income countries, women comprise 43% of the agricultural labour force. This figure is lower in South America (20%) but almost 50% in Eastern- and South-eastern Asia and sub-Saharan Africa (FAO, 2011). This demographic pattern is caused by male migration out of rural areas to cities or other countries in search for more lucrative occupations (Slavchevska et al., 2016).

Across regions, women have less access than men to agricultural resources and inputs, such as inorganic fertilisers and manure. Female farmers do not have equal control over land as men, they make less use of improved seed varieties, have limited access to credit, have lower education levels and have less access to extension services (FAO, 2011). According to UN Women (2017), globally, women are just 13% of agricultural land holders. These factors also prevent women from adopting new technologies (FAO, 2011). In addition, women have less time to devote to food production and other income opportunities, as they often are responsible for additional household chores. This, together with women not having the same access to markets as men and thus to income, make them more vulnerable to changes and shocks. (Sida, 2015). If these barriers were addressed and women had the same access to productive resources as men, they could increase yields on their farms by 20–30 per cent. This could raise total agricultural output in developing countries by 2.5–4 per cent, which could in turn reduce the number of hungry people in the world by 12–17 per cent (FAO, 2011).

In regard to forestry, women contribute to both the formal and informal sectors in many ways, playing significant roles in for example agroforestry, tree improvement, and forest protection and conservation. (FAO, 2011). Forests represent an important source of employment for women, however, sex-disaggregated data is inadequate (FAO, 2010b). In Africa and Europe, women tend not to hold senior or policy-making positions in the sector. There is however limited information on the numbers and roles of women in contracting or self-employed forestry work (FAO, 2011). Despite women's contribution to the sector, the roles of women are not fully recognized, their wages are not equal to those of men and their working conditions tend to be poor (FAO, 2011).

5.8.1 Agroforestry for gender equality

In Africa and other regions, women do not usually have the same access to savings and credit as men. In Kenya, 40% of all small-scale farm managers are women, but they receive less than 1% of the agricultural credit. Agroforestry is a low-cost system that requires small amounts of inputs, at least after establishment, and is therefore also accessible for women. Gender roles are also reflected in the ownership of trees and their products. Even if there are large differences in gender roles in sub-Saharan Africa, women tend to benefit from tree products with less commercial value, i.e. products that are not linked to forest plantations and their value chains. Several studies have confirmed that men usually deal with and benefit from timber and therefore favour timber-producing trees, while women favour trees that produce indigenous fruits, fodder, mulch and fuelwood. In west and southern Africa, studies have shown that such products provide a substantial part of women’s income. In general, men have financial objectives when planting trees while women have a stronger interest in soil protecting measures and trees for domestic consumption (Kiptot & Franzel, 2011).

These gender roles have implications for how agroforestry systems should be designed. For example, collecting fuelwood and fodder is often considered to be the women’s responsibility and thus, improving the access to these products on the farm would allow women to use more of their time for income generating activities. To financially quantify how this affects women is not thoroughly studied (Kiptot & Franzel, 2011), however some studies have been done (see 5.6.1). Milk is another important product from many agroforestry systems and according to Kitptot et. al (2014), a few studies have looked at women's access to income from dairy products. These studies have shown that women have a rather good access to cash generated from milk sales. In Uganda and Tanzania, women managed and controlled almost 40% of the income from formal markets and over 70% from the informal markets. These figures indicate that a formalization of the milk value chain can result in negative effects on gender equality and should be addressed in rural development projects, when milk production is promoted in agroforestry systems (Kiptot et al., 2014).

A recently conducted review by Lisa Westholm and Madelene Ostwald (2018) went through 104 articles focusing on gender equality and women in food production in multifunctional landscapes. In the review, it was revealed that practices such as agroforestry created opportunities as well as risks for women´s empowerment, participation and rights to economic and natural resources. Among other things the study shows that these landscapes do provide unique opportunities for women to play a central role in food production and value chains despite limited access to e.g. land. However, gendered norms around production and trade are unstable. Sensitivity to how local relations of power, tenure and ethnicity influence control over value chains and strength of voice in decision making is thus important in policy formulation or projects aimed at increased gender equality in these landscapes. Several studies of Non-Timber Forest Products (NTFPs) showed that without this sensitivity an unintended consequence can be that men take over parts of a value chain when the profitability from the products increases; such as the shea value chain in Burkina Faso. As access and benefit from NTFPs can be structured based on both gender and ethnicity, policies aiming at increasing their value can lead to increased competition and conflict. A way forward according to the authors is that: "Policy-makers need to be aware of the different products and services produced in multifunctional landscapes, and of the customary organisation that influences access to, and decision-making about, these products." (Westholm & Ostwald, 2018)

Summary: Agroforestry & Gender Equality

- Women are major, but largely neglected, food producers in many parts of the world and especially in sub-Saharan Africa and South Asia. There are a number of barriers discriminating and preventing female farmers from reaching their productive capacity, such as limited land rights, and limited access to extension services and to savings and credits. This inequality significantly contributes to global food insecurity and poverty.
- Agroforestry is in many ways a land management system that is suitable to support women and reduce gender inequalities.
- Agroforestry is a low-cost system that requires small amounts of inputs such as organic and inorganic fertilisers and chemicals for pest management, and is therefore also accessible for women. Gender roles are also reflected by the ownership of trees and their products, and as women tend to benefit from tree products with less commercial value such as fruits, fodder, mulch and fuelwood, these gender roles have implications for how agroforestry systems should be designed.

