ICIMOD Working Paper 2016/11

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Potential Synergies for Agroforestry and REDD+ in the Hindu Kush Himalaya

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The International Centre for Integrated Mountain Development, ICIMOD, is a regional knowledge development and learning centre serving the eight regional member countries of the Hindu Kush Himalayas – Afghanistan, Bangladesh, Bhutan, China, India, Myanmar, Nepal, and Pakistan – and based in Kathmandu, Nepal. Globalisation and climate change have an increasing influence on the stability of fragile mountain ecosystems and the livelihoods of mountain people. ICIMOD aims to assist mountain people to understand these changes, adapt to them, and make the most of new opportunities, while addressing upstream-downstream issues. We support regional transboundary programmes through partnership with regional partner institutions, facilitate the exchange of experience, and serve as a regional knowledge hub. We strengthen networking among regional and global centres of excellence. Overall, we are working to develop an economically and environmentally sound mountain ecosystem to improve the living standards of mountain populations and to sustain vital ecosystem services for the billions of people living downstream – now, and for the future.

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Potential Synergies for Agroforestry and REDD+ in the Hindu Kush Himalaya

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Foreword

In the past, agroforestry received attention for restoring denuded hillsides in an effort to reduce erosion and soil nutrient depletion. But today it enjoys renewed attention for its climate change mitigation potential.

For centuries agroforestry has been artfully practiced throughout the Hindu Kush Himalaya (HKH), and now the underlying principles of these time-tested practices, as well as the scope for applying scientific principles to improve them, are being explored vigorously. It has now become obvious that the science of agroforestry does, or should, involve a harmonious blending of both biophysical and social sciences.

Land management practices that integrate trees and shrubs with agriculture can provide benefits to the farm and the surrounding landscape. The HKH is a mosaic of different land uses from rangelands to agricultural land, from shifting cultivation areas to pasture land and forested areas governed under many different regimes. We hope the ideas and practices put forth in this paper will inspire and assist in decision-making related to managing land resources that involve trees, shrubs and agriculture products in a sustainable manner.

This paper presents a review of secondary literature related to agroforestry in the HKH. Chapter 1 provide an introduction to agroforestry. Chapter 2 focuses on the nexus between climate change, REDD+ and agroforestry. Chapter 3-5 examine the various design features and management practices of successful agroforestry approaches, include the carbon sequestration potential for each approach. Chapter 6 highlights existing knowledge gaps between REDD+ and agroforestry, offering helpful suggestions for future planning.

In the context of REDD+, the authors conclude that agroforestry has the potential to reduce deforestation and degradation by supplying timber and fuel wood from farmlands. Agroforestry is now seen as an intervention strategy for implementing REDD+ concepts which will ultimately help meet the commitments made under the Nationally Determined Contribution (NDC) plans as well.

On behalf of ICIMOD, I would like to thank all the professionals and individuals who contributed to this study.

David J Molden, PhD
Director General
ICIMOD

Executive Summary

Traditional subsistence practices in agroforestry have given way to improved commercial practices in recent years. Interest and action in agroforestry education, research and training has grown substantially. Growing trees in agricultural land not only improves the livelihoods of smallholder farmers, it also has the potential to contribute to climate change mitigation. It is increasingly recognized that agroforestry (i.e., growing trees in agricultural land) significantly contributes to climate change adaptation and mitigation.' There is growing interest in the assessment of carbon stocks and sequestration in agroforestry systems.

Agroforestry practices address food, nutritional and economic needs of households and help mitigate environmental degradation. Agroforestry can provide supportive and complementary benefits across a range of geographical, environmental and economic contexts. All types of forests in the HKH region provide various co-benefits in addition to carbon sequestration. Likewise, agroforestry provides multiple economic and environmental benefits. It also involves challenges requiring skillful management of land.

Agriculture in the HKH region, as in many parts of the world, involves integration of crop production and livestock rearing. In the hills across the Himalayan region, farmers grow and selectively protect useful native trees and bamboo species on their farmland and nearby forests to maintain farm productivity and to meet their subsistence needs. Tree species grown on farmland have been an integral component of local economies because they generate animal feed and food for human consumption as well as cash income for farmers with market access. A typical agroforestry system allows synergistic interaction between woody and non-woody components to increase productivity and diversify total land output while conserving the environment.

Four major types of agroforestry systems have been identified based on their composition: agri-silivi-cultural system, silvi-pastoral system, agri-silvi-pastoral system, and multipurpose tree plantation system. Common agroforestry systems include improved fallows, alley cropping, scattered trees on cropland, live fences, wind breaks, trees along boundaries, contour vegetation strips, trees and shrubs on terraces, shifting cultivation, and cultivation of tea, cardamom, coffee and medicinal plants under trees. All these agroforestry systems store substantial amounts of carbon in above ground biomass and in soil. However, available literature contains little information on their carbon sequestration and storage potential.

In the context of REDD+, agroforestry systems have the potential to reduce deforestation and forest degradation directly and indirectly. They supply timber and fuel wood that would otherwise be sourced from adjacent forests. In fact, agroforestry has been used in several protected area landscape buffer zones and in conservation programmes as a way of reducing pressure on forests. However, enabling market infrastructure, policies on tree rights and ownership and safeguards would be necessary for agroforestry to effectively contribute to the goals of REDD+.

Acronyms and Abbreviations

C	Carbon
CBS	Central Bureau of Statistics
CO_2	Carbon Dioxide
Eq	Equivalent
ESD	Energy for Sustainable Development
FAO	Food and Agriculture Organization of the United Nations
ha	Hectare
ICIMOD	International Centre for Integrated Mountain Development
ICRAF	International Centre for Research in Agroforestry
IPCC	Intergovernmental Panel on Climate Change
kg	Kilograms
LiDAR	Light Detection and Ranging
LULC	Land Use and Land Cover
LULUCF	Land Use, Land-Use Change and Forestry
t	Tonnes
NAMAs	Nationally Appropriate Mitigation Actions
NTFPs	Non Timber Forest Products
ToF	Tree outside forest
REDD+	Reduced Emissions from Deforestation and Forest Degradation
Spp	Species
WECS	Water and Energy Commission Secretariat

Introduction

Agroforestry, which involves integrating woody perennials in a farming system, has been a longstanding practice in the Hindu Kush Himalayan (HKH) region (Gilmour and Nurse, 1991). Trees are integral to hill farming and have tangible impact on rural farming systems. A great diversity of tree species, often exceeding 100 species, exists in upland farms; they are scattered in and around homesteads. These trees contribute substantially to carbon stocks in the system and carbon sequestration. It is important to understand agroforestry systems and their role in carbon sequestration to formulate future strategies for national-level carbon trading and natural resource management.

The major agroforestry practices in the hills of the eastern Himalayas include home gardens, agri-silviculture system (planting trees along terrace bunds, borders and slopes), silvi-pastoral system (livestock grazing in grasslands), agri-silvi-pastoral system (typical hill farming method, in which crops are grown on flat terraces, trees on terrace bunds and borders, and grasses on terrace slopes; and livestock are allowed to graze during fallow season), and alley cropping, agri-silviculture system, silvi-pastoral system, horti-silvi-culture system and aqua-silviculture. Shifting cultivation (also called slash and burn agriculture), though in decline, is still practised in many upland areas in the region.

Poplar with sugarcane

Climate Change, REDD+ and Agroforestry

REDD and agroforestry nexus

Anthropogenic causes of climate change are now widely acknowledged and efforts are underway to reduce carbon emissions from different sectors. The Fourth Assessment Report of the Intergovernmental Panel on Climate Change (IPCC) states that the forestry sector, mainly through deforestation, contributes about 17% of global greenhouse emissions. This is the second largest source after the energy sector. In many developing countries, deforestation, forest degradation, forest fires and slash and burn practices are the primary causes of carbon dioxide emissions. Reducing Emissions from Deforestation and Forest Degradation (REDD) is a policy instrument that attempts to create financial value for the carbon stored in forests, offering incentives for developing countries to reduce emissions from forested lands and invest in low-carbon paths to sustainable development. Compared to original REDD, REDD+ goes beyond deforestation and forest degradation (Joshi et al., 2010).

REDD+ includes five sets of activities that encourage developing countries to contribute to mitigation actions in the forest sector depending on context and national circumstances.

- Reducing emissions from deforestation
- Reducing emissions from forest degradation
- Conservation of forest carbon stocks
- Sustainable management of forests
- Enhancement of forest carbon stocks

The first two activities reduce emissions of greenhouse gases and they are the two activities listed in the original submission on REDD in 2005 by the Coalition for Rainforest Nations (van der Werf et al., 2009). The three remaining activities constitute the "+" in REDD+.

REDD's definition of forest is based on FAO's definition: "a minimum threshold for the height of trees (5 m), at least 10 per cent crown cover (canopy density determined by estimating the area of ground shaded by the crown of the trees) and a minimum forest area size (0.5 hectares)." Urban parks, orchards and other agricultural tree crops are excluded from this definition. Though agroforestry systems consist of trees, often in large numbers, they are not included in the definition of forest.

Trees outside forest

Trees and woody biomass, wherever they may be, play an important role in the global carbon cycle. Forest biomass accounts for over 45% of terrestrial carbon stocks, with approximately 70% and 30% contained within the above and below ground biomass respectively (Cairns et al., 1997; Mokany et al., 2006). Not all trees exist inside of forests. Trees feature prominently in agricultural landscapes globally. Almost half of all agricultural land maintains at least 10% tree cover (Zomer et al., 2014). Despite widespread distribution, "trees outside forests" are an often neglected carbon pool and little information is available on carbon stocks in these systems or their carbon sequestration potential (De Foresta et al., 2013; Hairiah et al., 2011).

Growing trees in agricultural land helps to improve the livelihoods of smallholder farmers livelihoods and to modify micro-climate (van Noordwijk et al., 2014). In addition, it contributes to global climate change mitigation (Nair et al., 2009 and 2010). Even when planted at low densities, the aggregate carbon accumulation in trees can help fight climate change because of the large spatial extent covered (Verchot et al., 2007). Such trees are estimated to accumulate 3–15 t C ha^{-1} yr^{-1} in above-ground biomass alone (Nair et al., 2010), a significant amount compared to other carbon sinks.

The Hindu Kush Himalayan (HKH) region is largely covered by forests (Schild, 2008). Substantial portions of the region are under other land use systems, such as agroforestry, with high potential for carbon sequestration and storage. Given the growing demand for food and livelihood benefits from natural resources in the hills of the HKH region, carbon incentives could be linked with various options for land management. A narrowly conceived REDD should be expanded to include other land use systems to adequately reward local community-based conservation initiatives and to address the complex drivers of deforestation and degradation that often lie outside of the forest sector (Joshi et al., 2010).

Agroforestry is receiving attention in many countries, quantification of biomass in these systems is simultaneously receiving greater attention (Thangata and Hildebrand, 2012). There is growing interest in the assessments of carbon stocks and sequestration, both for carbon monitoring and reporting as well as for evaluating agricultural interventions (Thangata and Hildebrand, 2012). Moreover, trees diversify diets, reduce soil erosion and expand market opportunities for smallholder farmers (van Noordwijk et al., 2011). Thus, trees in agricultural landscapes, or agroforestry systems, offer opportunities to mitigate climate change and improve the livelihoods of smallholder farmers (Kumar and Nair, 2011).

