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Agroforestry — A Sustainable Solution to Address Climate Change Challenges

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INTRODUCTION

Over the past two decades climate change has evolved from a debate about whether the planet is really warming to an increased focus on how to mitigate and adapt to its impacts. After an extensive review of the available literature on evidence of climate change, the Working Group I to the Fourth Assessment Report of the IPCC, 2007 concluded that "the warming of the climate system is unequivocal, as is now evident from observations of increases in global average air and ocean temperatures, widespread melting of snow and ice, and rising global average temperature". "The scientific evidence is now overwhelming; climate change presents very serious global risks, and it demands an urgent global response" (Stern 2007).

The developing countries mostly rely on agriculture for rural livelihoods and development. Nevertheless, agricultural systems in developing countries are adversely affected by land pressure and climate change, both of which threaten food production. Reduced productivity due to land degradation exacerbates the food deficit, despite the relative success of intensive agricultural systems that are promoted in many regions of the world. The various environmental impacts of agricultural intensification and food production, with negative impacts on soil and biodiversity, result in adverse feedbacks on climate, food security and on-farm income at local scale (Krausmann et al. 2013). Prior to the Green Revolution, the majority of subsistence farming anywhere in the world involved mixed species, usually including tree products (Mbow et al. 2014). Pressures towards higher production drove modern agriculture into monocultures. But in the background, subsistence agroforestry systems have also continued. As research has increasingly recognised the need to encompass ecosystems services other than food production, agroforestry has returned to the limelight. Recognizing the ability of agroforestry systems to address multiple problems and deliver multiple benefits, the IPCC Third Assessment Report on Climate Change states that "Agroforestry can both sequester carbon and produce a range of economic, environmental, and socioeconomic benefits. For example, trees in agroforestry farms improve soil fertility through control of erosion, maintenance of soil organic matter and physical properties, increased N, extraction of nutrients from deep soil horizons, and promotion of more closed nutrient cycling" (IPCC 2001). Agroforestry could be a win-win solution to the seemingly difficult choice between reforestation and agricultural land use, because it increases the storage of carbon as well as enhance agricultural productivity. This paper will discuss various adaptation and mitigation strategies to tackle climate change through agroforestry.

AGROFORESTRY BASED ADAPTATION AND MITIGATION STRATEGIES

Agroforestry systems comprise a long list of land management practices, including crop diversification, long rotation systems for soil conservation, homegardens, boundary plantings, perennial crops, hedgerow intercropping, live fences, improved fallows or mixed strata agroforestry. The well managed agroforestry can play a crucial role in improving resilience to uncertain climates through following interventions. Schoreneberger et al. (2012) highlighted the adaptation and mitigation measures in Table 1.

Table 1. Measures of climate change adaptation and mitigation through agroforestry (Adapted from Schoreneberger et al. 2012)

Climate change activity	Major C C functions	Agroforestry role
Mitigation		
Activities that reduces GHGs in the atmosphere or enhance the storage of GHGs stored in ecosystems	Sequester Carbon	Accumulate C in woody biomass and in soil.
	reduce GHG emission	Conserve existing C stock available in the forest providing alternate source of fuel, fodder and timber through AFS. Enhance forage quality, thereby reducing CH_4 Reduce fossil fuel consumption: Reduce equipment runs in areas with trees.

		Reduce farmstead heating and cooling Reduce CO_2 emission by C sink Reduce N_2O emissions: By greater nutrient uptake through trees By reducing N fertilizer consumption in tree systems
Adaptation		
Action to reduce or eliminate the negative effects of CC or take advantage of the positive effects	Reduce threats and enhance resilience	Amelioration of microclimate. To reduce impact of extreme weather events on crop production. To maintain quality & quantity of forage to reduce livestock stress. Provide greater habitat diversity to support organisms (e.g. native pollinators & useful insects). Provide greater structural and functional diversity to maintain and protect natural resources. Create diversified production opportunities to reduce risk under aberrant weather.
	Allow species to mitigate to more favorable conditions	Provide habitat corridors for species migration.

Verchot et al. (2006) also described that agroforestry systems have some definite advantages for mitigating and adapting to climate change risk in coming years which are as follows:

- Creating microclimatic condition which favors wide flora and fauna.
- Their deep root systems are able to explore a larger soil volume for water and nutrients, which will help during droughts.
- Increased soil porosity, reduced run-off and increased soil cover lead to increased water infiltration and retention in the soil profile which can reduce moisture stress during low rainfall years.
- Tree-based systems have higher evapotranspiration rates than row crops or pastures maintain aerated soil conditions by pumping excess water out of the soil profile more rapidly than other production systems.
- Agroforestry products can make a major contribution to the economic development of the millions of poor farmers by enhancing food security and alleviating poverty.

- Agroforestry systems often produce crops of higher value than row crops thus, diversifying the production system to include a signicant tree component may buffer against income risks associated with climatic variability.

Microclimatic modification

Microclimatic improvement through agroforestry has a major impact on crop performance as trees can buffer climatic extremes that affect crop growth. In particular, the shading effects of agroforestry trees can buffer temperature and atmospheric saturation deficit — reducing exposure to supra-optimal temperatures, under which physiological and developmental processes and yield become increasingly vulnerable (Lott et al. 2009). Trees on farm bring about favourable changes in the microclimatic conditions by influencing radiation flux, air temperature, wind speed, saturation deficit of understorey crops all of which will have a significant impact on modifying the rate and duration of photosynthesis and subsequent plant growth, transpiration, and soil water use (Monteith et al. 1991).