5.9 Deforestation

There are many different drivers for deforestation but, in general, a qualification of deforestation drivers is lacking. On a global scale, agricultural expansion is estimated to be the main driver of forest loss and responsible for around 80% of all deforestation. This expansion is driven by both large-scale export-focused production and subsistence agriculture, primarily producing for a local or national market. In many countries with a tropical climate, large scale production has been shown to be the prevalent driver of forest loss (FAO, 2016b). The scientific literature indicates that the drivers of tropical deforestation have become increasingly commercialised and globalised in recent decades; commercialised in the sense that the agents of deforestation have shifted from smallholders clearing forest for subsistence farming to large-scale agricultural corporations clearing for profits; globalized as the agricultural commodities produced on the cleared land are increasingly destined for export rather than domestic markets (Henders et.al, 2015).

Commercial agriculture and timber extraction play an important role in causing tropical deforestation. However, information is scarce on the extent to which production and trade of 'forest-risk' commodities like beef, soy, palm oil and wood products are actually driving tropical forest loss. A recent study (Henders et. al, 2015) show that in the period 2000-2011, the production and trade of four commodities in just seven tropical countries was responsible for 40 % of global tropical deforestation and associated carbon emissions (Henders et.al, 2015). In South America, large scale food agriculture accounted for almost 70% of all deforestation between 2000 and 2010. In the Amazon, deforestation was mainly due to production of meat and soybean and oil-palm plantations. In southeast Asia, oil-palm plantations for the food industry and to some extent biofuel production have replaced large areas of natural forests. In Africa, it is instead small-scale agriculture that is replacing forested areas and large-scale agriculture accounts for only one third of all deforestation (FAO, 2016b). Between 1963 and 2007 the area under cultivation increased globally with 176 million ha (FAO, 2017c) and between 2000 and 2010 basically all agricultural expansion took place in tropical regions at the cost of forest loss (FAO, 2016b). By 2050, the world's population is expected to increase to 9.8 billion people (UN Department of Economic and Social Affairs, 2017). Population growth together with a growing urban middle-class with dietary preferences for meat, fruits and vegetables produced for an international market is putting additional pressure on land and water resources (FAO, 2017c).

To meet this growing demand for food, biofuels and fibres, studies have estimated that the agricultural area needs to be expanded with over 70 million ha. In lower income countries, this will mean an expansion of arable land in use with 110 million ha and a decline in agricultural area in higher income countries with 40 million ha (Alexandratos & Bruinsma, 2012). Most of this agricultural expansion will take place in Africa and Asia, in tropical regions (Minang et al., 2015). FAO (2017c) emphasizes the importance of integration between different sectors, e.g. forestry and agriculture, to ensure that conflicting interests do not cause an unsustainable rural development. An integrated land-use approach is essential both on a policy level and on the ground, as agroforestry is one of the most important actions to improve the efficiency in subsistence agriculture to meet the growing demand for food, fuel and fibres.

5.9.1 Effects of agroforestry

Studying the link between deforestation and agroforestry has not been prioritized by agroforestry researchers. A study from Peru (Sanchez & Benites, 1987) has created a widespread belief that conversion of one hectare of agricultural land to agroforestry reduces deforestation with five hectares. This, because agroforestry is a more sustainable land management system that does not lose its productivity after a few years, and thus the need to clear new land for production is decreasing. However, if agroforestry increases profitability of land it is likely that pressure on land increases, as a return on an agricultural investment increase. This would attract more people to the sector and give farmers incentives to expand their land. This development is likely if there are no factors limiting the agricultural expansion. Such factors are strong commitments to forest conservation reflected in legislation and other regulatory mechanisms and lack of labour (Angelsen & Kaimowtz, 2004) See also 5.7.1 regarding how agroforestry could be effective to reduce illegal logging in forest reserves.

Summary: Agroforestry & Deforestation

- Expansion of agricultural land is the main driver for deforestation globally. In the future, it is likely that the growing need for food and animal feed will require even more land for crop and livestock production.
- Transforming agricultural land to agroforestry could both reduce and increase deforestation. It can reduce deforestation, as agroforestry is a more sustainable land management system that does not lose its productivity after a few years, and thus the need to clear new land for production decreases. Also, agroforestry can reduce pressure on forests, as it provides bioenergy, timber and other forest products. However, if agroforestry increases profitability of land, it is likely that pressure on land increases as a return on an agricultural investment increase. This would attract more people to the sector and give farmers incentives to expand their land. The final outcome is largely dependent on factors such as laws governing deforestation.

6 BARRIERS IN THE UP-SCALE PROCESS

A scale-up process starts by identifying improvements and innovations. These are then tested and refined in pilot projects and thereafter widely disseminated. This process can be more or less participatory (Coe et al., 2014).

Barriers can be identified on different levels and for different actors in the scale-up processes. Barriers are found at farmer level, where technical, economic and social challenges prevent farmers from implementing and spreading agroforestry practices. They can be found in the whole value chain, limiting the possibility for farmers to reach markets with their products and preventing companies to engage. Barriers are also commonly preventing dissemination of knowledge by for example limiting extension services and knowledge exchange between farmers. There are barriers that are preventing research from serving the scale-up processes and barriers in institutional environments and policies.

This chapter is organized according to the different types of barriers that can be found in an agroforestry scale-up process as described above. The information in the chapter is gathered from interviews with agroforestry experts, from scientific studies, and agroforestry project reports.