Fodder trees on farms provide feed for livestock, which in turn provide manure and fertilizers

Concept of Agroforestry

Agroforestry is a land-use system in which trees or shrubs are grown in association with agricultural crops, pastures or livestock. Such integration of trees and shrubs in the land-use system can be either a spatial arrangement, e.g., trees growing in a field at the same time as the crop, or in a time sequence, e.g., shrubs grown on a fallow for restoration of soil fertility. Agroforestry is traditionally practiced in Nepal and many other countries in the HKH region, where trees and agriculture crops are grown in the same patch of land. More than 70% of the population in the hills and mountains of South Asia live in rural areas and depend on agriculture and natural resources for livelihoods (Rasul and Kollmair, 2008). Different types of agroforestry practices exist; the exact type and intensity is determined by the local context.

Agroforestry has three components: forestry, agricultural crops, and livestock. The International Centre for Research in Agroforestry (ICRAF, also known as the World Agroforestry Centre) suggests the following definition:

> "Agroforestry is a collective name for land use systems and technologies where woody perennials (such as trees, shrubs, palms and bamboo) are deliberately used in the same land management unit as agriculture crops and/or animals either in the same form of spatial arrangement or temporal sequence." (Lundgren and Raintree, 1983)

According to Nair (1993) this definition implies that:

- Agroforestry normally involves two or more species of plants (or plants and animals).
- An agroforestry system always has two or more outputs.
- The cycle of an agroforestry system always lasts more than one year.
- Even the simplest agroforestry system is more complex, ecologically and economically, than a mono-cropping system.

In other words, agroforestry is a system of combining trees with crops (such as food, fruit, vegetables, fodder and forage) and/or livestock in a field at the same time or at different times.

Functions of agroforestry

- Productive: Agroforestry can produce food crops, fruits, leaf litter, timber, fuel wood and fodder for livestock from the same piece of land.
- Protective: Agroforestry helps to minimize degradation of farmland and other natural resources (e.g., it reduces wind and soil erosion).
- Ameliorative: Agroforestry with legume trees and crops help to maintain or improve the productivity of land.
- Livelihood improvement: Income can be generated from sale of trees and agricultural products.

Purpose of agroforestry

- To optimize overall production of food/fruits, woody crops and fodder and forage including livestock per unit area.
- To provide support for conservation of soil, water and other resources.
- To improve local environment.
- To enhance the socioeconomic condition of the farmers.
- To improve the livelihoods of the farmers.

Trees in agroforestry

The design and management of an agroforestry practice depends on existing sites and objective of landowners. Trees can be planted in single or multiple rows, on contours or in clusters. Different components can be combined depending on the desired products and services, available on-farm equipment and selected companion crops. For optimum benefits, it is necessary to select appropriate tree species and location and carry out regular thinning and pruning. Unmanaged and misplaced trees can heavily impact crop production.

Good practices to be considered for the management of trees:

- Weed control: Tree seedlings and saplings are vulnerable to competition from weeds. Regular weed control can reduce competition for moisture, nutrients and light. Options for weed control include the use of herbicides, mulches (including living mulches such as many clovers, and fabric mulches) and cultivation. To ensure that newly established trees grow to their full potential, weed control should be maintained for 3 to 5 years.

- Fertilizer application: The need for fertilizers depends on selected species and production objectives. Timely application of fertilizer may be necessary for high-yielding fruit and nut production. The tree must get certain nutrients at the appropriate time of year for flower and nut set. In timber production, the cost of fertilizer application cannot usually be justified in economic terms.

- Pruning: Pruning is required to improve the quality of timber; it is recommended for nut and fodder production. Pruning also increases space between trees for equipment to pass below the branches. The crown shape and density can be managed through proper pruning, and this facilitates and improve fruit production.

- Thinning: Regular thinning promotes tree growth by reducing competition between trees for water, light and nutrients. Removal of poorly formed, suppressed and unwanted trees promotes growth of good standing trees. The stage when crowns of adjacent trees begin to touch or overlap is a good time to consider thinning. In agroforestry systems where crops are grown between trees, the trees are usually far apart. Trees do affect crop production; hence tree species and distance between trees should be carefully managed. The design and thinning options are determined by the value of agricultural crops and tree products.

Desirable characteristics of trees

Trees with the following characteristics are suited for agroforestry systems:

- adequate shade regulation and upright stems
- minimum interference with crops with respect to soil moisture, nutrients and sunlight
- fast growth and good survival rate
- fixes atmospheric nitrogen
- high re-sprouting capacity after lopping, coppicing, pollarding and pruning
- deep root system with very few lateral roots
- no toxic effects on soil and on associated crop plants
- multiple products
- suitable for local climatic conditions
- acceptable to local farmers

Benefits of agroforestry

Agroforestry in private land reduces villagers' dependency on forests and helps to increase their household income, provided the species are commercially valuable. This also protects forests from degradation. By growing trees and shrubs on their farmland, farmers can be less dependent on firewood from forests. Suitable climatic conditions and the availability of marginal land offer an opportunity for growing different kinds of agroforestry species. All this depends on local people's knowledge, appropriate management techniques and other support services and facilities.

Agroforestry practices help to meet food and nutritional needs of households and to mitigate environmental degradation. Agroforestry can provide supportive and complementary benefits across a range of social, geographical and economic contexts.

Forests provide multiple co-benefits in addition to carbon sequestration (Joshi et al., 2013). Agroforestry provides the following socioeconomic and environmental benefits.

Socioeconomic benefits

- Production of multiple items to meet the needs of humans and livestock – food, vegetables, fruits, fodder and forage, fuel wood, timber, leaf litter for household use and farming
- Reduction in economic loss due to pests and diseases and market crash as agroforestry combines multiple components for multiple products
- Increase in farmers' income from sale of agroforestry products in the market
- Improvement in farmers' living standard through sustained agroforestry yield, income and employment
- Increase in overall productivity due to improved nutritive value of animal and human diet
- Reduction in use of chemical fertilizers as agroforestry promotes natural soil nutrient recycling

Environmental benefits

- Improvement in farm site environment through a reduction in surface runoff, soil erosion and nutrient loss, gully formation, landslides and river bank erosion
- Improvement in local micro-climate and productivity of farm
- Reduction in pressure on community forests and other natural forests for fodder, fuel wood and timber
- Beautification of landscape
- Storage and sequestration of carbon in trees in agroforestry systems

The following table summarizes the benefits from trees in agroforestry system.

Table 1: **Benefits of agroforestry trees**

Benefits	Role
Food and nutrition	food (fruits, nuts, bark, roots)
	additional nutrition, especially for children
	important source of nutrition during dry season
	important in rural areas
Wood fuel and conservation	regular supply of fuel
	conservation of wildlife (particularly birds)
Timber and shelter	construction material
	shade (for people and livestock)
Diverse household products	farm implements
	herbs as traditional medicine (people and livestock)
	boats, carving
	furniture
	ropes and fiber
Household income	fruits, timber and poles
	supports agriculture and livestock production
Agricultural productivity	conservation of soil and water
	enhance soil fertility and structure
	retain moisture (micro-climate) and reduce wind speed
Livestock	livestock feed
	shade and shed construction
	veterinary medicine
	support in beekeeping
Micro-climate and climate change	reduce wind speeds
	retention of moisture in the immediate surroundings
	provide shade and lower temperature
	carbon storage and sequestration

Limitations of agroforestry

Despite its various advantages, agroforestry has some limitations. These include:

- Given the diverse uses, the day-to-day farming issues are far more complex than in a straightforward forestry operation or monoculture farm.
- It is difficult to use farm machines in the confined space of agro-forests.
- Food crops may be damaged during the harvest of tree products.
- Trees might serve as hosts to diseases, insects, birds and small animals.
- Rapid regeneration of aggressive trees may displace food crops and take over entire fields.

These limitations can be minimized through skillful management practices. For example, once it is known that trees compete with food crops and may reduce food yields, the following approaches or strategies may be adopted to reduce negative tree-crop interactions.

- Select legume trees with small or light crowns to ensure sunlight reaches the food crops.
- Select deep-rooted trees to ensure they absorb moisture and nutrients from the deeper subsoil.
- Space the trees further apart to reduce their competitive effect on the food crop.

Classification of agroforestry systems

Nair's (1987) four bases for classification of agroforestry systems were later expanded by Dwivedi (1992) to include the following seven bases: structure, function, socioeconomics, ecology, floristic, history and land use. Each of these bases can be used to classify existing agroforestry systems. The most common classification uses the structure based on these components: forestry, agriculture and livestock. This component combination can be in time (short duration and long duration) or space, and other terms are used to justify the various arrangements.

Four major types of agroforestry systems are identified:

Agri-silvicultural system: Agri-silvicultural system refers to the use of land for agricultural production and forest farming, either simultaneously or sequentially. Examples include intercropping of forest plantation with agricultural crops and growing tree crops among forest trees. Tree species such

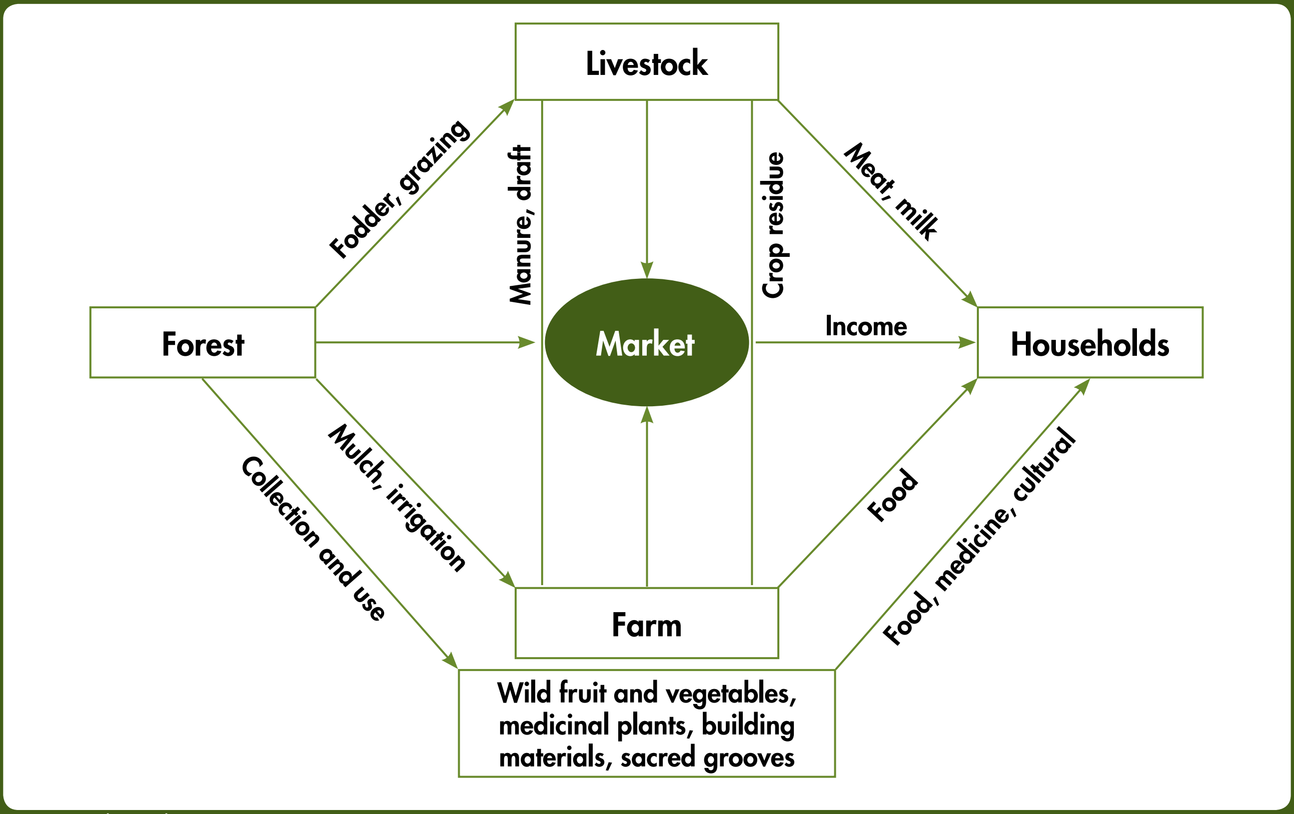
Box 1: **Carbon potential in agri-silvicultural system**