Some examples where the beneficial effects of microclimatic changes are experienced in shade trees which are used to protect heat sensitive crops like coffee, cocoa, ginger and cardamom from high temperatures. The windbreaks and shelterbelts are another way to slow down the wind speed to reduce evaporation and physical damage to crops. Similarly mulches reduce soil temperature and various crop tree mixes reduces soil erosion and maximize resource use efficiency (Rao et al. 2007). From the meteorological point of view agroforestry systems providing two key facts viz., shade tree concept (radiation) and mechanic concept. For the first concept, shade will create microclimates with lower seasonal means in ambient temperature and solar radiation as well as smaller fluctuations.The effect of solar radiation at day and night times increase surface temperature considerably and affecting the crop during critical periods such as flowering and seed maturing. The shade tree reduces evaporative demands from soil evaporation and crop transpiration. Shade trees are a potential adaptive strategy for farmers vulnerable to reduce water scarcity and microclimate alteration (Lin 2008). Beer et al. (1998) while reviewing the literature on shade management in coffee and cocoa plantations have observed that shade trees buffer high and low temperature extremes by as much as 5ºC. According to Steffan-Dewenter et al. (2007) the removal of shade trees increased soil surface temperature by about 4ºC and reduced relative air humidity at 2 m above ground by about 12%. Soil temperature under the Adansonia digitata and *Acacia* *tortilis* trees in the semi-arid regions of Kenya at 5-10 cm depth were found to be 6°C lower than those recorded in open areas (Belsky et al. 1993).

The mechanic concept of agroforestry explained in shelterbelts and windbreaks. Shelterbelts, parallel rows of trees over the landscape, is another widely used option to improve microclimates, more specifically to reduce the velocity of the wind by increasing the surface roughness and control wind erosion and evapotranspiration. The effects of properly designed shelterbelts extend from about 10 to 25 times the height of the belt downwind with the greatest effect close to the leeward side. Windbreaks and shelterbelts reduce wind velocity, increasing moisture and decreasing temperature and also providing shelter against direct sunlight. Therefore it is considered as good adaptive strategies of climate change (Montagnini and Nair 2004). Cleugh (1998) described that windbreaks are believed to reduce evaporative water losses from surfaces downwind, and thus conserve soil moisture, based on the notion that increased shelter from wind reduces evaporation (Fig. 1). In Rajasthan, windbreaks of *Prosopis cineraria* changing the scenario of agricultural field by depositing sands, reducing hot wind, lowering temperature and improving soil moisture status. Conserving fertile soil, protecting water quality, enhancing air movement and biological connectivity in the landscape, reducing energy bills while capturing carbon, but also recreation opportunities, esthetic, bird-watching and the solely cultural identity of a community are few examples of shelterbelts' multi-functionality.

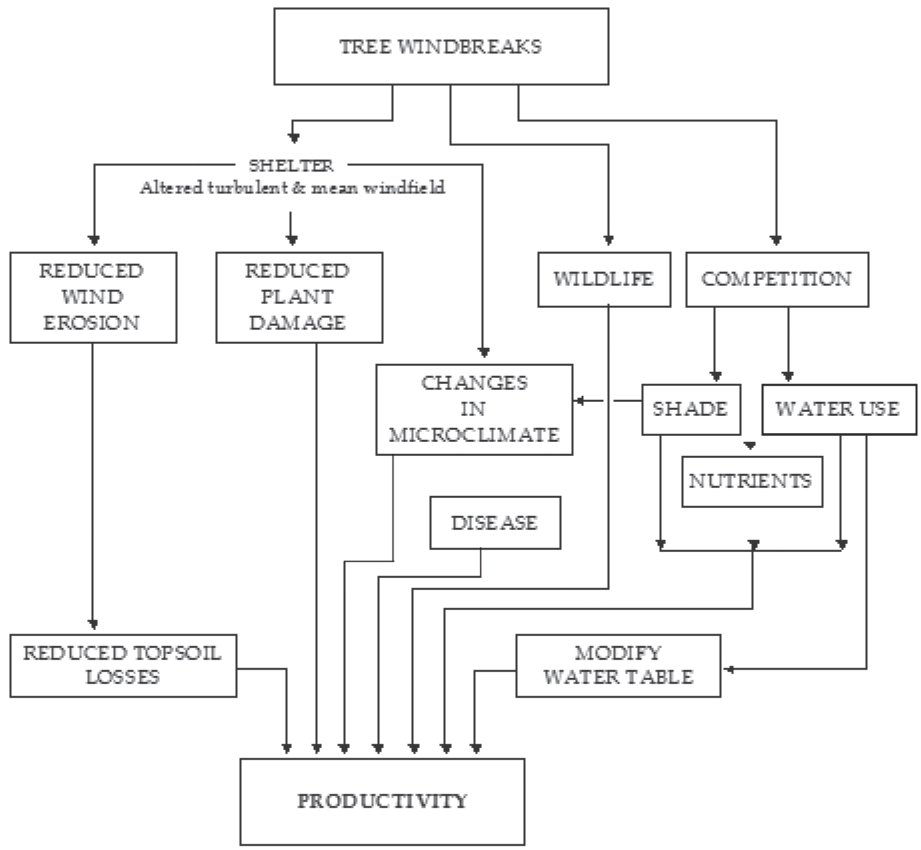

Fig. 1. Microclimate improvement effects of windbreaks
(Adapted from Cleugh, 1998)

Soil and water conservation through agroforestry

Climate exerts a strong influence over various soil processes that contribute to degradation, the expected changes in climate will have the potential to alter these processes and thereby soil conditions. There are several ways by which climate change manifests soil degradation. Higher temperatures and drier conditions lead to lower organic matter accumulation in the soil resulting in poor soil structure, reduction in infiltration of rain water and increase in runoff and erosion (Rao et al. 1998) while the expected increase in the occurrence of extreme rainfall events will adversely impact on the severity, frequency, and extent of erosion (WMO 2005). Arresting degradation and restoring the productive potential of soil calls for improvement in the physical, chemical and biological conditions. The advantage with agroforestry systems is in their ability to bring favourable changes in all the three conditions.

Agroforestry systems like improved fallows, contour hedgerows and other systems involving permanent cover play an important role in arresting and reversing land degradation via their ability to provide permanent cover, improve organic carbon content improve soil structure, increase infiltration, enhance fertility and biological activity.

The permanent tree cover helps in maintaining and improving the soil health through various functions as depicted in Fig. 2 (Uthappa et al. 2015). The tree cover protects soil from erosion and further degradation. Trees have potential of reducing soil erosion through five processes viz. interception of rainfall impact by tree canopy, surface runoff impediment by tree stems, soil surface cover by litter mulch, promotion of water infiltration and formation of erosion resistant blocky soil structure. The soil physical properties are maintained through an addition of organic matter and effects of roots. The soil biological properties are improved due to addition of different qualities of plant litter through supply of a mixture of woody and herbaceous material, including root residues. Agroforestry trees have the potential to promote positive changes in the abundance, diversity, and function of soil organisms through their impact on soil as habitat for soil biota.