6.1 Barriers to adoption of agroforestry

6.1.1 Access to credit and suitable financial models

Agroforestry requires an upfront investment in terms of money and time but the return on the investment is longer than for annual crops (Sharma et al., 2016). Many farmers living in poverty, who could benefit from adopting agroforestry practices, lack buffers and capital to do long-term investments and their access to credit is in general low. This is particularly apparent for women, who receive less than 10% of the credit in developing countries because they often lack ownership of land used a collateral (World Bank, 2007).

When loans are granted to farmers, they usually have a short payback time and high interest rates making long-term investments less profitable. Many credit institutes do not have credit lines for agroforestry, just for forestry and/or agriculture.

6.1.2 Land-use rights and right to trees

The long return on investment for agroforestry practices discourages farmers from investing when land and tenure rights are unclear. This is the case in many lower income countries and especially for farmers living in poverty (Celander et al., 2003), and women in particular. Furthermore, when farmers have informal rights to their land these usually allow them to claim the ownership of the crops but not of the trees. This phenomenon is especially apparent for women, as their rights to the land they manage are in general much weaker than for men. In many countries, farmers do not even have the right to trees on their land or their products. Such tree protective policy measures date back to the colonial era and are of course barriers for agroforestry implementation (FAO, 2013).

6.2 Barriers creating inefficient markets

6.2.1 Few value chains for products and inputs

Except for a few products, e.g. coffee, cocoa, rubber, acai and shea, value chains for non-timber agroforestry products are poorly developed (Millard, 2011; Belcher & Schreckenberg, 2007; Schackleton et al., 2007). This is especially true for products from indigenous trees, even if there are exceptions locally. The same goes for inputs used in agroforestry systems such as certified seeds and high-quality seedlings. In many countries, high quality germplasm for tree species suitable for agroforestry is difficult to get hold of, especially for indigenous tree species, and infrastructure such as nurseries, for large-scale implementation is poorly developed (Dawson et al., 2013; Dawson et al., 2011).

6.2.2 Diversification increases transaction costs

Discussion based on project implementation and interviews: When small- and large-scale farmers adopt agroforestry practices, the production is often diversified and farmers often start to produce relatively low volumes of some products. This implies many advantages, especially resilience, but also challenges in terms of high transaction costs. The relative transaction cost when selling a product decreases with the volume of this product, e.g. the time it takes to reach the market is the same regardless of the volume you are bringing. This risks lowering the profit for many agroforestry products unless producer groups are formed for joint activities on value addition and marketing of larger quantities.

6.2.3 Gender inequality in value chains

Female food producers face additional market-related challenges. In many regions they have less access to markets. One part of this problem can be that the mode of transportation to the physical market might not be culturally accepted for women, or that women are considered responsible for the household, giving them less time to travel to markets. Furthermore, female farmers tend to get less paid for the same products as men. This is because women's educational level is in general lower than men's, which reduces their access to market information systems that are developed to primarily serve highly educated traders (Kiptot & Franzel, 2011). Without access to market information systems, the bargaining power and the possibility to make market-informed decisions are limited.

Women also tend to be involved in the earlier steps of complex value chains, thus benefiting less from their work. For example, in the value chain of shea butter, see Figure 6.1, in Burkina Faso, rural women pick the shea nuts and take part in the early stages of processing and trade, but men dominate the rest of the value chain. This trend of women being collectors and men selling the goods is common for many agroforestry products. When women are involved in trade, their lack of capital and large volumes results in that they rarely can take on the role of wholesalers. Therefore, women tend to become retailers, e.g. selling fruits on the local market, while men are involved in the wholesale trade, which also requires more distant and time-consuming travels (Kiptot & Franzel, 2011).

Figure 6.1. Shea butter produced from the shea nut. This is an important product for many rural women in Burkina Faso and other countries in West Africa. (Daveynin, 2009)

6.2.4 Limited incentives to invest in ecosystem services

Discussion based on project implementation and interviews: Some of the positive effects from agroforestry directly benefit the farmer, but some are only seen at a landscape level. This means that the farmer is not provided with incentives for all the goods and services that she or he produces. Some practices could therefore fall victim for the “tragedy of the commons”, i.e. when a common resource is overused because each individual lacks incentives to take part in a collective action to conserve it.

Monetary valuation of ecosystem services is one of many ways to address the “tragedy of the commons” by for example implementing payment schemes for ecosystem services (Namirembe et al., 2017; Oborn et a., 2017). However, transaction costs are significant for such schemes and monitoring complex making implementation together with smallholder farmers far from trivial (Nair et al., 2009). It is also necessary to consider biodiversity and social safeguards for addressing potential unintended impacts of financing mechanisms (Ituarte-Lima et al., 2014) and to address political and legal frameworks and institutional set-up that can support a sustainable provision of ecosystem services.

6.2.5 Limited engagement of larger commercial actors

Agroforestry is a practice that requires small amounts of commercial inputs (e.g. inorganic fertilisers), at least after establishment, and the success is instead dependent on labour and correct management techniques and knowledge. Such services are more difficult to commercialize by large companies and these could thus be a barrier for agroforestry as they can potentially advocate against policy changes and drive the value chains of products and inputs to favour monocultures (Sharma et al., 2016).

6.3 Barriers for agroforestry extension services

6.3.1 Agroforestry extension cutting across between agriculture and forestry

Discussion based on project implementation and interviews: The current paradigm in land use management is predominately to separate forestry and agriculture. This is reflected by a general scepticism to agroforestry practices and institutional and infrastructural barriers. This requires policy changes and collaboration between sectors in order to include agroforestry as part of the extension services being offered from public and private rural advisory service providers.