Chauhan et al. (2010) besides the productivity of the system. At sixth year, total biomass in agri-silvicultural system was 25.2 tonnes/ha, which was 113.6% higher than sole wheat cultivation. Poplar tree stem alone contributed 21.99 tonnes/ha, which is very significant proportion and goes to the durable products. Net carbon storage (soil + tree/ crop biomass conducted a study during 2004-2006 to assess carbon storage by the poplar-based agri-silvicultural system and the change in soil organic carbon. In the sixth year, the total biomass in the agri-silvicultural system was 25.2 t ha^{-1}, which was 113.6% higher than in sole wheat cultivation. Poplar tree stem alone contributed 21.99 t ha^{-1}, which is significant and goes to the durable products. Net carbon storage (soil + tree/ crop biomass) was 34.61 t ha^{-1} in the wheat-poplar interface compared to 18.74 t ha^{-1} in sole wheat cultivation (soil + crop biomass). After six years of poplar planting, organic carbon in soil (0–15 cm depth) increased by 35.6% compared to pure wheat crop. Although wheat crop yield was substantially reduced under the poplar trees, the loss was compensated by the poplar trees in terms of biomass, economic gain and carbon mitigation potential.

Box 2: **Carbon potential of silvo-pastoral system**

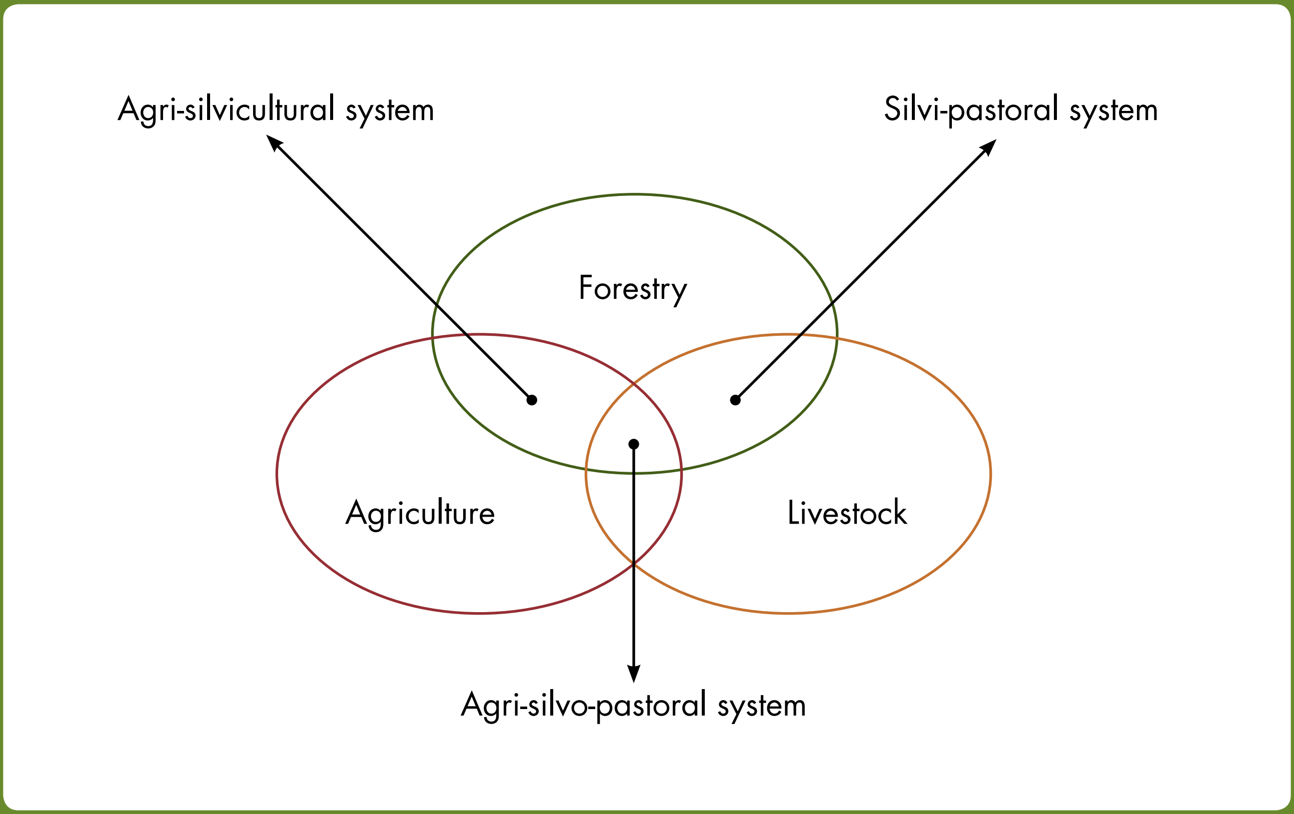
Agroforestry systems such as silvo-pastoral system can play an important role in carbon sequestration in soils and in woody biomass. For example, traditional cattle management involves grass monocultures, which become degraded in about 5–7 years of establishment, releasing significant amounts of carbon to the atmosphere. Veldkamp (1994) estimated that the cumulative net release of CO_2 from low productivity pastures (*Axonopus compressus*) varied from 31.5 to 60.5 t C ha^{-1} in the first 20 years after forest clearing. Well-managed silvo-pastoral systems can improve overall productivity (Bolívar et al.,1999; Bustamante et al., 1998) while sequestering carbon (Andrade, 1999; López et al., 1999), thus potentially increasing economic and environmental benefits. The total amount of carbon in silvo-pastoral systems varied between 68 and 204 t ha^{-1}, with the highest amount stored in soil, while annual carbon increments varied between 1.8 and 5.2 t ha^{-1}. The amount of carbon fixed in silvo-pastoral systems is affected by the tree/shrub species, density and spatial distribution of trees, and shade tolerance of herbaceous species.

Figure 1: **Integrated farming, the predominant method of agriculture in Nepal**



Source: Joshi et al. (2010)

Figure 2: **Classification of agroforestry systems based on composition**



as *Dalbergia sissoo*, *Eucalyptus* spp. and *Melia azedarach* are commonly grown in agro-silvicultural system in lowland areas. Mainly fodder trees such as *Artocarpus lakoocha*, *Bauhinia purpurea*, *Bauhinia variegata*, *Saurauia napaulensis*, *Ficus nemoralis*, *Ficus roxburghii*, *Morus alba* (mulberry) are grown in the hill farming system.

Silvo-pastoral system: Silvo-pastoral system refers to the land management system in which trees are managed for production of wood and other tree products, and domestic livestock are allowed to graze inside the woodland.

Agri-silvo-pastoral system: Agri-silvo-pastoral system entails the combination of agricultural crops, trees and livestock in the same piece of land. This is the predominant farming method in the hills of Nepal, one of the countries of the HKH. Under this method, crops are grown on terraces, trees are planted or retained along the borders and slopes, and livestock are allowed to graze during fallow seasons. Some farmers now plant improved legume and non-legume grasses such as Napier grass (*Pennisetum purpureum*) and Setaria (*Setaria splendida*) along terrace risers and borders.

Multipurpose tree plantation systems: This refers to a variety of management systems where woody perennials are combined with other components to yield products such as timber, fodder, fruits, honey, medicine, fish and silk.

Agriculture and forestry form an integral part of mountain livelihoods

Potential Agroforestry Systems of HKH Region

According to Nair (1993), there are hundreds of variations of agroforestry systems. The same or similar practices are found in various systems in different situations. Both the 'system' and 'practice' are known by similar names. The systems are (or ought to be) related to the specific locality or the region, or to other descriptive characteristics. However, the distinction between 'system' and 'practice' is vague and not particularly significant in terms of understanding agroforestry. Therefore, the two words are often used synonymously in agroforestry.

Agriculture is the most important sector in the HKH region. About 60–90% of the population is engaged in various agricultural activities, including crop production, animal husbandry, forestry and horticulture. In the past few years, mountain agriculture in most HKH areas has shown increasingly unsustainable trends due to increased population pressure, declining productivity and shrinking soil, water and forest resources. Most of the farming systems in the hills of the HKH can be categorized as agroforestry. Tree species grown on farmland are integral to local economy because they provide animal feed, food for families, and cash income to farmers with market access. A typical agroforestry system allows synergistic interactions between woody and non-woody components to increase productivity and diversify total land output while conserving the environment in a sustainable manner. Modern agroforestry with exotic trees and grass species is a relatively recent practice.

Potential agroforestry systems for the HKH region are described below.

Improved fallows

To address the problem of declining soil infertility, some resource-poor farmers leave degraded land uncultivated, or 'fallow'. This method allows natural regeneration of vegetation and soil fertility. The slash-and-burn system is a traditional fallow system. The 'improved fallow' system involves enriching a natural fallow by planting leguminous trees or shrubs at high density. This method restores soil fertility more rapidly than the traditional fallow system, thus shortening the fallow period. This practice reduces fertilizer requirement. The effect of improved fallow depends on the fallow period and the type of tree species grown.

Improved fallow requires a lot of individual shrubs with relatively short life spans. Therefore the propagation method should be simple and cheap. Planting short-lived shrubs at 1 m x 1 m is recommended. Dense spacing is effective in suppressing weed growth. Mixed seeds of improved fallow species can be sown for multiple benefits.

The shrubs require little management once they are established. Weeding during establishment and protection from livestock is necessary. Densely planted shrubs may require some thinning. Various trees or shrubs are suitable for agroforestry, but only a few are currently used in improved fallows. Key attributes used in selecting and screening species for improved fallows are:

- Fast growing species with high biomass production
- Nitrogen fixing leguminous woody species with high potential to fix nitrogen
- Tree residues high in nitrogen and low in lignin (rapidly decompose; nutrients released for use by associated crops)
- Easy to propagate (quick seed germination or easy to sprout from cuttings)
- Compatible with associated crops
- Easy to manage
- Pest and disease tolerant
- Adaptive in targeted ecosystem
- Not aggressive (non-weediness)

Benefits

- Improve soil fertility
- Accumulate nutrients
- Add organic matter
- Keep down undesirable weeds while land is not under cultivation
- Break up hard soil
- Regulate temperatures (less extremes of hot/cold)
- Provide shade
- Protect from winds
- Reduce erosion
- Encourage or sustain populations of beneficial soil microorganisms
- Break up physical barriers to root growth (rock and hard pan)

Acacia mearnsii, *Leucaena leucocephala*, *Sesbania* spp., *Gliricidia sepium*, *Cajanus cajan* and *Calliandra calothyrsus* are promising species for the improved fallow system.