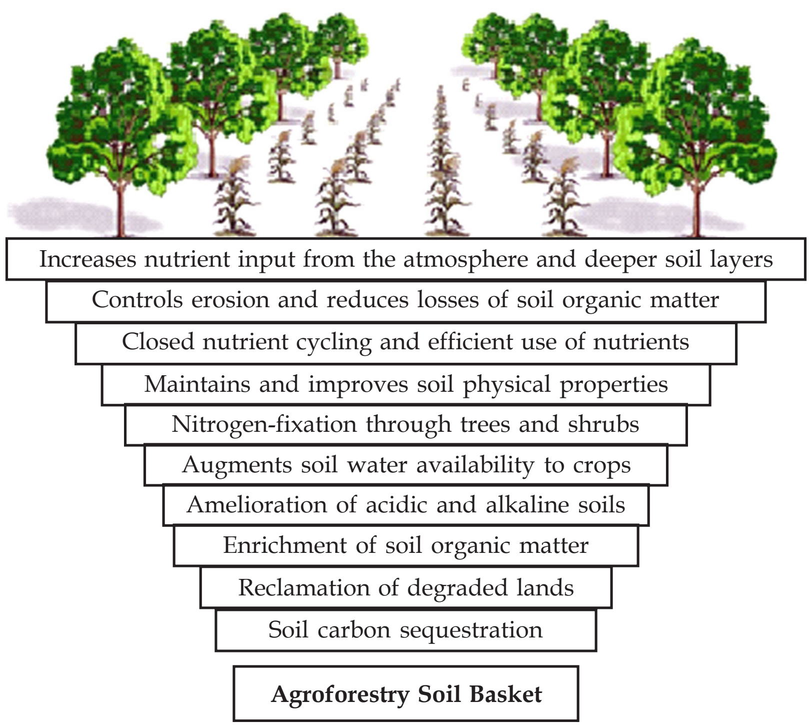

Fig. 2. Maintaining soil health through agroforestry

Carbon sequestration through agroforestry

Agroforestry has a particular role to play in mitigation of atmospheric accumulation of GHGs (IPCC 2000). Of all the land uses analyzed in the Land-Use, Land-Use Change and Forestry report of the IPCC, agroforestry offered the highest potential for carbon sequestration in non-Annex I countries (Fig. 3). Agroforestry has such a high potential, not because it is the land use practice with the highest carbon density, but because there is such a large area that is susceptible for the land use change. Improved agroforestry systems that reduce the vulnerability of small-scale farmers and that help them to adapt changing conditions often meet the conditions for an eligible afforestation/ reforestation (A/R) activity in the Clean Development Mechanism (CDM). These systems can be promoted through CDM projects to create synergies between mitigation and adaptation and to meet the requirements that CDM projects produce social as well as environmental benefits.

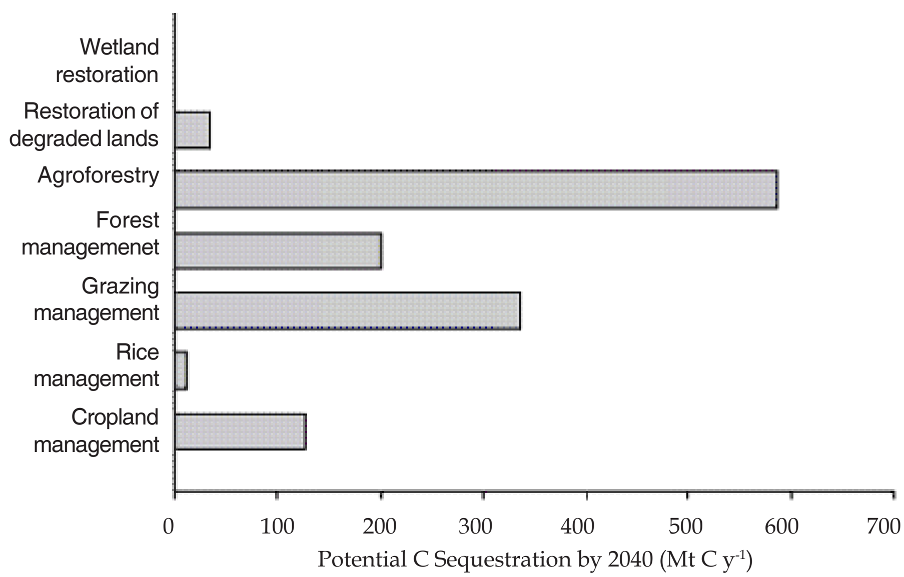

Fig. 3. Carbon sequestration potential of different land use and management options *Source:* IPCC (2000)

Carbon sequestered by trees and stored in aboveground biomass and soil contributes to reducing greenhouse gas concentrations in the atmosphere. Estimates of the carbon sequestration potential of agroforestry systems vary greatly, from under 100 Mt CO_2 per year by 2030 to over 2000 Mt CO_2 per year over a 30 year period. Regardless of the exact amount, agroforestry systems tend to sequester much greater quantities of carbon than agricultural systems without trees. Different agroforestry systems sequestrating varied amount of carbon based on type of system, species composition, soil and climate.