The paradigm of separation has also resulted in a generally low level of knowledge of agroforestry among stakeholders involved in land use management. Extension services in many countries have not acknowledged agroforestry as a land management system and do not have the capacity to share agroforestry practices. National extension services and farmer cooperatives are thus not well equipped to take on the role of scaling up traditional and new agroforestry systems (FAO, 2013).

Discussion based on project implementation and interviews: Another aspect to take into account when setting up extension services for agroforestry, e.g. as part of a development project, is that they require time and thus agroforestry development projects require long project cycles. The nature of agroforestry, i.e. that many practices take several years to develop, also speaks for more long-term investments in extension services as part of projects cycles. This, in combination with extension services to smallholder farmers is scarce in many regions, which leads to limited capacity building of farmers.

The risk of segregation of forestry and agriculture is further discussed in a policy brief from Focali and SLU Global (2017). Based on findings from qualitative fieldwork carried out in Thailand and Vietnam, the brief concludes that segregation of upland landscapes into exclusive zones of agriculture and forest increases risks to both livelihoods and ecosystems. A sectoral division of institutional structures and policies often reinforces this segregation and limits local initiatives to manage resources in alignment with livelihood needs and food security. Institutions and policies should allow communities to develop integrated land use that can help them safeguard livelihoods and food security in the face of climate change and other risks (Beckman, M. 2017)

6.3.2 Inequality in extension services and information systems

Women receive less extension services than men and face more challenges in acquiring knowledge from information systems. As women in general are tasked with taking care of the household, they have fewer opportunities to take part in off-farm extension workshops. Furthermore, men are more commonly approached by extension services, as they are wrongly believed to be the food producers. Most of the extension workers are also men and in some societies and communities, socio-cultural barriers prevent women from engaging with them. Extension services and information systems are as well often addressing farmers with higher educational levels, preventing many women from acquiring the information they have the right to, as they in general have a lower educational level than men (Kiptot & Franzel, 2011).

6.4 Barriers for relevant research

6.4.1 Research in the scale-up process

The mechanism behind an agricultural scale-up process starts with the identification of innovations that lead to sustainable land management (Coe et al., 2014). These innovations are then tested and refined in pilot locations and later disseminated widely. Lately, several high-profile policy papers and scientific reviews of agroforestry innovations have been published promoting a scale-up process. However, there are no reviews addressing the effectiveness of scaling-up. Instead success stories are communicated, creating a biased view of success among researchers and practitioners. Listening too much to such stories and not giving well-designed research processes adequate attention will result in inefficient scale-up processes, as success factors are not identified (Coe et al., 2014).

6.4.2 6.4.2 Bright-side science

By giving too much attention to certain case studies, the context of success is usually forgotten and results are extrapolated well beyond the ecological, social and economic conditions of the study. The risk of practising bright-side science, i.e. only listening to positive research result, is in the current research paradigm considerable and will in the long run be destructive for the scale-up process (Coe et al., 2014).

6.4.3 Research dominated by biophysical studies at the farm level

Agroforestry affects parameters in different spatial, temporal and institutional dimensions. Research can be done at different scales in all of these dimensions, but to this date, a majority of the agroforestry research has focused on biophysical parameters at the farm. This is due to many different factors, e.g. the complexity of doing landscape studies, the long-time series of data needed to study economic and social impacts, and the lack of baseline studies on levels larger than the farm. Researchers and organisations today request better and more studies done at landscape levels, including socio-economic aspects (Nair et al., 2009; Akinnifesi et al., 2010; Reed et al., 2017; Kuyah et al., 2016).

6.5 Barriers in institutional arrangements and policies

6.5.1 Agroforestry belongs to no institutions rather than all

The most apparent obstacle in policies and institutional environments (such as government agencies) is that agroforestry is not included or considered. Policies for agriculture and forestry exist but so far, they are lacking for agroforestry in most countries, except for India where an agroforestry policy was adopted in 2014 (Down To Earth, 2014). Ministries for forestry, rural development, environment, trade, and agriculture are common, but their work is rarely coordinated and thus agroforestry falls between the stools. Agroforestry is said to belong to all sectors, but in reality, it belongs to none. And even when agroforestry is recognized and included in a policy, little work has been done so far to harmonize with other policies and no governmental body takes on the lead for implementation. This creates numerous legal, economic and social barriers, preventing the potential of agroforestry to be fully exploited (FAO, 2013). However, there is recent progress in this area and in ASEAN (the Association for Southeast Asian Nations), Agroforestry Guidelines have been commissioned and in March 2018 being reviewed by the member states (Catacutan et al., 2017).

6.5.2 Focus on monocultures in rural land management

In most countries, policies, land-use planning and rural development programmes emphasise high input (e.g. machinery, inorganic fertilisers and irrigation) monocultures as the primary tool for development and a lack of agroforestry knowledge pervades the land management sector. Products supporting monocultures such as fertilisers, certified seeds for staple crops and fuel are often subsidised while products supporting diverse agroforestry systems such as seeds and seedlings of a variety of species are absent from the market. Farmers who plant trees can also be limited by heavy regulations regarding management, harvest and selling, preventing a good integration with the crops (FAO, 2013).

