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Chapter 12

Synthesis: Key agroforestry challenges in the future

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Introduction

According to the last report of the World Resources Institute on ‘Creating a Sustainable Food Future’ (WRI, 2013), the world must urgently improve the way in which it produces and consumes food. In the coming decades, agriculture must produce enough food for a rapidly increasing population and be an engine of inclusive economic and social development. However, the environmental impacts of agriculture are large and growing, creating risks for future food production. Expanding croplands and pastures are placing increasing pressure on tropical forests, and agriculture now accounts for almost 25% of global greenhouse gas emissions and 70% of all freshwater use. By 2050, agriculture alone could account for 70% of the total allowable budget of greenhouse gas emissions consistent with limiting global warming to 2˚C. To address this is an enormous challenge. To feed 9 billion people by 2050, the world must close a 70% gap between the amount of food produced today and that needed by 2050. To avoid new land conversion, future crop yields will need to increase 32% faster than historical rates, with the greatest contributions expected to come from potato and cassava (WRI, 2013). A potential disadvantage of such a shift is that it would increase carbohydrate supplies but reduce protein and mineral nutrient intake within the human diet in nations which are already facing health-threatening deficiencies of these essential compounds. Changes in temperature will also shift the current distribution of crops, pests, parasites, disease vectors and organisms, pollination, wild plants and animals. Refusing to adapt to a changing climate is no longer possible for governments, communities or anyone planning investments in land-use systems.

In such a scenario, can agroforestry contribute to narrow this food gap? The climate for trees and people is changing. Millions of people around the globe depend on the goods and services provided by forests and trees for their livelihood and even for survival. What are the opportunities and key challenges for agroforestry interventions? Surprisingly little is documented on how trees and people co-adapt to climate change compared to the extensive literature on forests (Seppala *et al.*, 2009). Part of this discrepancy is because the climate debate has focussed largely on the role of ‘forests’ as a carbon sink, while ‘trees’ were usually forgotten in the debate (van Noordwijk *et al.*, 2011). Furthermore, although ‘forests’ are a concept which has strong traditions and institutional roles, ‘trees’ do not.

A substantial number of the Sustainable Development Goals which are currently being discussed and formulated can be more readily achieved through an integrated agroforestry approach to land use in the tropics, rather than through a segregated agriculture plus forest perception of the world (Mbow *et al.*, 2014).

How climate change would affect forests and trees

It is helpful to start by examining the key findings of how climate change may impact on forest ecosystems and functioning to gain insight into the opportunities and challenges expected from agroforestry research. Fortunately, a peer-reviewed comprehensive global assessment of the impact of climate change on forests and people has been prepared by a panel of almost 100 internationally-renowned scientists organized by the first Global Forest Expert Panel for the Collaborative Partnership on Forests (CPF) (Seppala *et al.*, 2009). According to the CPF, the most important negative effects are expected to be on the ability of forests to continue as carbon sinks, the so-called ‘lungs of the world’, due to the projected warming of the boreal forests, higher frequency of fires and insect epidemics, resulting in the release of huge quantities of carbon to the atmosphere (Box 12.1).

Box 12.1. Key findings of how climate change will impact on forests (Seppala *et al.*, 2009).

1. Climate change over the past half century has already affected forest ecosystems and will increasingly affect them in the future. The carbon-regulating services of forests are at risk of being lost entirely unless carbon emissions are substantially reduced; this would result in the release of huge quantities of carbon to the atmosphere, exacerbating climate change. Boreal forests are expected to experience greater warming and increased incidence in forest fires and insect epidemics.
2. Climate change may increase timber supplies in some regions, although there will be considerable temporal variation.
3. The impacts of climate change on forest goods and services will have far reaching social and economic consequences for forest-dependent people, particularly the poor.
4. Sustainable forest management is essential to reduce their vulnerability to climate change. The current failure to implement this limits the capacity of forests and forest-dependent people to adapt to climate change. To meet the challenges of adaptation, commitment to achieving the goals of sustainable forest management must be strengthened at both national and international levels.
5. There is no universally applicable measure for adapting forests to climate change. Forest managers should therefore have sufficient flexibility to deploy the adaptation measures most appropriate for their local situations.
6. Flexible approaches to policy design that are sensitive to context and do not rely on a single, one-size-fits-all mechanism are needed. New modes of governance are required that enable meaningful stakeholder participation and provide secure land tenure, forest user rights and sufficient financial incentives.
7. Further research is required to reduce current uncertainties about the climate-change impacts on forests and people and improve knowledge about management and policy measures for adaptation. Nevertheless, despite the limitations of current knowledge, climate change is progressing too quickly to postpone adaptation action pending the outcomes of future studies.
8. Even if adaptation measures are fully implemented, unmitigated climate change would, during the course of the current century, exceed the adaptive capacity of many forests. Large reductions in greenhouse gas emissions from fossil fuels and deforestation are needed to ensure that forests retain their mitigative and adaptive capacities.