In India, evidence is now emerging that agroforestry system are promising land use system to increase and conserve aboveground and soil C stock to mitigate climate change. The average potential of agroforestry has been estimated to be 25 tonnes C ha^{-1} over 96 m ha (Sathaye and Ravindranath 1998). In this way the total potential of agroforestry in India to store C is about 2400 million tonnes. In another estimate, the area under agroforestry in world is 8.2% of total reported geographical area (305.6 m ha) and it contribute 19.3% of total C stock under different land uses (2755.5 mt C). Singh and Pandey (2011) describe the agroforestry for carbon sequestration is attractive because: (i) it sequesters carbon in vegetation and in soils depending on the pre-conversion soil C, (ii) the more intensive use of the land for agricultural production reduces the need for slash-and-burn or shifting cultivation, (iii) the wood products produced under agroforestry serve as substitute for similar products unsustainably harvested from the natural forest, (iv) to the extent that agroforestry increases the income of farmers, it reduces the incentive for further extraction from the natural forest for income augmentation, and finally, (v) agroforestry practices may have dual mitigation benefits as fodder species with high nutritive value can help to intensify diets of methane-producing ruminants while they can also sequester carbon. In India number of studies were conducted to estimate the total carbon storage potential of different agroforestry systems (Table 2). The carbon stock varied with the region and the system within the region. The aboveground carbon stocks are 17 to 36 Mg C ha^{-1} in tropical homegardens of Kerala (Kumar 2011) and 21 to 65.6 Mg C ha^{-1} in poplar based systems of North India (Rizvi et al. 2011). Many other studies have proved that agroforestry system are promising land use system to increase aboveground and soil C stock to mitigate greenhouse gas emissions (Sathey and Ravindranath 1998; Verchot et al. 2006; Verma et al. 2014, Arora et al. 2014; Goswami et al. 2014; Kanime et al. 2013). The C sequestration potential of tropical agroforestry system in recent studies is estimated between 12 and 228 Mg ha^{-1} with a mean value of 95 Mg ha^{-1} (Pandey 2007). Therefore based on global estimates of the area suitable for agroforestry (585-1215 x 106 ha), 1.1-1.2 Pg C could be stored in the terrestrial ecosystems over the next 50 years (Albrecht and Kandji 2003).

Table 2. Total C storage under agroforestry systems in different regions of the country

Region	Agroforestry system and components	Total C storage (t C ha^{-1})
Semi-arid region	Silvipastoral system (age 5 yrs)*	
	Acacia nilotica + natural pasture	9.5-17.0
	A. nilotica + established pasture	19.7
	Dalbergia sissoo + natural pasture	12.4
	D. sissoo + established pasture	17.2
	Hardwickia binata + natural pasture	16.2
	H. binata + established pasture	17.0
North-western India	Silvipastoral system (age 6 yrs)	6.8-18.55
	Acacia/Dalbergia/Prosopis + *Desmostacya*	1.5-12.32
	Acacia/Dalbergia/Prosopis + *Sporobolus*	
Central India	Block plantations (age 6 yrs)	24.12-31.12
	Gmelina arborea	
Arid region (Rajasthan)	Agrisilvicultural system (age 8 yrs)	
	Emblica officinalis + *Vigna radiata*	12.7-13.0
	Hardwickia binata + *Vigna radiata*	8.6-8.8
	Colophospermum mopane + *Vigna radiata*	4.7-5.3
Semi-arid region	Agrisilvicultural system (age 11 yrs)	26.02
	Dalbergia sissoo + crop	
Semi-arid region	Agrisilvicultural system (age 5 yrs)	
	Albizia procera + blackgram-mustard	34.77
	Albizia procera + greengram-wheat	35.13
North-western Himalayas	Silvipastoral system	2.17
	Agrihortipastoral	1.15
	Hortipastoral	1.08

Source: Newaj et al. (2014)

Soil Fertility Maintenance and Enrichment

The impact of many current agricultural practices is having a deplorable effect on the world's soils, water resources and rural environments. Natural levels of annual soil loss are very small (Morgan 2005) in the region of 0.0045 t ha^{-1} for areas of moderate relief and only rising to 0.45 tha^{-1} on steep slopes. This can be compared with rates of 45-450 t ha^{-1} for agricultural lands. It is not just the quantity of soil that is being lost as a result of unsustainable agricultural practices, soil quality suffers as soil fertility is associated with the preferentially eroded smaller soil particles. Fertilisers offer an easy way to replenish the soil fertility but escalation of price of fertilizers will seldom help the marginal and small farmers. In the climate change context, nitrogen-based fertilizers spur greenhouse gas emissions by stimulating microbes in the soil to produce more nitrous oxide. Nitrous oxide is the third most important greenhouse gas, behind only carbon dioxide and methane, and also destroys stratospheric ozone. Agroforestry systems provide economically viable and environmentally friendly means to improve soil fertility. Integration of trees in the croplands can help in maintaining the soil physico- biochemical properties both under sequential and simultaneous agroforestry. Tree litter and pruning biomass improve soil fertility through the release of nutrients in the soil by mineralization. The trees improve the soil health through maintenance or increase of soil organic matter through carbon fixation in photosynthesis and its transfer via litter and root decay. Published values for leguminous trees in different agroforestry systems show average annual additions of dry matter biomass of up to 20 t ha^{-1} yr^{-1} (Young 1989).

The leguminous and a few non-leguminous trees fix nitrogen in the soil. Trees act as a nutrient pump, which helps in taking up nutrients released by rock weathering in deeper layers of the soil. It also improves the soil by exudation of growth-promoting substances by the rhizosphere. The tree roots act as safety net trapping and recycling nutrients which would otherwise be lost by leaching including through the action of mycorrhizal systems associated with tree roots and through root exudation. The scientific studies have revealed that leguminous trees in alley cropping systems can contribute as much as 358 kg nitrogen (N) ha^{-1}, 28 kg phosphorus (P) ha^{-1}, 232 kg potassium (K) ha^{-1}, 144 kg calcium (Ca) ha^{-1}, and 60 kg magnesium (Mg) ha^{-1} (Palm 1995).

Trees and soil biota interact in a number of positive ways through facilitation and synergies. A major contribution of agroforestry trees to soil based ecosystem services occurs as a result of aboveground and belowground organic inputs that provide food and nutrients needed for the soil organisms involved in carbon transformations and nutrient cycling (Uthappa et al. 2015) (Fig 4).

Increased nutrient availability in agroforestry systems is often associated with higher levels of soil organic matter (SOM) under trees than away from trees. Tree biomass also serves as a substrate for the synthesis of SOM. Regular organic inputs through leaf litter, tree prunings and root turnover have a long term impact on soil carbon and nutrient stocks and thus agroecosystem sustainability.