7 ADDRESSING BARRIERS AND MOVING FORWARD

This chapter summarises the Agroforestry Networks conclusions on important actions to address barriers and challenges that keep agroforestry from being scaled up. The presented conclusions on interventions are derived from interviews with agroforestry experts and literature from academia and organisations. The proposed actions are presented as conceptual ideas and could be developed to action plans with road maps. The proposed ideas are organised similarly to Chapter 6, starting with actions that would improve farmers' access to knowledge, services and infrastructure to increase their production followed by market interventions that would provide better economic incentives, and research frameworks that would improve the scale-up process. The chapter ends with actions to be taken on institutional and policy levels to improve the enabling environment for an agroforestry scale-up. The presented ideas promote a scaling-up of agroforestry with high biodiversity as well as gender and financial equality.

7.1 Improving farmers' access to services and high-quality planting material

7.1.1 Domestication of indigenous trees should be prioritized

In Chapter 5 it was concluded that many of the ecosystem services, products and benefits that come with agroforestry are dependent on a high biodiversity on the farm and in the landscape. To achieve such a development, the use of indigenous tree species is essential. There is thus a need to domesticate indigenous tree species and to support value chains for these. Historically, such interventions have been few, as fast growing exotic species mostly have been used in forest plantations and also on smallholder farms (Nyaga et al., 2015).

Many of the products benefitting women with today's gender roles come from indigenous trees, see Chapter 5.9. Domestication of these tree species is therefore important to improve the livelihoods of women. By having access to these products on the farm, the time women spend collecting fruits, nuts and fuelwood would significantly decrease. By also focusing on value chains for these tree products rather than only on value chains for timber, women could further benefit from agroforestry systems (Kiptot & Franzel, 2011).

7.1.2 Improving access to credit

In Chapter 6, farmers' lack of credit was identified as an important barrier to agroforestry implementation. Access to monetary resources could be improved by supporting innovative scalable financial models that address the long return on investment of many agroforestry practices. In Kenya, a research project in collaboration with the Swedish University of Agricultural Sciences and Umeå University, is trying out a new financial model for bioenergy production in improved fallows (Nyberg, Personal Communication 19 April 2018). The farmers are given financial incentives for improved fallows and receive part of the payments before harvest.

Access to capital could also be improved by providing better systems for credit, either through informal village savings and loans groups or by more formal set-ups. It is though important that such credit systems are constructed to benefit also women (Kiptot & Franzel, 2011).

Figure 7.1. A village savings and loans group for women in Mozambique. These informal sources of credit can give women the possibility to invest in sustainable agroforestry practices and improve their livelihoods. Photo: Monte Allen (2012).

7.1.3 Innovation in extension services

Increasing the agroforestry capacity of different institutions working with extension services should be prioritized to enable further implementation of agroforestry. There is also a large potential for innovation in relation to extension services by using social marketing to change behaviours and to introduce new practices and products, i.e. create demands. New technology could as well partially replace physical extension service delivery. However, it is important that extension services keep working with extension officers, good examples and ambassadors showing the inherent possibilities of agroforestry. This enables horizontal knowledge dissemination between farmers and from farmers to extension programmes. Furthermore, by engaging with stakeholders, programmes can be kept relevant and applicable. Another important aspect of extension services is to acknowledge the role women have in food production and their rights to services. Extension programmes should address and work to erase current gender roles and provide services that are available and also apply to women.

7.1.4 Securing tenure rights of trees and land

Discussion based on project implementation and interviews: As explained in Chapter 6, unclear land-rights prevent farmers to invest time and money in practices with a longer return on investment. Securing land tenure rights could thus be a major driver for scaling up agroforestry. When advocating for, or working with, land rights it is important to also address women as they in general have very weak legal rights to land. Legal rights to land also improve access to credit, as land is the most common collateral in rural areas.

Secure tenure rights do not necessarily imply a complete privatisation and formalisation of land ownership. Such processes involve high costs and other more informal processes might benefit farmers living in poverty more. The right to trees should also be linked with the right to land. One way forward that would promote agroforestry could be to implement conditional leases or tenure agreements, where the farmers are obliged to plant or keep trees.

Development of the Forest Code in Niger

During the colonial years in Niger, rigid forest laws were implemented to protect trees and farmers were not even allowed to prune trees growing on their land. In the 1980s and the 1990s, revenues in the forest sector declined and the central government lost control of enforcing regulations in many remote regions. This created incentives for farmers to start using the trees and many stopped removing tree shoots from their farms. When the government realized the environmental, social and economic benefits of the increasing tree cover and saw that the changed land management did not pose any threat to the country's forest resources, private ownership of trees on farms were recognized in the law.

Source: Pye-Smith (2013).

7.1.5 Cooperatives, NGOs and community organisations

Cooperation among rural food producers is essential for scaling up agroforestry. Diversification of production must be met with mechanisms for pooling the produce so that the transactional costs for each product can be reduced. Furthermore, having strong communities that facilitate knowledge dissemination between farmers can provide an environment in which farmers are encouraged to test innovations as they get some stability from being a part of a group. When supporting cooperatives and other farmer organisations, it is necessary to address gender roles and youth discrimination. In the long run, to dissolve these but also to provide women and youth with appropriate pathways to exercise their rights to organisation.

Being a part of a community organisation also increases the incentives for the individual to do something for the common, i.e. work for a better environment as social contracts are formed. To feed of all these positive effects it is though important that the collective owns the process of organisation.