Carbon potential

Improved fallows and rotational woodlot agroforestry system accumulate carbon rapidly (Kumar and Nair, 2011). Carbon data on fallow systems in the HKH region is almost non-existent. However there is some information from other parts of the world. The study by Kaonga and Coleman (2008) in eastern Zambia estimated the above-ground plant carbon contribution at 2.8 t C ha^{-1} $year^{-1}$ for *Tephrosia vogelii*, 2.7 t C ha^{-1} $year^{-1}$ for *Sesbania sesban* and 2.5 t C ha^{-1} $year^{-1}$ for *C. cajan*. The figures were comparable with 2.7 t C ha^{-1} $year^{-1}$ documented for fully fertilized maize. The estimated total soil organic carbon stocks beneath these species were found to be higher at 27.3–31.2 t C ha^{-1} (Kaonga and Coleman, 2008) than under completely fertilized maize (26.2 t C ha^{-1}) and unfertilized maize (22.2 t C ha^{-1}).

Alley cropping

Alley cropping is a practice where crops are grown between rows of planted trees and/or shrubs, preferably leguminous species. The shrubs are pruned periodically during the crop's growth to provide green manure that enhances soil nutrient status and physical properties, and to prevent shading of the growing crop(s). This method helps increase production and land productivity by maintaining and improving soil moisture and fertility. There have been many studies on this method, which is known to have much potential for solving the problem of declining soil fertility where farmers cannot afford to use inorganic fertilizers. Alley cropping is suited to humid and sub-humid tropics, and the system has great potential to improve soil and water conservation in the hilly and mountain areas.

The multipurpose tree species in this agroforestry practice should have the following important characteristics:

- Fast growing – benefits become available to the farm family as soon as possible
- Good coppicing ability (re-sprouting)
- High biomass production
- Deep rooting
- Pest and disease tolerant
- Nitrogen fixing ability (leguminous)
- Adaptable to close spacing

Research indicates alley cropping is not feasible where average rainfall is less than 800 mm annually as woody perennials compete with agricultural crops for moisture (Tengnas, 1994). This method attains its highest potential in humid lowlands. Since it is a labour intensive method, it is suitable for small farms and where labour is not a limiting factor.

The establishment of alley cropping requires many trees or shrubs. Therefore propagation techniques should preferably be easy and inexpensive. Direct seeding or use of cuttings is ideal. If seedlings are to be raised, on-farm nurseries are recommended, as growing relevant species does not require much skill.

The spacing in field trials usually ranges from 4–8 m between rows and up to 2m within rows. In humid areas, close spacing can be tolerated, but in drier conditions, wider spacing is required to reduce competition for moisture. On flat land, hedgerows should have an east-west orientation to reduce shading. On sloping land, hedgerows must be oriented along the contours.

Intensive management is required in the alley cropping system. The first coppicing is done 6–18 months after establishment, depending mainly on growth rate. The frequency of cutting depends on the type of desired product, and on whether or not some reduction in crop yield due to shade can be tolerated. If the leaves are to be used for green manuring or fodder, frequent (up to monthly) pruning is required, but if firewood or staking material is the desired output, cutting may be done on a yearly basis.

Benefits

- Trees and shrubs in the alley cropping system provide the following benefits:
- Provision of green manure or mulch for companion food crops i.e., plant nutrients are recycled from the deeper soil layers.
- Pruning of trees and shrubs provides mulch and shade during the fallow period to suppress weeds
- Provision of favorable conditions for soil microorganisms
- When planted along the contours of sloping land, provide a barrier to control soil erosion
- Pruning of trees and shrubs not only provides staking materials and firewood but also supports livestock for browsing.
- Provision of biologically fixed nitrogen to the companion crop(s)

Species commonly used in the alley cropping system are *Leucaena leucocephala*, *Gliricidia sepium*, *Calliandra*, *Sebania sesban*, *Artocarpus lakoocha*, and *Morus alba*.

Carbon potential

Overall, soil carbon sequestration potential is much greater in alley cropping than in mono-cropping agronomic systems. For example, in Guelph, Ontario, Canada, carbon inputs through litter fall on a poplar-spruce alley cropping with wheat-soybean-maize rotation were 0.6 and 0.95 t C ha^{-1} in the 11th and 12th year respectively (Oelbermann, 2002). In a 6-year-old hybrid poplar site (111 trees ha^{-1}) in Canada, it was found that litter fall contributed 1.07 t C ha^{-1} (Thevathasan and Gordon, 1997). In the same study, hybrid poplar leaves and branches had C stocks of 1.3 and 5.5 t C ha^{-1} when trees were 13 years old (Peichl et al., 2006). After 13 years the tree component of the system added 14 t C ha^{-1} in addition to the 25 t C ha^{-1} added by litter and fine roots (Thevathasan and Gordon, 2004). The total carbon sequestration ha^{-1} was therefore 39 t C ha^{-1} in 13 years. The authors estimated that the system had immobilized 156 t ha^{-1} CO_2 or 43 t C ha^{-1} by age 13 and could potentially sequester significantly more carbon by the end of a 40-year harvest cycle. In general 40–50% of carbon sequestered by trees is believed to be below-ground (Turnock, 2001). In an alley cropping practice in southern Ontario, Norway spruce (*Picea abies*) sequestered twice as much carbon as poplar in a 13-year-old study (Peichl et al., 2006). Although the above-ground carbon stocks of poplars and spruce were almost the same (85% and 82% respectively), spruce had 63% of the carbon in branches and needles that provided greater quantities of litter material and thereby greater potential to add carbon to the soil pool.

Scattered trees on cropland

This practice involves growing individual trees and shrubs in wide spaces in the farmland, while field crops are grown underneath. This practice needs careful management and protection of naturally regenerated trees and / or planting new trees.

The trend of growing trees on farmland is on the rise in Nepal. REDD+ programmes should take the carbon storage potential of such farm trees into account.

The ideal tree species for scattered trees in cropland should have the following characteristics:

- Deep rooting habit
- A canopy that produces light shade
- A capacity to improve the soil through nitrogen-fixation and litter fall
- No tendency to harbor crop pests

In most situations, growing trees in cropland is feasible. The benefits to be obtained from the trees, in terms of soil fertility and soil structure, are usually more obvious in areas where little or no inorganic fertilizer is used.

Trees can be propagated through different methods. The simplest method is to leave the desirable trees while clearing land for agriculture. Spacing is determined by the size and property of tree species

Figure 3: **A sketch of a live fence**

in order to fit the tree component in a way that maximizes positive effects on food crops. A population of up to 100 trees per hectare, corresponding to a spacing of 10 m x 10 m, is appropriate in high-potential areas. A better option than square spacing may be to plant trees close together individually and maintain wider gaps between rows, to maintain good density. The tree and crop species and management methods chosen will influence decisions on spacing.

Tree management practices depend on the tree and crop species and the desired products. Generally there is a need to protect the young seedlings from livestock and fires, especially during the dry season. Regular pollarding or pruning is essential for crops that need light, but this does not apply to shade-tolerant crops or to trees that have a natural light shade. Timber production and light reduction both require pollarding high up, at 12–15 m, but shade tolerance and pole production require lower and less frequent pollarding. It is important to consider the land-use pattern throughout the year before recommending tree planting in cropland. Post-harvest grazing and burning of crop residues are other factors that need to be taken into account.

Benefits

Benefits that may be obtained from trees in the fields are:

- Improved soil fertility as scattered trees on the cropland converts atmospheric nitrogen to a form that can be used by plants, and leaves and other residues get decomposed into organic matter.
- Reduction of soil erosion because leaf litter acts as mulch, conserves soil moisture, improves water infiltration and suppresses weeds
- Provision of fodder for livestock
- Provision of poles and timber
- Provision of fuelwood and medicine
- Improvement in microclimate on cropped land
- Advantageous to maintain indigenous tree species

Recommended species for this agroforestry practice are leguminous, with a deep root system, having light branches, deciduous, with decomposable leaves such as *Grevillea robusta*, *Erythrina brucei*, *Faidherbia albida*.

Carbon potential

Trees can be an additional source of income for resource poor farmers during crop failure. Planting multipurpose tree species serves a dual environmental purpose, i.e. promotion of biodiversity and carbon sequestration. A study conducted by Ngwayi (2012) in Kayerkhola watershed of Chitwan, Nepal showed that the carbon amount in the majority of trees was <1000kg/tree, and only a very few trees had a carbon amount >5000kg/tree. In this study, tree height estimation had the highest carbon stock at 163.92 tonnes/ha. This result is smaller compared to that obtained in the Chitwan area for sparse vegetation of 140 t C/ha^{-1} of total forest carbon density for the whole mid-altitude Kayarkhola watershed (ICIMOD et al., 2011). However, the result of this study is only based on trees outside forest while those for ICIMOD et al. (2011) encompasses everything in the watershed including sapling, herb, litter, soil and below-ground carbon.

Live fences

Live fences are closely spaced trees or shrubs (see Figure 3) that act as barriers and protect crops against livestock and human interference. It is commonly established around homesteads and gardens. Live fences can be combined with other trees for the production of wood and fruits. They can be made of single or multiple species. Alternatively, one row of living fence posts can be planted widely spaced, with wire, sticks or dead branches between the trees.

Building live fences is a cheap method of fencing large areas for the long term. Live fences do not require expensive materials and they are easy to maintain. They may also provide products such as edible fruits.

Figure 4: **A sketch showing windbreaks**

Tree species used for live fencing should be:

- able to keep off livestock (thorny and/or densely branched)
- easy to establish and maintain
- able to withstand temporary water logging
- resistant to fire – act as firebreak
- tolerant to minor injuries: it is susceptible to frequent injuries from pruning or animals
- provide multiple products.

This practice is relevant to most farming systems. Lots of individual trees/shrubs are required to make a fence. Thus the propagation method must be simple and cheap. Direct seed sowing or use of cuttings (depending on species) is highly recommended. It is best to plant seeds, seedlings or cuttings in two staggered rows so that an impenetrable fence or hedge is formed. The distance between the rows can be 15–30 cm with the same space within the rows. Directly sown fences must be well looked after and protected.

Regular management activities include:

- protection of young seedlings against livestock and fires
- weeding
- replacing dead seedlings as quickly as possible to minimize gaps
- trimming and pruning to make a dense fence; most species make a better fence if trimmed in a pyramidal shape so that even the lowest branches can get some light
- applying manure/fertilizer if seedlings do not grow well or show other signs of nutrient deficiency

Benefits

Live fences are often multipurpose and have several advantages. Some of the uses are:

- Once established and regularly managed, live fences are permanent.
- Produce by-products, e.g., poles, fruits, fodder, and fuelwood.
- Provide mulch for gardens, bee forage or wood.
- Provide shade, protection and can also serve as a windbreak for the compound
- Control movement of livestock.
- Ornamental value.
- Help in soil conservation

Recommended species for this system include Berberis ceratophylla, *Berberis lyceum*, *Betula utilis*, *Hippophae salicifolia*, *Juglans regia*, *Rosa macrophylla*, *Juniperus communisn*, *Salix wallichiana*, *Taxus wallichiana*, *Pinus wallichiana*. It is mixed with thorny plants, such as blackberry, berberris, bael, blackthorn, hawthorn, honey locust, mesquite (*Prosopis*) and cutch tree.