Another expected outcome is the occurrence of more intense and frequent droughts, leading to more frequent fires in southern temperate forests. Warnings have also been raised regarding the increased incidence of diseases of coffee associated with warming in East Africa, Central America and India (*e.g.* Stigter, Chapter 5, this volume). Agroforestry research on the buffering role of shade trees offers an exciting opportunity to reduce the harmful effects of high temperatures on the reproductive development of rice and coffee (Chapter 10). Knowledge of how to design agroforestry systems to make use of beneficial effects on pests and diseases, is however, still grossly inadequate. An earlier literature review of pests and diseases (Schroth *et al.*, 2000) optimistically predicted that well-designed agroforestry systems would reduce crop stress by providing the appropriate level of shade, reducing temperature extremes, improving soil fertility and thereby improving tolerance to damage by pests and diseases. However, Ratnadass *et al.* *2012), cautioned that it is not necessarily true that vegetational diversification reduces the incidence of pests and diseases. They concluded that we need to improveme our understanding of the mechanisms involved to explain how, where and when exceptions to the above principle are likely to occur, with a view to developing sustainable agroecosystems based on sound ecological processes of pest and disease control by vegetational diversification.

Under various climate change scenarios, tree growth in tropical forests is projected to increase where water is sufficiently available and decline in dry and seasonally dry environments. Tropical forests could be severely affected by climate change, with consequent impacts not only on the local climate but also on the global carbon cycle because of the release of substantial amounts of carbon. The IPCC (2014) has projected that global increases in temperature of 2-3°C above pre-industrial levels will put 20-30% of vascular plants in tropical forests, particularly rainforests, at an increased rate of extinction. Yet, estimates of temperature increases in tropical forests exceed global averages. It is likely that even modest losses of biodiversity would cause consequential changes in the delivery of some tropical forest ecosystem services. Mangrove forests in the tropics provide an example of these endangered services, particularly with the expected rise in sea levels. Although a comparable analysis of the projected changes in agroforestry due to climate change is not yet available, we could obtain some useful insights into where agroforestry is most likely to be practiced due to changes in land use and policy. The most significant opportunities for agroforestry in the future are areas which are considered biophysically suitable for tree growth and appropriate for the Clean Development Mechanism for afforestation (CDM-AR). According to a recent global analysis using satellite imagery and canopy cover, it was estimated that a total area of 750 Mha is suitable for CDM-AR: with 330 Mha in South America, 220 Mha in Africa and 200 Mha in Asia (Zomer *et al.*, 2008). The vast majority of the land in South America and Sub-Saharan Africa suitable for CDM-AR is classed as grassland or savannas where native agroforestry is already a common feature of the landscape, albeit at a very low level of intensification. Therefore, the greatest opportunities for agroforestry in terms of land area will be similar to the parkland systems already popular in the Sahel and dominated by widely dispersed *Faidherbia albida, Parkia biglobosa* and *Vitellaria paradoxa* trees (*cf*. Chapter 11).

Regreening the Sahel

A massive effort, known as the African Re-greening Initiative (ARI) began in 2009 to revegetate a green belt of trees across the Sahel following the remarkable resurgence of agroforestry in the Maradi and Zinder regions in Niger. According to Reij (2011), about 5 Mha of parklands have been transformed from formerly barren and degraded lands by the protection and management of spontaneous woody species during the last three decades. By encouraging farmers to support regreening without expensive inputs, and managing natural regeneration (FMNR), which produces much better results at lower costs than tree planting, ARI is expanding this approach to Burkina Faso and Mali. According to Reij (2011) several key steps are important for scaling up regreening. First, there is a need to identify successes in regreening and analyze why and how they emerged in various farms. These examples often go unnoticed because most countries have not yet focussed on monitoring landscape-level and farm-level changes in the age and density of on-farm trees. Second, it is necessary to organize regional and local policymakers to visit areas regreened by farmers to promote awareness of the urgent need to scale up regreening and the policy reforms needed to trigger landscape-level transformation. Third, it is vital to organize farmer-to-farmer visits as ARI is more concerned with knowledge management and commitment of labour than with investments in costly inputs. Fourth, it is important to build village institutions responsible for tree management, and finally, it is vital to develop research activities to support regreening as it is important to generate hard data concerning the socioeconomic and biophysical impacts of regreening, as such information can help influence decision makers and inform policy reforms. There are intriguing new perspectives on active roles of green vegetation in the hydrological cycle beyond what is currently recognized (van Noordwijk *et al.*, 2007, 2014a).