Community organisation for biodiversity conservation at the landscape level

The consultant company NIRAS is implementing the Agro-Biodiversity Initiative (TABI) in northern Laos to improve rural livelihoods while conserving biodiversity in food-producing systems. The initiative is managed by a Laotian project manager. One component of the 11years long project aims to reduce the negative effects of shifting cultivation while preserving the positive outcomes in terms of biodiversity. Shifting cultivation is an important land management practice in Lao People's Democratic Republic (PDR) and involves more than 25% of the rural population. It creates a landscape mosaic that can host a variety of wild flora and fauna, especially if the fallow periods are long. The landscape diversity generates different opportunities for food and income. If the fallow period is long enough, the fertility of the soil is also restored eliminating the need of inorganic fertilisers. However, shifting cultivation can sometimes result in forest fires and destruction of property and thus cause conflicts with the forest sector.

NIRAS has supported a process to improve the land-use planning in villages practising shifting cultivation. By promoting participatory land zonation, land classification, and production of GIS-based maps, the villages are equipped with tools necessary to plan land management. This has resulted in increased coordination of land burning and implementation of necessary actions to avoid forest fires. The potential for a community land use registration, providing a certificate that secures the villages' formal right to the land, is another important aspect of the land use planning, mainly in the light of an increasing number of land concessions given to companies for industrial use of land. Rubber plantation and large-scale fodder production are the most common such enterprises.

This is a good example of how community organisation and planning can be a driver for biodiversity conservation at the landscape level.

Sources: TABI (2014), Björn Hansson (personal communication, 2017), Higashi (2015) and NIRAS (2017)

7.2 Improving farmers' access to markets

7.2.1 Market information systems

In market information systems, there is a large potential to include groups, e.g. women or youth that previously have been excluded. It is important that this opportunity is seized when developing new innovative forms for information sharing. This can be done by targeting women and youth acknowledging everyone's right to information regardless of their age, gender or educational background.

7.2.2 New value chains for agroforestry products

Developing new value chains for agroforestry products, especially those that are connected to indigenous trees, is an important action to scale-up agroforestry. This will benefit women further if local processing is promoted, as women in general are benefiting from products with a short shelf life. Gender roles are essential to address in this process, as men are usually the main beneficiaries from larger markets (Kiptot & Franzel, 2011).

Value chains could aim to connect the rural population in lower income countries with the growing urban middle-class. One possible way is to focus on a couple of agroforestry products by for example, guaranteeing a minimum price. When local value chains are established there are possibilities to scale-up some linkages and to develop other to the international market.

At the same time, targeting international markets (meaning often high value agricultural markets) could imply a risk for smallholder farmers that may have limited capacity to adapt sufficiently to market risks (Orr et al., 2018). It has been put forward that local and domestic markets, which smallholders can engage in through ad-hoc or in informal ways, could provide flexibility for smallholders and fewer barriers to entry (FAO CFS, 2015).

One way to further gain momentum in the scale-up process is to engage with the private sector having resources and logistics to support larger supply chains. However, private companies, for example supermarket chains, are dependent on a steady stream of products with uniform quality and thus set high demand on quality control throughout the supply chain. To avoid a homogenisation of the landscape, such initiatives need to be complemented with strong pooling mechanisms for a diversity of products, e.g. through producer cooperatives.

7.2.3 Payment for ecosystem services and other incentives

As described in Chapter 6, farmers implementing agroforestry practices do not fully benefit from their investments as many ecosystem services are generated at landscape or global levels (HLPE, 2017; Kuyah et al., 2016; Mbow et al., 2014). There are numerous ways of providing economic incentives to promote environmental services. Ituarte-Lima et al (2014) argue that it is crucial to consider effects on the rights and livelihoods of different individuals and groups, including considerations of gender, in implementing such incentive schemes. Biodiversity and social safeguards are necessary for addressing potential unintended impacts of financing mechanisms (Ituarte-Lima et al., 2014).

Below follow a few examples of possible mechanisms:

- Expand schemes for payments of ecosystem services, i.e. provide farmers with direct financial benefits if they implement certain practices. This has to some extent been successful for carbon credits and for watershed management, where hydropower producers or companies selling bottled water are paying upstream farmers (Namirembe et al., 2017). However, for the carbon projects, transaction costs are high and monitoring complex. Again, effects on people’s rights and livelihoods need to be addressed and particular attention is needed to the impacts and contribution of indigenous peoples, local communities and women, including their participation in the choice, design and operationalization of financing mechanisms.

- Introduce an agroforestry certification that will allow farmers to get more money for their products, as suggested by many experts and scientists and would also give access to public procurement. However, certification systems are in general very complex, expensive and require public awareness.

- Create partnerships between companies with sustainability profiles and agroforestry farmers. Farmers could be given a premium price for their products without certification and the companies promote agroforestry products using a storytelling approach.

- Implement minimum prices for certain agroforestry products that are linked to biodiversity conservation. Could involve both governments and larger companies.

7.3 Improving research to facilitate a scale-up process

7.3.1 Demand driven, participatory and inclusive research

There is a need for research in agroforestry to move away from studying only biophysical parameters to focus more on socioeconomic aspects and address impacts at larger spatial and longer temporal scales. This could be done through landscape studies with a social-ecological systems approach in multidisciplinary research teams, linking biophysical parameters to socioeconomic impacts, exploring synergies and how to manage trade-offs. Furthermore, agroforestry research could focus more on the context of implementation and the scale-up processes to determine why and how practices, initiatives, and extension methods are successful. This goes beyond studies on farmer level and addresses market functionality and value chains as well as policies and the institutional environment. By being closely involved in development projects, scientists can thus take on a larger responsibility to identify drivers of change in successful projects.