Carbon potential

Live fences in agroforestry have low opportunity costs but have potential for carbon sequestration (28-54 t C ha^{-1}) (Torres et al., 2010) and for biodiversity conservation (Harvey et al., 2004). Some site-specific modelling efforts have been undertaken to evaluate the suitability of carbon sequestration as an income option for farmers in the West African Sahel (Doraiswamy et al., 2007; Takimoto et al., 2008; Tschakert, 2004). However, these assessments indicate that payments for carbon sequestration by live fences in agroforests are unlikely to generate substantial income for smallholder farmers in most cases.

Windbreaks

Windbreaks are obstacles that reduce wind velocity (Figure 4). These could be stone walls or strips of living trees and shrubs that provide shelter to crops, fruits, livestock and farm houses against hot, dry and cool wind, sun and snowdrift. In agroforestry systems, windbreaks are established to protect crops and/or livestock from wind. Where wind is a major cause of soil erosion and moisture loss, windbreaks can make a significant contribution to sustainable production. It helps preserve soil and maintain soil fertility and improves the microclimate for crops. Well-designed windbreaks, i.e., ones that are not too dense, not only reduce wind speed but may also increase humidity and reduce water loss from the soil. Leaving a shelterbelt while establishing new fields can provide some protection from runoff and wind. A properly designed windbreak can protect a field at least ten times as long as the height of the tallest trees, i.e. 10-metre tall trees protect a crop field of up to 100 metres long downwind. The trees' capacity to slow down wind depends on the architecture and position of their crowns.

In Nepal, windbreaks are common in the Terai, where strong hot and dry winds damage crops. Large-scale farming areas require large windbreaks, as small windbreaks would extend over many small farms, thus complicating logistics and planning, and requiring co-operation between the farmers. Planting trees along the boundary and live fence may be sufficient in small-scale farming areas.

Trees suitable for windbreaks should be:

- Easy to propagate, establish and manage: minimize labour inputs
- Not harbour pests and diseases
- Deep rooted: less susceptible to uprooting by wind
- Provide minimum competition for light, water and nutrients to adjacent crops
- Small open crown: reduces the risk of wind damage

Trees for windbreak should be planted at a right angle to the prevailing wind direction. It can either consist of a single line of trees with a spacing of 1.5–2.0 m, or two lines with a spacing of 4–5 m within the line and 2–4 m between the lines. In addition to one or two lines of trees, a line of shrubs spaced at approximately 1 m can be planted on the side facing the prevailing wind. Spacing between trees may vary according to species.

Trees are integral to hill farming in the middle hills of Nepal.

The windbreak must not be too dense. If the wind is blocked completely, it will cause turbulence over the crops. Windbreak must be semi-permeable so that it can slow down wind. Proper management entails the following activities:

- Protect young trees against livestock and fire.
- Carefully weed and replace dead seedlings
- Protect from termites and other pests and diseases
- Selectively prune or pollard trees to maintain a suitable density and to reduce shading on the adjacent agricultural crops

Benefits

- Reduced wind damage and increased retention of moisture
- Protection of crops and soil against wind, which increases yield
- Minimize the amount of soil moisture that gets evaporated
- Produce wood

Eucalyptus camaldulensis, *Casuarina equisetifolia*, *Dalbergia sissoo*, *Acacia auriculiformis*, *Melia azedarach*, *Leucaena leucocephala* and bamboos are usually selected for windbreak.

Carbon potential

Like many other agroforestry systems, windbreaks have potential for carbon sequestration (Schoeneberger, 2009). In addition to carbon sequestered by trees, windbreaks provide value adding carbon sequestration due to improved crop and livestock production and energy savings (Kort and Turnock, 1999). The sparse literature demonstrates the importance of species selection for high carbon sequestration. For example, hybrid poplar sequestered 0.367 t C tree^{-1} in above- and below-ground compared to 0.11 t C tree^{-1} in green ash (Kort and Turnock, 1999). The above-ground carbon storage by single row conifer, hardwood, and shrubs for a windbreak in Nebraska was 9.14, 5.41 and 0.68 t km^{-1} respectively (Sampson et al., 1992).

Nair and Nair, (2003) estimated that 85 million ha of land globally is under windbreaks with sequestration potential of 4 million t C $year^{-1}$. According to Sampson et al. (1992), if we assume that 5% of the cropland with 120 million trees are windbreaks, 11.4 million t C $year^{-1}$ can be sequestered.

Trees along boundaries

Multipurpose trees and shrubs are generally planted along the boundaries of fields. The most common form of boundary planting consists of a single line of widely spaced trees and shrubs. If trees are to be planted along a property line affecting more than one landowner, the neighbors have to reach agreement to avoid conflicts.

The spacing for smaller and medium-sized fruit and fodder trees is normally 3 m. Other multipurpose tree species can be spaced between 2 and 4 m depending on the species. For double rows, the spacing between the rows should not be less than 2 m. The tree propagation method will depend on the species, but the common method entails the use of seedlings or transplantation of wildlings.

Management aspects

- Protect young trees against livestock and fires
- Tend the trees by pruning and pollarding to reduce shade on the adjacent crops. The pruned and pollarded branches can be used as construction materials or firewood.

Benefits

- Production of fuelwood, poles, fruits, fodder and timber
- Marking of field or farm boundaries effectively
- Protection of crops and soil against wind (yields are known to increase when windbreaks are established in areas with strong winds)

Tree species such as *Azadirachta indica*, *Grevillea robusta*, and *Leucaena leucocephala* can be used as boundary markers. Trees with a short lifespan, e.g., *Sesbania* spp. are less suitable unless combined with more permanent trees. Competitive trees such as eucalyptus and pine should be avoided.

Carbon potential

Trees on boundaries diversify land use and improve soil quality. These trees can provide fuelwood and poles to the farmers, and help enhance biodiversity and beekeeping. Boundary planting can be carried out by individuals or groups. The estimated net carbon benefit of this system above the baseline (with 20% set aside as risk buffer) is 46.1 t C ha^{-1} as a long-term average over 50 years. This is equivalent to 169 t C ha^{-1}. For this tree planting system, it is better to calculate the number of carbon credits per 100 metres. This equates to 2.3 tonnes of carbon per 100 metres, which is equivalent to 8.4 tonnes of carbon dioxide (Clinton Development Initiative, 2011).

Contour vegetative strips

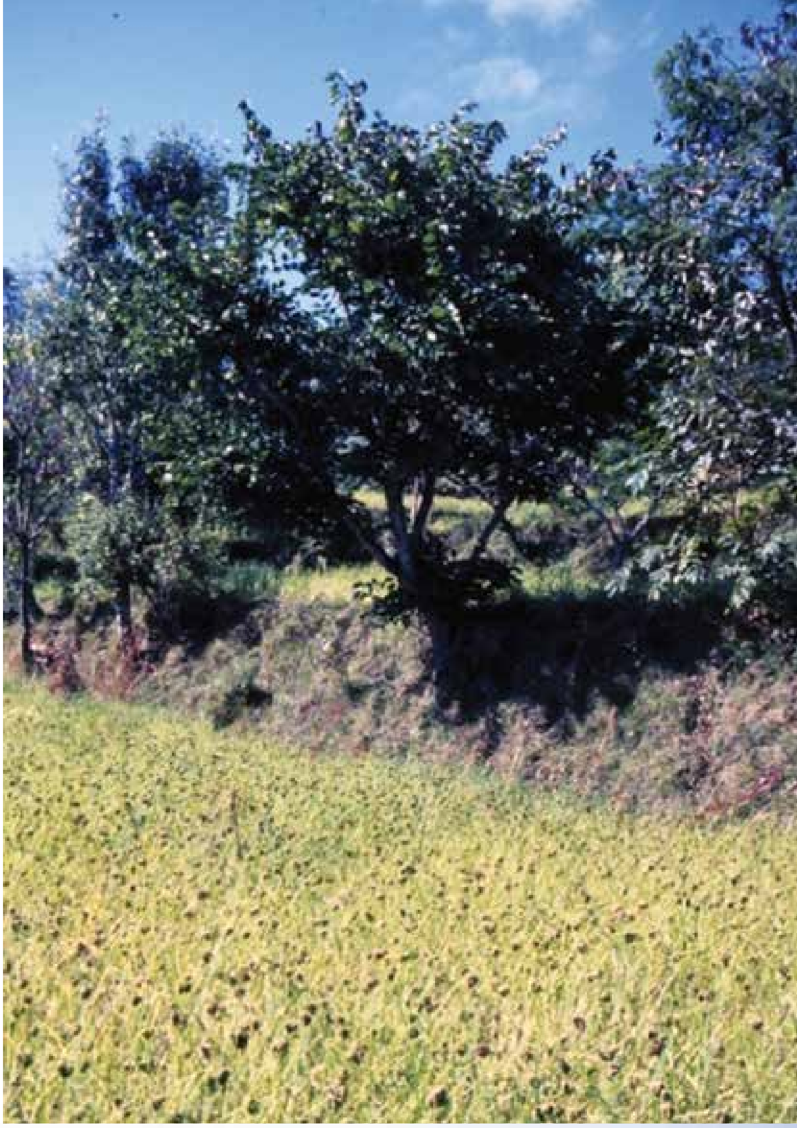
This is one of the traditional farming systems of Nepal, where live barriers of grasses, lines of stone or wood, are placed across hillsides to control runoff and soil erosion. Combinations of trees, shrubs, grasses and creeping vines planted along the contour can serve the same purpose. They result in greater structural stability and can provide a higher yield and diversity of useful products. The contour strip is also known as a barrier strip or hedge, horizontal vegetation strip, contour hedge or horizontal hedgerow. It is an erosion-control measure for sloping farmland, which provides useful products and enriches the soil. Establishing and maintaining horizontal strips of vegetation on sloping ground is one of the most direct, cost-effective and ecologically sound erosion control interventions.

Contour vegetation strips may be planted. The method may also entail allowing natural vegetation to grow along the slope. If the strips are dense and wide enough, they can stop water from flowing downhill and trap soil particles in a web of vegetation and litter. If the soil is permeable, water can then soak slowly into the ground. The strips consist of one or two rows of shrubs and trees with at least one line of tightly spaced grasses planted on the down slope side to trap eroding soil. Trees and shrub species used on contour strips must be compatible with surrounding crops and cultivation practices.