Where, when and how does tree cover influence rainfall?

Most hydrological studies have assumed that rainfall is an ‘exogenous’ variable which responds to ocean temperatures and global circulation patterns, but not in a predictable way to land cover. Local ecological knowledge offers frequent suggestions that changes in rainfall have occurred in conjunction with changes in tree cover but such effects have not been observed in paired catchment studies. However, several research lines within the past decade have changed this perspective (Box 12.2), suggesting that serious re-evaluation of current thinking where the relations between vegetation and climate are almost exclusively discussed in terms of carbon storage and impacts on global climate, without the regional specificity that such rainfall effects have. These relationships cannot be treated as a ‘co-benefit’ of carbon-based climate policy as, in many locations, it will probably be the other way around, with carbon stock changes being a co-benefit of tree cover policies aimed at improving the hydrological cycle. If the dominant paradigm of payments for environmental services shifts from a ‘carbon market’ towards a co-investment scheme (Namirembe *et al.,* 2014), a better balancing of local and external co-benefits and shared risk may well emerge.

Box 12.2 Evidence that tree cover not only responds to, but also influences rainfall.

1. Availability of satellite observations of wind at multiple levels in the atmospheric column and humidity (a measure of precipitable water) have allowed calculation of the net moisture transport vectors over the earth surface. In combination with satellite-derived rainfall grids, this showed that terrestrial recycling, and hence the type of land cover, has a significant role in securing there is sufficient atmospheric moisture to account for the rainfall received.
2. The concept of a ‘precipitationshed’ (Keys *et al*., 2012), as the area of ocean and/or land that contributes moist air to the rainfall recorded at specific locations or to watersheds and the algorithms to derive this from data. The inclusion of land in a ‘precipitationshed’ implies dependency on current levels and patterns of evapotranspiration.
3. Backtracking the geographic pathway of airflows that brought rainfall has revealed a correlation with the leaf area index beneath the air movement trajectory, implying a role for terrestrial evapotranspiration in causing rainfall elsewhere.
4. Isotope studies of rainfall, surface and groundwater, current uptake of water and growth rings allows reconstruction of past rainfall patterns and its potential relationship with land cover in the precipitationshed (Gebrekirstos *et al.*, 2014).
5. Better understanding of the role vegetation can play in triggering rainfall where sufficient atmospheric moisture is present through Volatile Organic Compounds (VOCs), ice-nucleating bacteria derived from the phyllosphere, pollen and atmospheric turbulence (forest edge effects).
6. The realization that the traditional focus of hydrology on ‘blue water’, or water in streams and rivers that can be allocated for irrigation, industrial and domestic users addresses only some 40% of the total rainfall, while the ‘green water’ used for evapotranspiration so far remains unaccounted for. As contributor of ‘rainbow water’ it can now be recognized in explorations of the full hydrological cycle (van Noordwijk *et al.,* 2014a).
7. Careful case studies, such as that of the Rungwe mountain water tower in Tanzania (Williamson *et al.,* 2014) where forest conversion (‘aridification’) on the lower slopes may imply that more water reaches streams in this part of the landscape, but less water falls on the higher slopes and therefore fewer crosses between watersheds, affecting water levels in Lake Masoko.

Opportunities: huge scope for expansion of agroforestry globally

According to CPF, numerous studies have projected that climate change may eventually increase global supplies of timber, although there will be considerable regional and temporal variation. Regions that will benefit from 20-30% higher forest productivity over the next 50 years include large areas in South America, Africa, South East Asia and China. Regions which are most vulnerable to the impacts of climate change on timber production include North America, Europe, Australia and New Zealand. Output in North America and Europe as a whole are expected to decline due to climate-induced dieback of existing stocks of trees combined with lower investments in timber production due to lower prices. Climate change is anticipated to have negative effects on the production of wood and non-wood products in many regions, and especially on people who depend on fuelwood for domestic energy and non-wood forest products for their livelihood. For example, it is projected that gum arabic, a non-wood forest product from *Acacia senegal* in southern Sudan will fall by 25-30% due to increased water stress associated with a rise in temperature (Seppala *et al.,* 2009). Unfortunately, there is, as yet, no projected impact of climate change on global agroforestry productivity. The closest analysis was by the World Agroforestry Centre (ICRAF) on current trends in agroforestry globally, which provided good insight of its potential distribution (Zomer *et al.,* 2014).