To further study a process rather than parameters, to make research more inclusive, to facilitate knowledge exchange and dissemination in different directions and make results more relevant, land management researchers could use a more participatory approach. In participatory research, the control of the process is to a large extent handed over to the participants and researchers act as facilitators and collect knowledge rather than document a linear course of events. This allows participants to influence processes according to their priorities and needs. To do participatory research, scientists need to be embedded in rural land management projects.

Another important action that would make research more inclusive and relevant outside academia is to create forums where researchers, local leaders, companies, extension workers and farmers can interact. Below is a story of such an initiative.

Inclusive workshops in West Pokot, Kenya

At the end of 2016, the research initiative TripleL (Land Livestock Livelihood) arranged a workshop in Kenya on the development of the agro-pastoral landscape in the county West Pokot. The workshop assembled stakeholders from Swedish and Kenyan universities, non-governmental organisations, county officials and agricultural extension workers. The objective was to address future development scenarios in the drylands in West Pokot and identify gaps in knowledge and needs for future research and policy development.

The Triple L workshop identified climate change, population growth and economic development as the main drivers for future development in West Pokot. From these drivers, four storylines were produced with the extensive experience and knowledge of the workshop participants. For each of these storylines, the need of further research was identified. The findings from the workshop will feed into the Triple L initiative and ensure that its research continues being relevant.

Source: Röhss et al. (2017).

7.3.2 Development of agroforestry practices

Significant amounts of research and money have been spent on mechanising and rationalising agriculture and forestry. Today, there is a significant gap between many agroforestry practices and monocultures with commodity crops. To avoid a consolidation of agroforestry as a practice only suitable for small-scale farmers in tropical countries, the agroforestry sector also needs to develop. Otherwise, a global scale-up will be impossible as the transition from high-input mechanized agriculture to agroforestry will be too difficult. If decision-makers are shown that agroforestry can be implemented at different scales, the land management system will also be much more desirable. Furthermore, as most of the high quality agricultural inputs (seeds of modern varieties, fertiliser blends, etc.) today have been developed for monocultures, crops are not fully adapted to intercropping as in agroforestry. One example of an initiative addressing this is the N2Africa research project (Section 5.3.1) that developed a fertiliser mix with low nitrogen content suitable for improved fallows. Another example is the research project BREEDCAFS described below.

BREEDCAFS: A multi-million euro research project to improve agroforestry coffee production

The French agricultural research organisation CIRAD is leading a new EU-funded research project to develop new coffee varieties better suited for agroforestry and with a better tolerance to climate variability.

More than 60% of the plantations with Arabica coffee plants are in small-scale agroforestry systems but very few of the smallholder farmers have access to improved coffee breeds resistant to diseases and drought. If improved breeds are available, they are developed for large-scale plantations and require large amounts of fertilisers and other expensive inputs such as pesticides. The research project BREEDCAFS, with a budget of 4.5 million euros, aims to develop, test and disseminate new breeds that better fit the management practices and the economy of small-scale farmers.

The project has 20 partners from academia, professional organisations and the coffee industry. It will run between 2017 and 2021, with extensive field tests of new varieties in Montpellier, Lisbon, Nicaragua, Cameroon and Vietnam. The new breeds will be subjected to a variety of different light and water regimes, temperatures and CO_2-scenarios. The most promising and productive varieties will be tested in agroforestry clusters in Viet Nam, Cameroon and Nicaragua.

Source: World Coffee Research (2017) and CIRAD (2017).

7.4 Improve national and international enabling environments in terms of financing and policy

7.4.1 New models for funding

To be successful in rural land management projects and especially in those involving trees, you need time. A scale-up of agroforestry would thus benefit from longer funding cycles from international and national investors and donors, and new funding mechanisms involving other stakeholders such as investors in sustainable development. Furthermore, scale-up processes are based on innovation and thus funders of projects must be able to take on the risk of project failures.

7.4.2 National policies and coordination between ministries and other institutions

By including agroforestry in policies and other guiding documents, the status will improve and no longer be seen as a specific technology within either forestry or agriculture. However, including and writing policies for agroforestry is not enough to ensure a change in land management. Appropriate coordination between ministries and other institutions is necessary to avoid rural development programmes, land-use planning and legal frameworks to be dominated by the objectives of one single actor. Of course, it is also necessary to harmonise related policies in forestry, agriculture, environment, etc. to dismantle all those practical barriers preventing agroforestry implementation. A first step to achieve these goals could be to improve policy makers' capacity in agroforestry in tropical countries with large rural populations living in poverty.

Summary: Addressing barriers and moving forward

- There are a number of barriers working at different levels (such as barriers creating inefficient markets, barriers for extension services, barriers in land rights, barriers for relevant research, barriers in institutional arrangements and policies) that are preventing scaling-up gender equal and biodiverse agroforestry practices. These barriers limit farmers' access to appropriate inputs (seeds, seedlings, etc.), credit, land, education and agroforestry extension services. By addressing these barriers farmers can invest more in sustainable agroforestry practices and increase their production. Therefore, by developing new value chains and improving farmers' access to markets, farmers could earn more money from their produce.
- To determine drivers of change in agroforestry research and development projects, researchers should use more participatory methods and further study socioeconomic aspects. By also devoting resources to the development of agroforestry practices and addressing larger systems, agroforestry can become more suitable for larger actors, more attractive for decision-makers. It is also important to increase these decision-makers' agroforestry knowledge to take the first step of including agroforestry in policies and other steering documents. This action should be accompanied by the harmonisation of policies and coordination between institutions to create effective enabling environments for agroforestry on national and international levels.