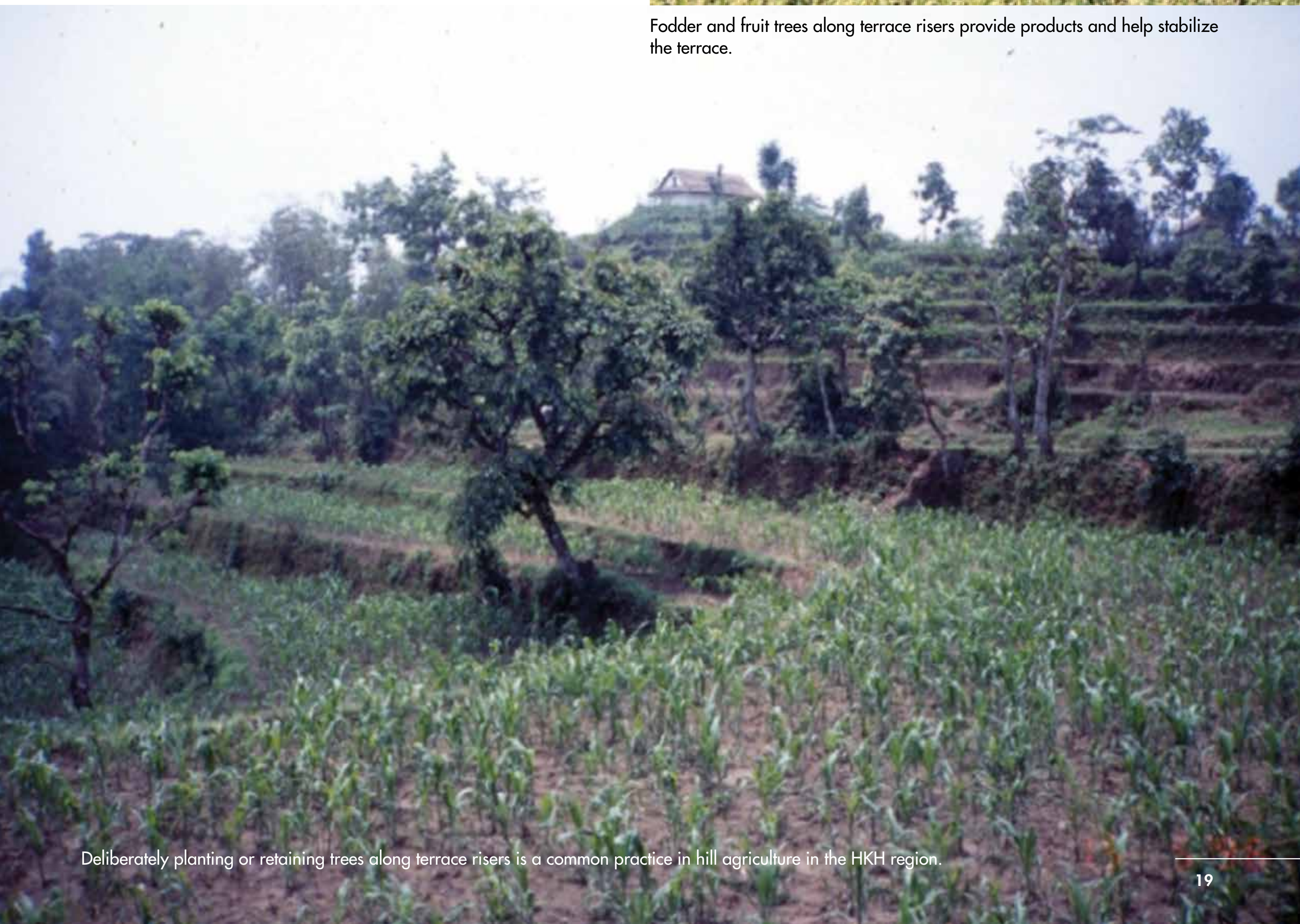
The effectiveness of contour vegetation strips largely depends on slope, rainfall intensity and soil conditions. The width of the strips and the interval between them are the two most important factors to be considered for soil and water conservation. In general, steeper slopes require wider strips spaced closer together.

Effective contour vegetation strips requires proper maintenance. Management of grass and legume filters involves several simple steps:

- Inspect contour vegetation strips frequently, especially after intense rainfall events and runoff events of long duration. Small breaks in the sod and small erosion channels can quickly become big problems.



Fodder and fruit trees along terrace risers provide products and help stabilize the terrace.



Deliberately planting or retaining trees along terrace risers is a common practice in hill agriculture in the HKH region.

Sample agroforestry practice in the tropical region.

- Reseed or inter-seed bare areas of the strips.
- Soil test periodically and apply soil amendments accordingly.
- Control trees, brush and noxious weeds in the filter.

Benefits

- Slows water runoff.
- Removes up to 75% or more of sediment in runoff.
- Serves as a source of food, nesting cover, and shelter for wildlife.
- Provides a setback distance for agricultural chemical use from watercourses.
- Reduces downstream flooding.
- Represents a profitable, common sense conservation method for landowners.
- Establishes natural vegetation.

Recommended species include pineapple (*Ananas comosus*), ginger (*Zingiber officinale*), gabi (*Colocasia esculenta*), castor bean (*Ricinus communis*), sweet potato (*Ipomoea batatas*), peanut (*Arachis hypogaea*), mung bean (*Vigna radiata*) and melon (*Cucumis melo*).

Cardamom grows under Alnus trees in eastern Nepal.

Trees and shrubs on terraces

Terraces are built mainly to conserve the soil and stabilize the slopes of steep land, while providing level areas for sustained cropping. The terrace method increases yields and makes it possible to grow a variety of crops by improving soil-moisture conditions. Trees and shrubs are planted/retained on slopes above and below the terrace to stabilize it and to produce leaf mulch, shade and shelter from wind. In most cases, pre-existing trees and shrubs can be maintained on undisturbed parts of a slope or by adjusting terrace design and construction. Terraces can also improve site conditions for introducing valuable tree crops.

Trees can be placed either at the toe of the terrace riser or along its edge. In areas where soil moisture is scarce, tree roots find better growing conditions along the toe. In fact, the soil immediately behind the edge of the terrace is

People in the mid hills and Terai now promote agroforestry

drier than anywhere else on the structure. In areas where rains and winds are heavy, trees planted along the terrace edge will protect crops and increase yield. The greater portion of the leaf litter will fall near the edge of the terrace if the trees are planted along the edge. Thus, in terms of site improvement and effect on crops, the best place for trees is at the edge of the terrace, whereas in terms of the tree's own requirements, the toe of the riser is best.

Trees help stabilize rock-wall terraces and the earth behind them, fastening themselves by sending roots into rock crevices deep below the surface and acting as anchors to tie different soil layers together, thus reducing the chance of mass earth movements such as mudslides. Planting trees may improve the stability of slopes that are unstable due to high level of soil moisture. Trees planted on such slopes absorb some of the excessive water, thus reducing water pressure and preventing soil slippage down the slope.

Ziziphus jujuba, *Bauhinia purpurea*, *Bauhinia variegata*, *Citrus species*, *Mangifera indica Leucaena leucocephala* are recommended tree species for planting on terrace risers. In the mid hills of Nepal, *Ficus neriifolia*, *Ficus roxburghii*, *Saurauia napaulensis*, *Schima wallichii*, *Prunus cerasoides*, *Artocarpus lakoocha*, *Albizia julibrissin* and many other species are commonly seen along the terraces of agriculture fields.

Shifting cultivation

Shifting cultivation is one of the earliest farming systems and dates back to about 7000 B.C. (Pareta and Pareta, 2015). It is a common form of traditional agriculture in the Third World countries. It is practiced by small farmers who only have traditional tools and little or no capital. Shifting agriculture involves clearing forest land and cultivating it for two to three years. When crop production decreases due to declining soil fertility, the fields are left uncultivated or fallow for 10–20 years to allow regeneration of the natural forest and restore soil fertility. Although shifting cultivation is declining in many parts of the world, the system is still practiced on the hill slopes of Nepal and north India. Pareta and Pareta (2015) reported that the total land area under shifting cultivation in Nagaland state actually increased from 2239.85 km^2 in 2003 to 2630.39 km^2 in 2013.

Increase in population demand more area of crop land and bush fallow, resulting in demand for more area under shifting cultivation. This encroaches on forested area and also causes forest degradation. Farmers practicing shifting cultivation must rely on long natural fallows of 3-30 years or more in forest areas.

Strategies for controlling shifting cultivation

- Provide employment and income generation opportunities on a regular basis through proper utilization of land resources, i.e., equitable distribution of waste land among the indigenous people. But the plan by the country/state/province have to pump in significant resources for proper reclamation and development of the wasteland through agroforestry and silvi-pasture practices for the indigenous people (Elevitch and Wilkinson, 2000) .
- Encourage cooperative efforts for carrying out forest-based activities. Basket making, rope making, cane furniture processing of minor forest produce, honey collection, etc. have to be made commercially viable by providing proper marketing mechanisms. This will not only discourage tribals from practicing shifting cultivation but will also help them monetarily (Sati and Rinawma, 2014).
- Specific policies suited to the context of the mountain region should be framed and implemented to avoid any discrepancies in practicing shifting cultivation (Sati and Rinawma, 2014).

Shifting cultivation in Chitwan district

- Terracing fields, promoting cultivation of vegetables, fruits and high value crops, and proper use of timber and non-timber forest products may substantially contribute to sustainable practices in shifting cultivation (Sati and Rinawma, 2014).

Carbon Potential

Not much is known about the impacts of shifting cultivation on forest losses and carbon sequestration in the global context (Zhang et al., 1998). Though overall carbon stock in shifting cultivation land in Nagaland has increased from 1.12 million tonnes in 2003 to 1.32 million tonnes in 2013 (Pareta and Pareta, 2015), carbon content remained constant at about 5 t C ha^{-1} which is a relatively low value. Total carbon in shifting cultivation was estimated to be 1.03% of the total of all land uses, second only to forest land.

Tea, cardamom, coffee and medicinal plants under trees

While some plants do not grow well in low light, many others thrive under such conditions. Just as moisture, temperature, and soil conditions may limit plant growth, the amount of shade present may determine which plants will grow successfully. Tea, cardamom, cacao and coffee grow well under shade in tropical and sub-tropical climates.

Carbon potential

Coffee agro-forests are known to store substantial amounts of carbon in above-ground biomass and soil. Total carbon stock is heavily dependent on non-coffee biomass with trees, saplings, and their associated root biomass storing up to 57% of the total carbon in the system (Schmitt-Harsh et al., 2012). The research demonstrated that the total carbon stocks of coffee agroforests range from 74 to 259 t C ha^{-1} with a mean of 127.6 $\pm$ 6.6 (SE) t C ha^{-1}.

Agroforestry and REDD+

One of the major drivers of deforestation and forest degradation in the HKH region is agricultural expansion. Agroforestry is a sustainable and permanent type of land management; potentially large amounts of carbon could be conserved in the terrestrial habitat. Agroforestry integrates growing trees with agricultural and tree products and helps reduce deforestation indirectly by providing tree products and services, including carbon sequestration and storage in the system. It also helps reduce pressure on forests for fuel wood, charcoal and timber.

Farmers plant trees in their fields to harvest timber and non-timber products. The trees in the field create a carbon sink by sequestering carbon and simultaneously reduce emissions as they produce timber and non-timber products and reduce pressure on other forest areas.

The carbon sequestration potential of agroforestry systems is attracting much attention, especially following the Kyoto Protocol's recognition of agroforestry as an option for mitigating greenhouse gases (Nair et al., 2009). However, there is a dearth of data on carbon in agroforestry systems, particularly from the HKH region. Although there's limited data on carbon in agroforestry system in the HKH region, evidence from other parts of the world suggests that agroforestry has significant potential for carbon sequestration and storage.