The first quantification of the extent of agroforestry globally was made by ICRAF in 2009 to address the widely varying estimates regarding its importance (Zomer *et al.,* 2009). Since then, the global remote sensing dataset upon which that estimate was based has been updated, with improved quality and now includes annual datasets available for 11 years (2000-2010). The geospatial analysis of remote sensing-derived global datasets conducted in 2009 investigated the correspondence and relationship of tree cover, population density and climatic conditions within agricultural land at 1 km resolution. This has now been reanalysed based on the improved data, along with an investigation of changing trends between 2000 (averaged 2000-2002) and 2010 (averaged 2008-2010). Among the key results are that (i) agroforestry increased globally in terms of both its extent and the number of people involved; (ii) it remains a significant feature of agriculture in all regions; (iii) its extent varies significantly between regions (for example, it is more widespread in Central America and less extensive in East Asia); (iv) tree cover is strongly positively related to humidity; and (v) there are mixed relationships between tree cover and population density depending on region. Agroforestry, defined by tree cover on agricultural land of greater than 10%, is widespread: found on more than 43% of all agricultural land globally, where 30% of rural populations live. Based on this analysis, agroforestry represents over 1 bn ha of land and more than 900 m people. Agroforestry is particularly prevalent in Southeast Asia, Central America and South America with over 50% of the land area under agroforestry. Globally, the amount of tree cover on agricultural land increased substantially in the decade under investigation, with the area of >10% tree cover increasing by 3%, or more than 828000 km^2. South America showed the largest increase of 12.6%. South Asia also showed a large increase (6.7%), along with East Asia (5%), Oceania (3.2%) and Southeast Asia (2.7%). In Central America, the agroforestry area increased by 1.6% to become 96% of all agricultural land. Surprisingly, sub-Saharan Africa showed an increase of only 2%. Only Northern and Central Asia showed a decrease, equivalent to 2.9%. Thus, agroforestry cover apparently is still an increasingly common feature on agricultural land throughout the world, but there is still a huge scope for further expansion in many regions (Fig. 12.1).

Tree diversity to spread risk

The impact of climate change on forest goods and services will have far-reaching social and economic consequences for forest-dependent people, particularly those who are poor. CPF stated that adaptation measures must go beyond single technical solutions and address also the human-institutional dimensions of the problem. In the initial rounds of the climate change debate, emphasis was on mitigation, stopping the growth of, and eventually reducing, net emissions resulting from human activity and avoiding the need for adaptation. By now it is clear that mitigation efforts are too slow and too limited to stop, or to reverse climate change, therefore adaptation is equally important. At the local level, actions to mitigate climate change by enhancing carbon storage need to be closely matched with actions to adapt and reduce vulnerability to climate change. According to ICRAF, it is more desirable to pay attention to the primary benefits of tree adaptation than to chase the relatively small mitigation carbon market, which is probably based on hype and hope rather than reality (van Noordwijk *et al.*, 2011). A focus on adaptation implies several activities. First, the choice of germplasm and its diversity needs to be adjusted to the likely future range of local climate variability rather than on high performance. Second, a mixture of trees in a landscape needs to be ensured and tree specialization based on what is currently most profitable may not serve well in the future. Third, policy barriers to the use of trees on farms including the rights to future harvests need to be removed and strong incentives established. In combination, these can lead to active management of ‘tree diversity transition curves’, reducing the loss of tree diversity in the early stages of land cover change and facilitating subsequent recovery of tree diversity in the form of locally adapted and multifunctional tree cover (Ordonez *et al.*, 2014). While considering tree mixtures and germplasm characteristics, attention should be paid to the possibilities of reducing root competition between trees and crops and increasing the resilience of crops through appropriate management and selection strategies (Chapters 4, 8 and 9, this volume).

Buffering role of trees is underexploited

The buffering role of agroforestry has been elaborated in Chapters 5 and 6. According to van Noordwijk *et al*. (2014b) further interdisciplinary research on how dynamic landscapes provide buffering and other ecosystem services may benefit from the considerable local ecological knowledge and experience in dealing with past shocks. The biggest obstacles for realizing the full contributions agroforestry can make to the challenge of adapting our food production systems are probably still: (i) the mindset of agricultural scientists trained to believe that open-field agriculture is the norm; (ii) climate scientists who have not even started serious downscaling of climate change predictions to include effects of local land cover change on temperature, humidity, windspeed and other parameters of direct human relevance and: (iii) the makers and shapers of agricultural, forestry and land use policies who treat forestry and agriculture as opposite sides of a coin that can only fall on either side of the institutional divide. The main supporters of the emergence of agroforestry as part of the solution are the farmers of the world who have defied the advice to over-simplify and over-intensify their farms and landscapes. Studies by Nguyen *et al.* (2012) have started to document the ways farmers perceive how trees can substantially reduce their exposure to climate risk, and part of the research community is picking up this challenge but they are still very much in the minority.