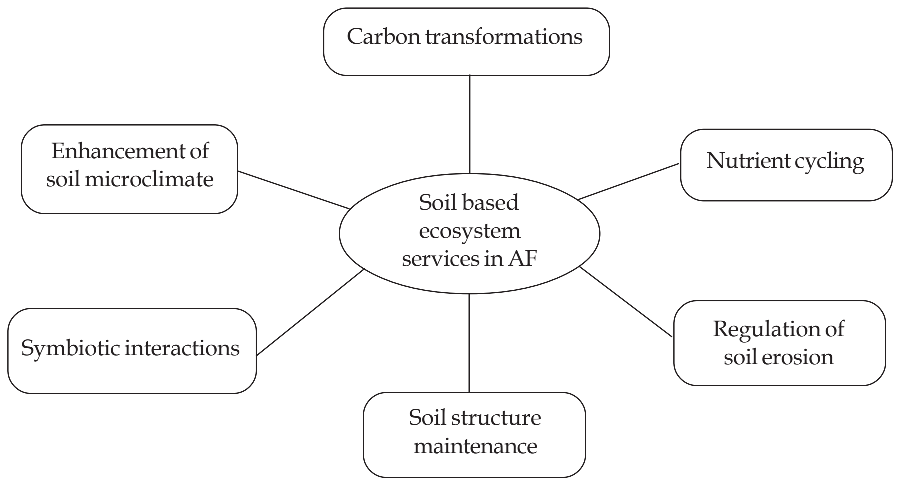

Fig. 4. Soil based ecosystem services in agroforestry system

Crop diversification

Diversification of agricultural enterprises is one of the oldest practices adopted by the farmers to reduce the risks and capitalise on the opportunities associated with variable climate through better exploitation of potential synergies and complementarities among different farm enterprises. Diversification is an adjustment of the farm enterprise pattern in order to increase farm income or reduce income variability by reducing risk, exploiting new market opportunities and existing market niches, diversifying not only production, but also on-farm processing and other farm-based, income-generating activities (Dixon et al. 2001). Agroforestry systems are examples of agricultural systems with high structural complexity. Although the primary crop of interest (e.g., coffee, cocoa) is sometimes grown in more intensively managed systems with little shade cover, the more structurally complex systems have been shown to buffercrops from large fluctuations in temperature (Lin 2007), thereby keeping crops in closer-to-optimal conditions. The more shaded systems have also been shown to protect crops from lower precipitation and reduced soil water availability (Lin et al. 2008) because the overstory tree cover reduces soil evaporation and improves soil water infiltration. At the farm level it is the adoption of multiple production activities that are complementary in economic and/or ecological dimensions involving crops, trees, livestock and post-harvest processing. Integrated agroforestry systems are a suitable pathway for sustainable diversification of agricultural systems (Rao et al. 2007).

Agroforestry systems also protect crops from extreme storm events (e.g., hurricanes, tropical storms) in which high rainfall intensity and hurricane winds can cause landslides, flooding, and premature fruit drop from crop plants. In one example from Mexico, greater farming intensity of coffee agroforestry systems was correlated with the percentage of farm area lost to landslides and the amount of coffee production lost to premature fruit drop (Philpott et al. 2008). In another example of diverse agriculture systems and hurricanes, a study of Nicaraguan farms following Hurricane. Mitch in 1998 showed that less intensively managed land, which exhibited greater diversity and structural complexity, suffered less erosion, had more vegetation, and experienced lower economic losses from hurricane damage (Holt-Giménez 2002). Homegarden has been described as an important social and economic unit of rural households, from which adverse and stable supply of economic products and benefits are derived (Christanty 1990). A global review on the contribution of home gardens to food and nutrition of households found that up to 44% of calorie and 32% of protein uptake are met by the products from home gardens. The diversification also helps in pest suppression and climate change buffering (Table 3)

Table 3. Examples of diversification in agricultural systems and the potential benefits for farmers under climate change

Benefit	Examples
Pest suppression	Willow trees grown in natural willow habitats experience lower rates of pest outbreak of the leaf beetle.
Pest suppression	Greater shade diversity increased bird natural enemy abundance for larval control on crop plant.
Pest suppression	Coffee berry borer control increased with greater ant diversity and abundance in shade systems.
Climate change buffering	Greater shade cover led to increased buffering of crop to temperature and precipitation variation.
Climate change buffering	Greater shade tree cover led to increased buffering from storm events and decreased storm damage.

Source: Lin (2011)

Biodiversity Conservation

Biodiversity is threatened worldwide, and despite some local successes, the rate of biodiversity loss does not appear to be slowing. Therefore, precautionary investments are required for managing biodiversity over the landscape. Actions focused on enhancing and restoring biodiversity are likely to support increased provision of ecosystem services.The literature on the role of agroforestry in biodiversity conservation is growing rapidly. A large body of research in India (Pandey 2007) and elsewhere (Jose 2009) suggests five major roles of agroforestry in conserving biodiversity: (i) agroforestry provides habitat for species that can withstand a certain level of disturbance in agroecosystems; (ii) agroforestry helps preserve germplasm of socially useful and associated species; (iii) agroforestry helps reduce the rates of conversion of natural habitat by providing goods and services alternative to traditional agricultural systems that may involve clearing natural habitats; (iv) agroforestry provides connectivity and acts as stepping-stone by creating corridors between habitat remnants and thereby conservation of area-sensitive plant and animal species; and (v) agroforestry helps conserve biological diversity by providing other ecosystem services such as erosion control and water recharge, thereby preventing the degradation and loss of surrounding habitat.

Agroforestry also leads to a more diversified and sustainable rural production system than many treeless farming alternatives and provides increased social, economic, and environmental benefits for land users at all levels.Although agroforestry may not entirely reduce deforestation (Angelsen and Kaimowitz 2004), but in many cases it acts as effective buffer to deforestation. Trees in agroecosystems in Rajasthan and Uttaranchal have been found to support threatened cavity nesting birds, and offer forage and habitat to many species of birds (Pandey and Mohan 1993). These systems also act as refuge to biodiversity after catastrophic events such as fire. Agroforestry systems, in some cases, do support as high as 50-80% of biodiversity of comparable natural systems, and also act as buffers to parks and protected areas (Bhagwat 2008). Designing and managing an agroforestry system with conservation goals would require working within the overall landscape context and adopting less intensive cultural practices to achieve the maximum benefits (Table 4).