Albrecht and Kandji (2003) which have been proposed to compensate greenhouse gas (GHG carried out a study to analyse carbon storage data in some tropical agroforestry systems and to discuss their role in reducing CO_2 in the atmosphere. The carbon sequestration potential of agroforestry systems is estimated between 12 and 228 t C ha^{-1} depending on the system, with a median value of 95 t C ha^{-1}. Long rotation systems such as agroforests, home gardens and boundary plantings can sequester significant quantities of carbon in plant biomass and in long-lasting wood products. Soil carbon sequestration constitutes another realistic option achievable in many agroforestry systems.

The carbon sequestration potential of afforestation/reforestation varies according to the ecosystem, species, growth rate, management, etc. It is reported that globally 630 million hectares of land would be available for agroforestry, with a potential to sequester 586 t C per year = yr^{-1} by 2040 (Sharma et al., 2015).

Albrecht and Kandji (2003) which have been proposed to compensate greenhouse gas (GHG estimated that carbon sequestration by agroforestry systems ranges from 0.29 to 15.21 t C ha^{-1} yr^{-1} above ground. Carbon stored in soil can be between 30 and 300 t ha^{-1}. Recent studies on various agroforestry systems in diverse ecological conditions showed that tree-based agricultural systems, compared to treeless systems, store more carbon in deeper soil layers near the tree; higher soil organic carbon content was associated with species richness and high tree density.

Knowledge gaps

Agroforestry is widely practised in the HKH and internationally recognized as a farming practice with the potential to secure and store carbon (Albrecht and Kandji, 2003; Isaac et al., 2005; Robert, 2001) which have been proposed to compensate greenhouse gas (GHG. However, there is inadequate information on the amount of carbon sequestered in agroforestry systems. In the HKH, no studies have been conducted to quantify the amount of soil carbon sequestered in the agroforestry systems. There have been a number of studies on the biophysical potential of carbon sequestration in dry land soils (Batjes, 2001; Lal, 2002; Schlesinger, 2000). However, no efforts have been made to identify suitable agroforestry systems and their carbon sequestration potential (Albrecht and Kandji, 2003) which have been proposed to compensate greenhouse gas (GHG).

Many gaps exist in agroforestry practices in rural areas. The agroforestry model involves an integrated land use approach and can enhance production using low input technology (Branca et al., 2011; Law et al., 2014; Mbow et al., 2014), but it requires advanced policy actions (right institutions, local capacities, adapted technologies, appropriate social context, equity, gender, governance) (Mbow et al., 2014). Policy should also manage the demand side in relation to population growth and change in diet (Buttoud et al., 2013; Garnett et al., 2013; Mbow et al., 2014), particularly with growing urban populations.

The extent of carbon sequestered in agroforestry systems largely depends on the local environment and management practices. Trading sequestered carbon is a viable opportunity for agroforestry practitioners to get economic benefits. However, given the diversity of agroforestry systems and lack of carbon data, there is a need for more rigorous research on agroforestry systems before agroforestry can be incorporated in global agendas of carbon sequestration.

Agroforesty has potential to become an important REDD+ intervention for carbon sequestration in mountain areas

Conclusion

Agricultural lands have significant potential to absorb large quantities of carbon if trees are judiciously planted and managed together with crops. Agroforestry is increasingly recognized as an important land use system not only for agricultural sustainability but also for addressing issues related to climate change. It is a dynamic system of natural resource management that integrates trees in agricultural land to diversify and enhance production for increased social, economic and environmental benefits.

Agroforestry practices are known to have positive impact on the environment. The two major environmental benefits are carbon sequestration and biodiversity conservation. Agroforestry supplements farmers' incomes, controls soil erosion, maintains soil fertility, and provides livestock feed. About 33% of the total land area of Nepal is under non-forest land use systems such as pasture and agroforestry (Joshi et al., 2010). With sustainable management, non-forest land can bring multiple benefits to farmers including carbon benefits. However, the potential of agroforestry systems has not received enough space in carbon projects. There are very few studies that can demonstrate the best agroforestry practices and sustainable agricultural land management. Verified Carbon Standard, among several voluntary greenhouse gas programmes, has come up with methodologies for carbon accounting and GHG monitoring. But such information should be widely disseminated so that it informs the development of appropriate models for REDD+ payments at the regional level.

Agroforestry plays an important role in improving the resilience of farming systems to climate variability. Agroforestry promotes farm trees that can sequester carbon and thus contributes in mitigating climate change, building resilience to climate variability and increasing food security and income at the household and national level. There is a need to scale up proven tree-based farming practices, such as combining conservation agriculture with agroforestry. Policymakers need to provide start-up inputs, including high-quality seeds, nurseries, and agroforestry training and extension materials. Further requirements include markets for agroforestry products, effective systems for managing carbon credits and payments for environmental services, and financial stimuli for farmers to plant trees. REDD strategies will also have to address the causes of deforestation, sustainable forest management and monitoring capacity.

In the past few years, the hope that REDD+ programmes will significantly change tropical forest management has been challenged by slow progress in the operationalization of the concepts (Minang and van Noordwijk, 2013). REDD's scope has gradually expanded, with a 'plus' (REDD+) now referring to forest restoration, though it still depends on the concept and definition of 'forest'. Scientifically, there is a need for more holistic carbon accounting and the inclusion of whole landscapes. This will also help avoid perverse incentives and achieve fairness (van Noordwijk et al., 2011; Joshi et al., 2013). Often, governments' rulings about 'forest', or all land managed by forestry authorities, are at odds with actual tree cover on the land. There are many treeless forests but also many trees outside forests, including those in agroforestry systems. One REDD+ option with considerable potential, beyond the domain of pure forestry, is agroforestry, i.e., planting trees on farms to sustainably intensify agriculture, increase yields and conserve the environment.

All countries participating in a future REDD+ mechanism will need to demonstrate substantial capacity for monitoring, reporting and verification of their carbon emissions and removals from land use change. It is necessary to provide a critical standard from which to assess long-term carbon dynamics and forest and agroforest sustainability.

In the context of REDD+, agroforestry has the potential to reduce deforestation and forest degradation by supplying timber and fuelwood that would otherwise be sourced from adjacent or distant forests. In fact, agroforestry has been used in several protected area landscape buffer zones and within conservation as a way to alleviate pressure on forests. However, enabling market infrastructure, policies on tree rights and ownership and safeguards would be necessary for agroforestry and other tree-based systems in the landscape to effectively contribute to the goals of REDD+. Agroforestry should be a direct target of REDD+ programmes, and is one of the necessary conditions for the success of REDD+.

References

Albrecht, A., and Kandji, S.T. (2003). 'Carbon sequestration in tropical agroforestry systems'. *Agriculture, Ecosystems and Environment*, 99(1-3), 15–27. http://doi.org/10.1016/S0167-8809(03)00138-5

Andrade, H.J. (1999). Dynamic systems: Productive pasture with Acacia mangium and Eucalyptus deglupta in the humid tropics. Tesis Mag. Sc. CATIE, Turrialba, Costa Rica. Turrialba, Costa Rica, 1–70

Batjes, N.H. (2001). 'Options for increasing carbon sequestration in West African soils: An exploratory study with special focus on Senegal'. *Land Degradation and Development*, 12(2), 131–142.

Bolívar-Vergara, D.M., Ibrahim, M., and Jiménez, F. (1999). 'Production of Brachiaria under a silvopastoral system with Acacia mangium in the humid tropics'. *Agroforestry in the Americas*, 6 (23), 48-50. Retrieved from http://moodle-agricultural.ifxnetworks.com/:8080/xmlui/handle/123456789/166

Branca, G., McCarthy, N., Lipper, L., and Jolejole, M.C. (2011). 'Climate-smart agriculture: A synthesis of empirical evidence of food security and mitigation benefits from improved cropland management'. *Mitigation of Climate Change in Agriculture Series*, 3, 1–42

Bustamante, J., Ibrahim, M., and Beer, J. (1998). 'Agronomic evaluation of eight grass improved in a silvopastoral system pore (Erythrina poeppigiana) in the humid tropics of Turrialba'. *Agroforestry in the Americas*, 5(19), 11–16

Buttoud, G., Place, F., and Gauthier, M. (2013). *Advancing agroforestry on the policy agenda: A guide for decision-makers*. Rome: FAO

Cairns, M.A., Brown, S., Helmer, E.H., and Baumgardner, G.A. (1997). 'Root biomass allocation in the world's upland forests.' *Oecologia*, 111(1), 1–11

Chauhan, S.K., Sharma, S.C., Beri, V., Ritu, Yadav, S., and Gupta, N. (2010). 'Yield and carbon sequestration potential of wheat (Triticum aestivum)-poplar (Populus deltoides) based agri-silvicultural system.' *Indian Journal of Agricultural Sciences*, 80(2), 129–135. Retrieved from http://www.scopus.com/inward/record.url?eid=2-s2.0-77952272579andpartnerID=40andmd5=df2cb4a421f96a490b738a741e6e8e64

Clinton Development Initiative (2011). *Boundary planting, technical specifications*. Trees of Hope Project, Malawi.

De Foresta, H., Somarriba, E., Temu, A., Boulanger, D., Feuilly, H., and Gauthier, M. (2013). *Towards the assessment of trees outside forests*. Food and Agriculture Organization of the United Nations (FAO), Rome, Italy, 335

Doraiswamy, P.C., McCarty, G.W., Hunt, E.R., Yost, R.S., Doumbia, M., and Franzluebbers, a. J. (2007). 'Modeling soil carbon sequestration in agricultural lands of Mali.' *Agricultural Systems*, 94(1), 63–74. http://doi.org/10.1016/j.agsy.2005.09.011

Duguma, L.A., Minang, P.A., and van Noordwijk, M. (2014). 'Climate change mitigation and adaptation in the land use sector: From complementarity to synergy.' *Environmental Management*, 54(3), 420–432

Dwivedi, A.P. (1992). *Agroforestry: Principles and Practices*. Oxford and IBH Publishing Company

Elevitch, C.R., and Wilkinson, K.M. (2000). Economics of farm forestry: Financial evaluation for landowners. Agroforestry Guides for Pacific Islands # 7. Permanent Agriculture Resources, Holualoa, Hawaii, USA.