Biofuels: opportunities and pitfalls

The production of biofuels presents a new economic opportunity for many developing countries, as well as a possible mechanism for developed countries to reduce their greenhouse gas emissions and enhance energy security. Their societal value depends on the extent to which they can address those needs, while at the same time minimizing social and environmental costs. Opportunities and choices vary considerably between various countries. Currently, demand for biofuels has had little impact on changes in land use in Asia compared to Latin America, where soybean and sugarcane are being grown for this purpose, but this could change rapidly and the biofuel sector has the potential to become a major driver of land use change in the near future (Koh, 2007). Phalan (2009) compared the opportunities facing many Asian countries and the biological footprints of particular biofuel crops or ‘feedstocks’ on land use impacts and highlighted some of the potential pitfalls. The most important consideration is the release of greenhouse gases (GHGs) and the time required to offset the savings gained by replacing fossil fuels with biofuels during land conversion of carbon-rich landcovers.

Degraded or abandoned land is probably the only viable option for large-scale cultivation if biofuels are to contribute to emission reduction (de Vries, 2012). For example, calculations for carbon payback time or the number of years taken for the biofuel carbon savings from avoided fossil fuel use to offset the carbon emissions from the land use change involved in growing the necessary feedstock range from 213 years for cassava to 1628 years for soybean when land is converted from forest (Table 12.1). For oil palm, the carbon payback time ranges from decades to centuries when forested or peat soils are cultivated (Fitzherbert *et al.*, 2008).

Table 12.1 Carbon payback times (years) for crop-based biofuels produced from different feedstocks and on different land uses in the South-East Asian humid tropics. Carbon payback time is the number of years taken for the biofuel carbon savings from avoided fossil use to offset the carbon emissions from the landuse change (adapted from Phalan, 2009).

Crops	Grassland	Savanna	Forest
Castor oil	192	707	1845
Soybean	169	624	1628
Groundnut	75	275	717
Maize	58	213	557
Rice	35	130	340
Cassava	22	82	213
Coconut	0	120	489
Sugarcane	9	36	98
Oil palm	0	15	71

Biofuels and agroforestry

A major challenge in the choice and management of biofuel is that the plant organs harvested for energy also contain nutrients. Biofuel schemes can easily become a new form of nutrient mining (van Noordwijk, 1999), especially if the plants used are efficient nutrient scavengers that grow at acceptable rates on marginal soils. For example, oil palm (*Elaeis guineensis*) makes efficient use of year-round radiation and currently is one of the most effective ways of using solar energy to produce usable oil (Table 12.1). If grown on mineral soil sites where no carbon debt is incurred and no peat emissions are caused, it has the lowest ‘carbon footprint’ of currently used biofuels (Davis *et al*., 2013). However, the harvested fruits are rich in nutrients and the nutrient-rich palm oil mill effluent (POME) is currently recycled on a limited extent to oil palm plantations, enriching the soil there beyond what is needed, while the rest of the plantation depends on ‘new’ fertilizer inputs.

Conclusions

Agroforestry offers farmers the opportunity to meet both their nutritional and energy needs by providing a wide range of food and economically valuable tree products including timber, fruits, nuts and oils. By providing multiple products, trees increase the range of economic resources available to farmers by capturing water and nutrients which have leached beneath the maximum rooting depth of crops and using off-season rainfall (*cf*. Chapters 2 and 8). However, although agroforestry offers these opportunities, it is vital for farmers to understand that there is a need to manage trees to maintain the balance between tree and annual crop products, and that they receive the training and tools to do so. Additional functions such as biofuel production from agroforestry should be a by-product of agriculture, rather than a primary purpose of such land use systems. Timber is a low mineral nutrient form of biomass but there are opportunities to harvest other energy-rich products with an even lower mineral nutrient content than timber. However, it is vital to strike an appropriate balance between depletion of scarce soil nutrient reserves and providing adequate dietary supplies of mineral nutrients into the human food chain.

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Figure 12.1. The global extent of agroforestry during 2008-2010 from remote sensing; agroforestry is defined by tree cover on agricultural land of greater than 10% cover; with kind permission from Zomer *et al*. (2014).