Table 4. Desirable characteristics of agroforestry for biodiversity conservation

Type of activity	Variable	Desirable characteristics
Design of AFS	Species composition	Diverse species composition, mixture of early, mid and late successional species, preferably native species
	Tree/shrub density	Higher tree/shrub density (and greater areas) leads to greater biodiversity
	Type of agroforestry system	Any system as long as it is oristically and structurally diverse

	Duration of agroforestry system	Long rotation is desirable to provide stability
Management of AFS	Management regime	Minimal management is preferable Management strategies should maximize habitat heterogeneity and availability of diverse resources for wildlife
	Soil management	minimal
	Harvesting of products	Minimal harvesting or harvesting that emulates natural disturbance regimes
	Fire management	Fire regimes should follow natural are regimes to the extent possible
	Management of snags and Coarse woody debris	Maintain snags and coarse woody debris as habitat for certain species
Spatial configuration	Location within broader landscape	Position the agroforestry practices strategically to enhance landscape connectivity, by functionally linking habitat fragments
	Types land	Degraded sites, where re-vegetation through agroforestry will have a benecial impact on biodiversity

Source: Harvey et al. (2007)

Conservation Agriculture with Trees (CAWT)

Conservation agriculture (CA) is based on the integrated management of soil, water and agricultural resources in order to reach the objective of economically, ecologically and socially sustainable agricultural production. It relies on three major principles like minimal soil disturbance, permanent vegetative cover and diversified crop rotations (Jat et al. 2012). FAO (2014) stated the CA aims to conserve, improve, and make more effcient use of natural resources through integrated management of available soil, water, and biological resources combined with external inputs. It contributes to the environmental conservation as well as to the enhanced and sustained agricultural production. Therefore, it can also be referred to as resource effcient or resource effective agriculture.The combination of CA and agroforestry gives enormous benefits over their existing form and providing way towards the sustainable agriculture and evergreen revolution. Raintree, who invented D&D in agroforestry, mentioned that there is need to shift on new paradigms in agroforestry i.e. conservation agriculture with trees. Conservation agriculture with trees can be seen as a new way forward for conserving natural resources, mitigating climate change and enhancing productivity to achieve the goals of evergreen revolution, which demands a strong knowledge base and combination of institutional and technological innovation. The complementary and compatible relationship between conservation agriculture and agroforestry was given by Elevitch (2004) (Table 5).

CAWT can improve agricultural system adaptation to the impact of change by improving their resilience through providing better soil structure and infiltration rates which will reduce the danger of flooding and consequent soil erosion resulting from extreme weather events. Increased SOM will also improve soil water holding capacity which will, in some cases, allow a crop to reach maturity in extreme drought situations where conventionally tilled soils will dry out completely (Sims 2009). Carbon sequestration in CAWT systems have the potential to contribute to mitigating the impact of climate change as greenhouse gas (GHG) release is reduced and the increase in global warming could be slowed. With increased C sequestration (in SOM and biomass) under CAWT, carbon can be stored for long periods, if not permanently.

A renewed, strengthened commitment to conservation agriculture, agroforestry and other best practices for agriculture with more integrated landscape management will help create tropical agricultural landscapes that can adapt and mitigate: contributing enormously to food security, poverty alleviation and biodiversity conservation for the billions of people who rely on them (Finlayson 2013).

Table 5. Benefits, complementarity and compatibility of Agroforestry and CA (adapted from Elevitch 2004)

Concept	Constituents	Potential of AF and CA
Efficiency of natural resource use	Soil nutrients	Trees promote nutrient cycling and N fixation. Compare this benefit with the cycling capacity of rotating main and cover crops with different rooting depths in CA systems. Leguminous cover crops also fix N.
	Solar energy	Multi-storied cropping systems intercept and use sunlight at all levels. Although this is a benefit better illustrated by AF systems, crop associations in CA demonstrate similar efficiency.

	water	Both AF and CA reduce runoff while increasing water infiltration and holding capacity in the soil.
Favourable environment for sustained production	Shade	AF (and some CA) systems can provide filtered shade which conserves water and reduces evapotranspiration, keeps topsoil cool and helps maintain healthy soil biota activity.
	Wind protection	Tree wind breaks protect crops from wind damage and soils from wind erosion and drying. Wind breaks combined with CA give more complete protection.
	Soil conservation	Undisturbed tree, crop and cover crop roots and mycorrhizal systems reduce nutrient leaching, bind soil and prevent erosion. Tree leaf litter and CA soil cover enhance soil physical, chemical and biological conditions making soils more resilient to erosive forces.
	Nutrient cycling	Through nutrient uptake from deep soil layers and N fixing species, trees, bushes and cover crops promote more closed nutrient cycling and more efficient use of nutrients.
	Habitat diversity	Both CA and AF, but more especially in association, provides habitats for diverse biota that help to enhance biodiversity and pest/predator balance in the system.
More profitable systems	Reduced cost	Nutrient cycling and legume trees reduce the need for purchased fertilizers. Fuel and labour costs are reduced in CA systems compared with plough-based agriculture.
	Diversified products	Multipurpose tree species give more economic products. E.g. Legume tree gives fodder, fuel wood, timber, fruits, soil improvement etc.
	Continuous flow of products	With multiple cropping in both AF and CA, there can be a more even supply of products throughout the year.
	Greater self-reliance	AF and CA can reduce the farm family's dependence on purchased products as well as reducing vulnerability to enhancing market conditions, especially from monocropping systems.

Environ-mental improv-ement	Reduced pressure on natural forests	This is particularly an advantage for AF systems which reduce pressure for forest products.
	Species diversity	Both AF and CA provide enhanced habitat and support for biodiversity for macro and micro fauna.
	Resource conservation	AF and CA improve the conservation of soil, nutrients and water in the landscape.
	Carbon sequestration	Trees and, especially soils, store C and so reduce GHG emissions.
	Decreased pollution	Nutrient cycling can reduce the need to inorganic fertilizers and reduced erosion and runoff mean that nutrient loss approaches zero.