Garnett, T., Appleby, M.C., Balmford, A., Bateman, I.J., Benton, T.G., Bloomer, P., Burlingame, B., Dawkins, M., Dolan, L., Fraser, D., and Herrero, M. (2013). 'Sustainable intensification in agriculture: Premises and policies.' *Science*, 341(6141), 33–34

Gilmour, D.A., and Nurse, M.C. (1991). 'Farmer initiatives in increasing tree cover in central Nepal.' *Mountain Research and Development*, 329–337

Hairiah, K., Dewi, S., Agus, F., Velarde, S.J., Ekadinata, A., Rahayu, S., and van Noordwijk, M. (2011). *Measuring carbon stocks across land use systems: A manual*. World Agroforestry Centre-ICRAF, South East Asia Regional Office, Bogor, Indonesia

Harvey, Celia A.; Tucker, Nigel I.J.; Estrada, A. (2004). 'Life fences, isolated trees and windbreaks: Tools for conserving biodiversity in fragmented tropical landscapes (Chapter 11). In *Agroforestry and Biodiversity*

Conservation in Tropical Landscapes. Island Press, Washington, DC, 523. Retrieved from http://books.google.com/books?hl=enandlr=andid=etuh8kXYMDQCandpgis=1

ICIMOD, ANSAB, and FECOFUN. (2011). *Report on Forest Carbon Stocks Changes in REDD Project Sites*, March 2010, 35

Isaac, M.E., Gordon, A.M., Thevathasan, N., Oppong, S.K., and Quashie-Sam, J. (2005). 'Temporal changes in soil carbon and nitrogen in west African multistrata agroforestry systems: A chronosequence of pools and fluxes. *Agroforestry Systems*, 65(1), 23–31

Joshi, L., Karky, B.S., Poudel, K.C., Bhattarai, K., Dangi, R., Acharya, K., Uprety, B., Singh, V., Chand, N., and Manandhar, U. (2013). 'Co-benefits of REDD+ in community managed forests in Nepal'. *Journal of Forest and Livelihood*, 11(2), 65–68

Joshi, L., Paudel, N.S., Ojha, H., Khatri, D.B., Kanel, K., Pradhan, R., Karky, B., Pradhan, U., Karki S. (2010). *Moving beyond REDD: Reducing emissions from all land uses in Nepal. Final National Report*. Nairobi: ASB Partnership for the Tropical Forest Margins. 88 pp

Kaonga, M.L., and Coleman, K. (2008). 'Modelling soil organic carbon turnover in improved fallows in eastern Zambia using the RothC-26.3 model'. *Forest Ecology and Management*, 256(5), 1160–1166

Kort, J., and Turnock, R. (1999). 'Carbon reservoir and biomass in Canadian prairie shelterbelts'. *Agroforestry Systems*, 44(2-3), 175–186

Kumar, B.M., and Nair, P.K.R. (2011). 'Carbon sequestration potential of agroforestry systems: Opportunities and challenges'. *Springer Science and Business Media*, Vol. 8

Lal, R. (2002). 'Carbon sequestration in dryland ecosystems of West Asia and North Africa'. Land Degradation and Development, 13(1), 45–59

Law, R., Briefing, P., and Dooley, E. (July 2014). *Climate-smart agriculture and REDD + implementation in Kenya*, 1–61.

López, a, Schlönvoigt, a, Ibrahim, M., Kleinn, C., and Kanninen, M. (1999). Cuantificación del carbono almacenado en el suelo de un sistema silvopastoril en la zona Atlántica de Costa Rica. *Agroforestería En Las Américas*, 6(23), 51–53. Retrieved from http://web.catie.ac.cr/informacion/RAFA/rev23/nlopez_1.htm

Lundgren, B.O., and Raintree, J.B. (1983). *Sustained Agroforestry*. ICRAF Nairobi

Mbow, C., Van Noordwijk, M., Luedeling, E., Neufeldt, H., Minang, P.A., and Kowero, G. (2014). 'Agroforestry solutions to address food security and climate change challenges in Africa'. *Current Opinion in Environmental Sustainability*, 6, 61–67.

Mbow, C., Van Noordwijk, M., Prabhu, R., and Simons, T. (2014). 'Knowledge gaps and research needs concerning agroforestry's contribution to sustainable development goals in Africa'. *Current Opinion in Environmental Sustainability*, 6, 162–170

Minang, P.A., and van Noordwijk, M. (2013). 'Design challenges for achieving reduced emissions from deforestation and forest degradation through conservation: Leveraging multiple paradigms at the tropical forest margins'. L*and Use Policy*, 31, 61–70.

Mokany, K., Raison, R., and Prokushkin, A.S. (2006). 'Critical analysis of root: Shoot ratios in terrestrial biomes'. *Global Change Biology*, 12(1), 84–96

Nair, P.K.R. (1987). 'Agroforestry systems inventory'. *Agroforestry Systems*, 5(3), 301–317

Nair, P.K.R. (1993). 'An introduction to agroforestry'. *Springer Science and Business Media*

Nair, P.K.R., Kumar, B.M., Nair, V. D., and others. (2009). 'Agroforestry as a strategy for carbon sequestration'. *J Plant Nutr Soil Sci*, 172(1), 10–23

Nair, P.K.R., and Nair, V.D. (2003). 'Carbon storage in North American agroforestry systems'. *The Potential of US Forests to Sequester Carbon and Mitigate the Greenhouse Effect*, 333–346

Nair, P.K.R., Nair, V.D., Kumar, B.M., and Showalter, J.M. (2010). 'Carbon sequestration in agroforestry systems (Chapter 5)'. In *Advances in Agronomy*, 108, 237–307

Ngwayi, N.C.I. (2012). Mapping carbon stock in trees outside forest: Comparing a very high resolution optical satellite image (GEO-EYE) and airborne LiDAR date in Chitwan, Nepal, 1–65

Oelbermann, M. (2002). *Linking Carbon Imputs to Sustainable Agriculture in Canadian and Costa Rican Agroforestry Systems*. University of Guelph.

Pareta, K., and Pareta, U. (2015). LULC and climate change impact on carbon stocks: A case study through satellite remote sensing data, 3(5), 167–179.

Peichl, M., Thevathasan, N.V, Gordon, A.M., Huss, J., and Abohassan, R.A. (2006). 'Carbon sequestration potentials in temperate tree-based intercropping systems, southern Ontario, Canada'. *Agroforestry Systems*, 66(3), 243–257

Rasul, G., and Kollmair, M. (2008). *Sustainable livelihood promotion through agricultural development in the hills of South Asia*, 1–18

Robert, M. (2001). *Soil Carbon Sequestration for Improved Land Management*.

Sampson, R.N., Moll, G. a, Kielbaso, J.J., Sampson, R.N., and Hair, D. (1992). 'Opportunities to increase urban forests and the potential impacts on carbon storage and conservation'. *Forests and Global Change: Opportunities for Increasing Forest Cover*, 1, 51–72

Sati, V.P., and Rinawma, P. (2014). *Nature and Environment Review of Existing Research*, 19(2), 179–187

Schild, A. (2008). 'ICIMOD's position on climate change and mountain systems: The case of the Hindu Kush Himalayas'. *Mountain Research and Development*, 28(3), 328–331

Schlesinger, W.H. (2000). 'Carbon sequestration in soils: Some cautions amidst optimism'. *Agriculture, Ecosystems and Environment*, 82(1), 121–127

Schmitt-Harsh, M., Evans, T.P., Castellanos, E., and Randolph, J.C. (2012). 'Carbon stocks in coffee agroforests and mixed dry tropical forests in the western highlands of Guatemala'. *Agroforestry Systems*, 86(2), 141–157. http://doi.org/10.1007/s10457-012-9549-x

Schoeneberger, M.M. (2009). 'Agroforestry: Working trees for sequestering carbon on agricultural lands'. *Agroforestry Systems*, 75(1), 27–37. http://doi.org/10.1007/s10457-008-9123-8

Sharma, R., Chauhan, S.K., and Tripathi, A.M. (2015). 'Carbon sequestration potential in agroforestry system in India: An analysis for carbon project'. *Agroforestry Systems*, 1-14

Takimoto, A., Nair, P.K.R., and Nair, V.D. (2008). 'Carbon stock and sequestration potential of traditional and improved agroforestry systems in the West African Sahel'. *Agriculture, Ecosystems and Environment*, 125(1–4), 159–166. http://doi.org/10.1016/j.agee.2007.12.010

Tengnas, B. (1994). *Agroforestry extension manual for Kenya*. Nairobi: International Centre for Research in Agroforestry, 188

Thangata, P.H., and Hildebrand, P.E. (2012). 'Carbon stock and sequestration potential of agroforestry systems in smallholder agroecosystems of sub-Saharan Africa: Mechanisms for reducing emissions from deforestation and forest degradation (REDD+)'. *Agriculture, Ecosystems and Environment*, 158, 172–183

Thevathasan, N.V, and Gordon, A.M. (1997). 'Poplar leaf biomass distribution and nitrogen dynamics in a poplar-barley intercropped system in southern Ontario, Canada'. *Agroforestry Systems*, 37(1), 79–90

Thevathasan, N.V, and Gordon, A.M. (2004). 'Ecology of tree intercropping systems in the North temperate region: Experiences from southern Ontario, Canada'. *Agroforestry Systems*, 61(1-3), 257–268

Torres, A.B., Marchant, R., Lovett, J.C., Smart, J.C.R., and Tipper, R. (2010). 'Analysis of the carbon sequestration costs of afforestation and reforestation agroforestry practices and the use of cost curves to evaluate their potential for implementation of climate change mitigation'. *Ecological Economics*, 69(3), 469–477. http://doi.org/10.1016/j.ecolecon.2009.09.007

Tschakert, P. (2004). 'The costs of soil carbon sequestration: An economic analysis for small-scale farming systems in Senegal'. *Agricultural Systems*, 81(3), 227–253

Turnock, B. (2001). The carbon sequestration potential of prairie shelterbelts and their contribution to a national greenhouse gas mitigation strategy. In *Temperate Agroforestry: Adaptive and Mitigative Roles in a Changing Physical and Socioeconomic Climate*. Proc. of the 7th Biennial Conf. on Agroforestry in North America and 6th Ann. Conf. of the Plains and Prairie Forestry Association, pp. 27–33

Van der Werf, G.R., Morton, D.C., DeFries, R.S., Olivier, J.G., Kasibhatla, P.S., Jackson, R.B., Collatz, G.J., and Randerson, J.T. (2009). 'CO_2 emissions from forest loss'. *Nature Geoscience*, 2(11), 737–738

Van Noordwijk, M., Bayala, J., Hairiah, K., Lusiana, B., Muthuri, C., Khasanah, N., and Mulia, R. (2014). Agroforestry for buffering climate variability and adapting to change. *Climate Change Impacts and Adaptation in Agricultural Systems*, 216 – 232.

Van Noordwijk, M., Hoang, M.H., Neufeldt, H., Öborn, I., and Yatich, T. (2011). *How trees and people can co-adapt to climate change: Reducing vulnerability through multifunctional agroforestry landscapes*. Nairobi: World Agroforestry Centre (ICRAF), 134

Veldkamp, E. (1994). 'Organic carbon turnover in three tropical soils under pasture after deforestation'. *Soil Science Society of America Journal*, 58(1), 175. http://doi.org/10.2136/sssaj1994.03615995005800010025x

Verchot, L.V., Van Noordwijk, M., Kandji, S., Tomich, T., Ong, C., Albrecht, A., Mackensen, J., Bantilan, C., Anupama, K.V., and Palm, C. (2007). 'Climate change: Linking adaptation and mitigation through agroforestry'. *Mitigation and Adaptation Strategies for Global Change*, 12(5), 901–918

Zhang, P., Shao, G., Zhao, G., Master, D.C. Le, Parker, G.R., Jr, J.B.D., and Li, Q. (1998). China's forest policy for the 21st century. *Science*, 288(5474), 2135–2136

Zomer, R.J., Trabucco, A., Coe, R., Place, F., Van Noordwijk, M., and Xu, J.C. (2014). Trees on farms: An update and reanalysis of agroforestry's global extent and socio-ecological characteristics.

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On behalf of:
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UN-REDD PROGRAMME

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