8 CONCLUSION

More and more actors are acknowledging the importance of ecosystem services provided by trees. At the same time, population increase and changing consumption patterns are putting additional pressure on the remaining forests in the world. This development is especially apparent in the tropics and sub-Saharan Africa, where large parts of the population are food insecure smallholder farmers living in poverty. Ecosystem services from trees and forests are crucial for their livelihoods and resilience to climate change.

This review shows that implementation of agroforestry practices can provide many of the tree-related ecosystem goods and services that are essential for a sustainable and resilient food production. Agroforestry is also particularly suitable for food producers living in poverty and for female farmers. However, agroforestry as a land management system is not sustainable per se, as many of the positive effects correlate with the complexity of the system and the use of suitable and, where possible indigenous, trees. To optimize synergies and minimise trade-offs, careful design of agroforestry practices based on different knowledge systems, including indigenous and local knowledge and research, is necessary. By doing so, agroforestry will be an essential component to mitigate current and future land conflicts, produce more food, feed, fuel and fibre with less input, and adapt food-producing systems to climate change while mitigating greenhouse gas emissions.

The paradigm in traditional land management has though been to separate agriculture and forestry and to promote high-input monocultures. This has resulted in numerous barriers preventing farmers from implementing and benefitting fully from agroforestry. These barriers are found at institutional levels and are accompanied by a general low capacity in agroforestry technologies. This report has identified a number of actions that could create better enabling environments for agroforestry, provide farmers with economic incentives to implement environmentally friendly practices, and make research efficient in the support of a scaling-up process. By developing the proposed actions with road maps, organisations, institutions and other actors working with rural land management, new and efficient ways to promote and spread agroforestry can be found.

TERMINOLOGY

Alley cropping/ Hedgerow cropping	Rows of trees or bushes where crops are planted in the alleyways between the rows.
Aridity index	Can be defined in different ways. In this thesis, the aridity index (AI) is defined as the annual precipitation divided by the annual reference evapotranspiration (ETo). A climate is semi-arid when AI is between 0.2 and 0.5, arid conditions occur when AI is between 0.05 and 0.2. The conditions are defined as sub-humid when the aridity index is between 0.5 and 0.75.
Bulk density	Refers to the density of a dry undisturbed soil sample.
Endemic Species	Species that are unique and only found in a defined geographic location, e.g. an island or a lake.
Evapotranspiration	The amount of water consumed during a given period in e.g. an agricultural field. This amount includes evaporation, water vapour leaving a moist surface, and transpiration, water lost through the stomata of the plants. Evapotranspiration is usually expressed in mm per day.
Eutrophication	Enrichment of nutrients in a water body. May result in algae blooms and oxygen deficiency at the bottom.
Greenhouse gas sequestration	The process of long term capture and storage of greenhouse gases, thus removing these from the atmosphere "permanently".
Home gardens	A complex smaller plot often near the house, where trees, cattle, vegetables and crops are combined.
Improved fallows	Fallows when trees, shrubs or vines are deliberately planted to improve the restoration process, usually nitrogen-fixing trees or bushes are used.
In-situ	On-site.
Intercropping	Different practices that involve two or more crops in proximity.
Meta-study	A study that combines the results from multiple studies.
Non-rotational agroforestry	An agroforestry system where the spatial distribution of crops and trees is kept rather constant over time, e.g. hedgerow intercropping.

Remote sensing The use of satellites or other aerial photography to gather data. Please note that this data can contain more information than a photograph, as more wavelengths can be analysed with many sensors.

Restricted-range species Species with a geographically restricted area of distribution.

Rhizodeposition The process of carbon exchange between plant roots and the surrounding environment.

Shifting cultivation An agricultural practice where plots are cultivated for a short while and then abandoned so that natural vegetation can return. Some farmers practise this with a slash-and-burn strategy while others do the clearing without burning the land.

Soil macrofauna Soil animals that are larger than 2 mm, e.g. worms, snails, ants, beetles, but also badgers and rabbits.

Soil microflora Small flora in the soil, e.g. bacteria, fungi, actinomyces and algae.

Soil structure A description of how much aggregate there is present in the soil. A good structure means that water and air will move freely within the soil. If the soil structure is bad the macro pores are either absent or not well connected.

Soil texture The soil texture is a classification based on the particle size distribution. A fine soil contains a large portion of clay and silt; a coarse soil has a high percentage of sand.

Standard potential evapotranspiration Water consumption for a standard crop growing under optimal conditions. Also called reference evapotranspiration.

Stomata Small openings found on the leaves of plants.

Turbidity Cloudiness of a fluid. The turbidity usually increases when a lake is eutrophicated.

Understory vertebrates The vertebrates that live mostly in the understory, i.e. the vegetation layer above the forest floor but below the canopy.

Unsaturated zone The zone between the soil surface and the groundwater table. In this zone the pressure head in soil pore water is lower than the atmospheric pressure.

Water Use Efficiency WUE is defined in this work as marketable production per volume water, consumed through transpiration and evaporation.

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APPENDIX

Table A1. Interviews conducted during the preparation of this report.

NAME	AFFILIATION
Amos Wekesa	Vi Agroforestry
Anders Malmer	SLU Global
André Gonçalves	Centro Ecológico
Björn Hansson	NIRAS
Erik Andersson	Stockholm Resilience Centre
Gert Nyberg	SLU Global/Triple L
Ingrid Öborn	ICRAF
Karin Höök	NIRAS
Madeleine Fogde	SIANI
Torsten Krause	Lucsus Lund University

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