Adaptation-mitigation in Agroforestry

Combining adaptation with mitigation has been recognized as a necessity in developing countries, particularly in the AFOLU (agriculture, forestry and other land use) sector. In reality, there is no dissociation between crop production and other ecosystem services from land use. Agroforestry in general may increase farm profitability through improvement and diversification of output per unit area of tree/crop/livestock, through protection against damaging effects of wind or water flow, and through new products added to the financial diversity and flexibility of the farming enterprise (Molua 2005). It can also substantially contribute to climate change mitigation (Pandey 2002). Agroforestry may nevertheless involve practices that raise GHG emissions, such as shifting cultivation, pasture maintenance by burning, nitrogen fertilization and animal production. In order to optimize agroforestry for adaptation and mitigation to climate change, there is a need for more integrated management to increase benefits and reduce negative impacts on climate (Fig. 5).

		Mitigation	
		Positive	**Negative**
Adaptation	**Positive**	Soil carbon sequestration, improved water holding capacities, use of manure, mixed agroforestry for commercial products, income diversification with trees reduced nitrogen fertilizer, fire management	Dependence on biomass energy, overuse of ecosystem services, increased use of mineral fertilizers, poor management of nitrogen and manure, over extraction of non-timber producrts, timber extraction
	Negative	Integral protection of forest reserves, limited rights to agroforestry trees, forest plantation excluding harvest	Use of forest fires pastoral and land management, tree exclusion in farming lands

Fig. 5. Examples of positive or negative implications of agroforestry practices for adaptation or mitigation to climate change (Adapted from Mbow et al. 2014).

Conclusion

The farming communities are vulnerable to environmental, climate and weather-related stress, including climate change. There is an increase in understanding of the benefits of agroforestry systems both at farm and landscape scales, and that incorporating trees on farms through agroforestry systems has emerged as having the potential to enhance the resilience of smallholders to current and future climate risks including future climate change. This paper shows how agroforestry systems readily bundle both mitigation and adaptation strategies and provide several pathways to securing food security for poor farmers, while contributing to climate change mitigation. Agroforestry systems offer a win-win opportunity by acting as sinks for atmospheric carbon while helping to attain food security, increase farm income, improve soil health and discourage deforestation. Agroforestry offers the potential to develop synergies between efforts to mitigate climate change and efforts to help vulnerable populations adapt to the negative consequences of climate change.

References

Albrecht A, Kandji ST(2003) Carbon sequestration in tropical agroforestry systems. Agriculture, Ecosystems & Environment 99:15- 27.

Angelsen A, Kaimowitz, D (2004) Is agroforestry likely to reduce deforestation? In: Schroth G, Fonseca GAB, Harvey CA, Gascon C, Vasconcelos HL, Izac AMN (ed)Agroforestry and Biodiversity Conservation in Tropical Landscapes. Island Press, Washington DC,pp 87-106.

Arora G, Chaturvedi S, Kaushal R, Nain A, Tewari S, Alam NM, Chaturvedi OP (2013) Growth, biomass, carbon stocks and sequestration in age series Populus deltoides plantations in tarai region of central Himalaya. Turk J Agric For 38: 550-560.

Beer JW, Muschler RG, Somarriba E, Kass D (1998) Shade management in coffee and cocoa plantations-a review. Agroforestry Systems 38: 139–164.

Belsky AJ, Mwonga SM and Duxbury JM(1993) Effects of widely spaced trees and livestock grazing on understory environments in tropical savannas. Agroforestry Systems 24: 1–20.

Bhagwat SA, Willis KJH,Birks JB, Whittaker RJ (2008) Agroforestry: a refuge for tropical biodiversity?, Trends in Ecology and Evolution. 23(5): 261-267.

Christanty L (1990) Home Gardens in Tropical Asia, with Special Reference to Indonesia. In:Landauer K, Brazil M (ed) Tropical Home Gardens. United Nations University Press, Tokyo, pp 9-20.

Cleugh, HA (1998) Effects of windbreaks on airflow, microclimates and crop yields. Agroforestry Systems 41: 55–84

Dixon JA, Gibbon DP and Gulliver A (2001) Farming Systems and Poverty: Improving Farmers' Livelihoods in a Changing World. Rome: FAO; Washington, D.C.: World Bank.

Elevitch CR (2004)Theoverstory book: cultivating connections with trees.Second edition. Holualoa, Hawai'i. Permanent Agricultural Resources.

FAO (2014) Food and Agriculture Organizations http://www.fao.org/ag/ca/11.html.

Finlayson R (2013) Agriculture can mitigate and adapt to climate change. Agroforestry World blog. http://blog.worldagroforestry.org/index.php/2013/11/11/agriculture-can-mitigate-and-adapt-to-climate-change/. Accessed 26 January 2016

Goswami S, Verma KS, Kaushal R (2013) Biomass and carbon sequestration in different agroforestry systems of a Western Himalayan watershed. Biol Agric Hortic 30 (2), 88-96.

Harvey CA, Schroth G, Zerbock O (2007) Designing agroforestry systems to mitigate climate change, conserve biodiversity and sustain rural livelihoods. http://web.catie. ac.cr/cd_multistrata/Poster/session2/Designing_ agrofores try.pdf Accessed on March 26, 2009.

Holt-Giménez E (2002) Measuring farmers' agroecological resistance after Hurricane Mitch in Nicaragua: A case study in participatory, sustainable land management impact monitoring. Agriculture, Ecosystems and Environment 93: 87–105.

IPCC (2000) Special Report on Land Use, Land Use Change and Forestry. Summary for Policy Makers. Geneva, Switzerland. 20 pp.

IPCC (2001) Climate Change 2001: The Scientific Basis. Contribution of the Working Group 1 to the Third Assessment Report of the IPCC. Cambridge, Cambridge University Press.

Jat RA, Wani SP, Sahrawat KL (2012) Conservation agriculture in the semi-arid tropics: prospects and problems. In: DL Sparks (ed)Advances in Agronomy, Elsevier, pp191–273.

Jose S (2009) Agroforestry for ecosystem services and environmental benefits: An overview, Agroforestry Systems 76 (1): 1-10.

Kanime N, Kaushal R, Tewari SK, Raverkar KP, Chaturvedi S, Chaturvedi OP (2013) Biomass production and carbon sequestration in different tree-based systems of Central Himalayan tarai region. Forests, Trees and Livelihoods 22(1):38-50

Krausmann F, Erb HK, Gingrich S, Haberl H, Bondeau A (2013) Global human appropriation of net primary production doubled in the 20th century. Proc.

Natl. Acad. Sci. USA. 110:10324-10329.
Kumar BM, Nair PKR (2011) Carbon sequestration potential of Agroforestry systems: opportunities and challenges. Advances in Agroforestry. Springer Science, The Netherlands, 307 p.
Lin BB, Perfecto I, Vandermeer J (2008) Synergies between agricultural intensification and climate change could create surprising vulnerabilities for crops. BioScience 58: 847–854.
Lin BB (2007) Agroforestry management as an adaptive strategy against potential microclimate extremes in coffee agriculture. Agricultural and Forest Meteorology 144: 85–94.
Lin BB, Perfecto I, Vandermeer J (2008) Synergies between agricultural intensication and climate change could create surprising vulnerabilities for crops. BioScience 58: 847–854.
Lott JE, Ong CK, Black CR (2009) Understorey microclimate and crop performance in a Grevillea robusta-based agroforestry system in semi-arid Kenya. Agric Forest Meteor 149:1140-1151.
Mbow C, Smith P, Skole D, Duguma L, Bustamante M (2014) Achieving mitigation and adaptation to climate change through sustainable agroforestry practices in Africa.Current Opinion in Environmental Sustainability 6: 8–14.
Molua EL (2005)The economics of tropical agroforestry systems: the case of agroforestry farms in Cameroon. Forest Policy Econ 7:199-211.
Montagnini F,Nair PKR (2004) Carbon sequestration: An underexploited environmental benefit of agroforestry systems. Agroforestry System 61: 281-295.
Monteith JL, Ong CK, Corlett JE(1991) Microclimatic interactions in agroforestry systems. For Ecol Manage 45: 31-44.
Morgan RPC (2005) Soil erosion and conservation. Third edition. Blackwell Publishing (UK, USA, Australia). 304p.
Palm C (1995) Contribution of agroforestry trees to nutrient requirements of intercropped plants. Agroforestry Systems 30: 105-124.
Pandey DN (2002) Carbon sequestration in agroforestry systems. Climate Policy 2:367-377.
Pandey DN, Mohan D (1993) Nest site selection by cavity nesting birds on *Melia azedarach*L. and management of multiple use forests. Journal of Bombay Natural History Society 90:58–61.
Pandey DN (2007) Multifunctional agroforestry systems in India. Current Science 92(4): 455-463.
Philpott SM, Lin BB, Jha S, Brines SJ (2008)A multi-scale assessment of hurricane impacts on agricultural landscapes based on land use and topographic features. Agriculture, Ecosystems and Environment 128: 12–20.
Ram Newaj, Dhyani SK, Chavan SB, Rizvi RH, Rajendra Prasad, Ajit, Badre Alam Handa AK (2014) Methodologies for Assessing Biomass, Carbon Stock and Carbon Sequestration in Agroforestry Systems. National Research Centre for Agroforestry, Jhansi 45p
Rao KPC, Verchot LV, Laarman J (2007) Adaptation to Climate Change through Sustainable Management and Development of Agroforestry Systems. SAT eJournal 4(1): 1-30.
Rao KPC, Steenhuis TS, Cogle AL, Srinivasan ST, Yule DF and Smith GD (1998) Rainfall infiltration and runoff from an Alfisolin semi-arid tropical India. II Tilled systems. Soil and Tillage Research 48:61-69

Rizvi RH, Dhyani SK, YadavRS,SinghR (2011) Biomass production and carbon storage potential of poplar agroforestry systems in Yamunanagar and Saharanpur districts of north-western India. Current Science 100:736-742.

Sathaye JA, Ravindranath NH (1998) Climate change mitigation in the energy and forestry sectors of developing countries. Annu. Rev. Energy Environ 23:387-437.

Schoreneberger M, Bendrub G, Gooijer H, Soolanayakanahal R, Tom Sauer, Brandle J, Zhan X, Den Cuer (2012) Branching out: agroforestry as a climate change mitigation and adaptation for agriculture. Journal of Soil and Water Conservation 67(5): 128-136.

Sims B, Theodor Friedrich, Amir Kassam, Josef Kienzle (2009)Agroforestry and Conservation Agriculture: Complementary practices for sustainable development. In II World Congress of Agroforestry pp 1-17.

Singh VS, Pandey DN (2011) Multifunctional Agroforestry Systems in India: Science-Based Policy Options. RSPCB Occasional Paper No. 4/2011. Rajasthan State Pollution Control Board.

Steffan-Dewenter I, Kessler M, Barkmann J, Bos M, Buchori D, Erasmi S, Faust H, Gerold G, Glenk K, Gradstein RS, Guhardja E, Harteveld M, Hertel D, Hohn P, Kappas M, Ko¨hler S, Leuschner C, Maertens M, Marggraf R, Migge-Kleian S, Mogea J, Pitopang R, Schaefer M, Schwarze S, Sporn GS, Steingrebe A, Tjitrosoedirdjo SS, Tjitrosoemito S, Twele A, Weber R, Woltmann L, Zeller M, and Tscharntke T (2007) Tradeoffs between income, biodiversity, and ecosystem functioning during tropical rainforest conversion and agroforestry intensification. PNAS 104:4973–4978.

Stern N (2007) The Economics of Climate Change: The Stern Review. New York: Cambridge University Press.

Uthappa AR, Chavan SB, Dhyani SK, Handa AK, Newaj Ram (2015) Trees for soil health and sustainable agriculture. Indian Farming 65(3): 2-5.

Verchot LV, Noordwijk MV, Serigne Kandji, Tomich T, Chin Ong, Albrecht A, Jens Mackensen, Bantilan C, Anupama KV, Palm C (2006) Climate change: linking adaptation and mitigation through agroforestry. Mitig Adapt Strat Glob Change 12:901-918.

Verma Archana, Kaushal R, Alam NM, Mehta H, Chaturvedi OP, Mandal D, Tomar JMS, Rathore AC, Singh Charan (2014) Predictive models for biomass and carbon stocks estimation in *Grewia optiva* on degraded lands in western Himalaya. Agroforestry Systems 88 (5):895-905.

Young A (1989)Agroforestry for Soil Conservation. CAB International, Wallingford.

WMO (2005) Climate and Land Degradation WMO-No. 989 2005, World Meteorological Organization.