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Impact of Agroforestry Systems on Ecological and Socio-Economic Systems: A Review

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Keywords: *agroforestry, impact, biodiversity, soil fertility, climate change mitigation and adaptation.*

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IMPACTOFAGROFORESTRYSYSTEMSONECOLOGICALANDSOCIOECONOMICSYSTEMSAREVIEW

Strictly as per the compliance and regulations of :

Impact of Agroforestry Systems on Ecological and Socio-Economic Systems: A Review

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Keywords: agroforestry, impact, biodiversity, soil fertility, climate change mitigation and adaptation.

I. Introduction

Agroforestry (AF) can be defined as "a collective name for land-use systems in which woody perennials (trees, shrubs, etc.) are grown in association with herbaceous plants (crops, pastures) or livestock, in a spatial arrangement, a rotation, or both; there are usually both ecological and economic interactions between the trees and other components of the system" (Lundgren, 1982). In simple terms, it consists of raising tree species and agricultural crops on the same piece of land, resulting in unique ecological interactions and maximized economic returns (Young, 2002).

These systems are deliberately designed and managed to maximize positive interactions between tree and non-tree components and encompass a wide range of practices like contour farming, intercropping, established shelterbelts, riparian zones/buffer strips, etc. The fundamental idea behind the practice of AF is that trees are an essential part of natural ecosystems, and their presence in agricultural systems provides a range of benefits to the soil, other plant species and overall biodiversity. With threats that smallholder farmers in the developing world face with predicted impacts of climate variability and change, the scope of AF systems to reduce vulnerability and adapt to the conditions of a warmer, drier, more unpredictable climate is now being recognized (McCabe, 2013). AF systems are also being increasingly recognized as a tool for mitigating climate change by reducing the overall volume of greenhouse gases in the atmosphere and profiting the economically weaker sections from emerging carbon markets.

Significant research on the types of AF systems, their impacts on the environment, social and economic aspects has been carried out over the years at a range of spatial scales, right from local to regional and global scale. In this paper, the impacts of AF systems on various aspects such as ecology and environment, aesthetics and culture, social and economic status of farmers practicing AF and finally, climate change mitigation and adaptation is discussed, based on a review of papers over the temporal and spatial scale.

II. Methodology

Many of the research and review papers of the last 35 years, published in peer reviewed journals during the period 1981 to 2016, were analysed by the authors. These papers have been listed in the reference section, and range from "Consumption and supply of wood and bamboo in Bangladesh" by Douglas, 1981 to "Variation in pollinator density and impacts of large cardamom (*Amomum subulatum* Roxb.) crop yield in Sikkim, Himalaya, India" by Gaira et al. 2016. The papers have been reviewed for the varied impacts reported on implementation of AF systems in different parts of the world. The review not only summarizes the positive impacts, but also some of the negative impacts that have been reported by the papers.

III. Results and Discussion

In this section the positive and negative impacts of AF are summarized, based on impacts reported by

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various studies across the world. The positive impacts reported across the many papers include impacts on biodiversity – both flora and fauna, soil fertility, air quality, reliance on fossil fuels and fuelwood, aesthetics, culture and finally climate change mitigation and adaptation. In Section 3.1.2., the negative impacts of AF systems on biodiversity, water table, nutrients and related aspects, as reported by various studies is discussed.

a) Positive impacts of agroforestry

i. *Biodiversity*

The United Nations Convention on Biological Diversity defines 'biodiversity' as "the variability among living organisms from all sources, including, inter alia, terrestrial, marine and other aquatic ecosystems, and the ecological complexes of which they are part; this includes diversity within species, between species, and of ecosystems." From the 1990s, AF had also begun to be identified as an integrated land-use which enhances biodiversity while simultaneously reducing habitat loss (Noble, 1998).

Flora conservation: Agroforestry contributes to landscape conservation of biodiversity by extending natural habitats, creating corridors between habitat remnants, buffers to existing reserves, and landscape heterogeneity in multi-functional landscapes (Bichier et al., 2000; WAC, 2006; Bhagwat et al., 2008; Nath and Vetaas, 2015). AF in the Western Ghats and the Satoyama landscapes in Japan are excellent examples of this (Kumar and Takeuchi, 2009). Additionally, trees (including native, endangered (Sujatha et al., 2011), medicinal (Rao et al., 2004) or fuelwood species (Kumar, 2006)) grown in these systems reduce the pressure on formally protected reserves (Bhagwat et al., 2008).

Agroforestry systems can help combat species loss outside formal conservation zones. One study (WAC, 2006) conducted in Eastern and Western Africa showed that AF systems usually contain more than half of the tree species that are found in nearby primary forests. Nath et al. (2015), report higher tree species richness in some AF systems of the Nepalese Himalayas than in nearby natural forests. Dawson et al (2013), reviewed evidences for circa situm conservation in the case of smallholder AF. According to Bhagwat et al., 2008, many AF systems (Table 1) have been shown to be important to maintain heterogeneity at the habitat and landscape scales even amidst competition for land.

Table 1: Animal and plant taxa represented in tropical agroforestry systems and the richness and similarity in species composition in relation to neighbouring forest reserves

Taxa reported	Number of examples	Agroforestry systems* represented	Richness compared to forest % (mean)	Similarity with forest % (mean)
Bats	3	Bn, Co	139	61
Birds	12	As, Bn, Cf, Co, Ft, Jr, Mf	92	52
Herptiles	1	As	62	34
Insects	19	Bn, Co, Cc, Cf, Jr	86	49
Macrofungi	1	Cf	89	61
Mammals (excluding bats)	3	As, Bn, Co	93	65
Plants (lower)	5	Co, Jr	112	42
Plants (herbaceous)	5	Co, Cc, Cf, Hg	64	25
Trees		Bn, Bz, Ca, Co, Cc, Cf, Ft, Hg, Jr, Rt	64	39

Source: Bhagwat et al., 2008

**Agroforestry systems: As-allspice, Bn-, Bz-benzoin, Ca-cardamom, Cc-cocoa-coffee, Cf-coffee, Co- cocoa, Ft-farm trees, Hg-home gardens, Jr-jungle rubber, Mf-mixed fruit orchard, Rt-rattan.*

Schroth (2004), identified and discussed three roles of AF in biodiversity conservation on a landscape scale: "the provision of supplementary, secondary habitat for species that tolerate a certain level of disturbance; the reduction of rates of conversion of natural habitat in certain cases; and the creation of a more benign and permeable 'matrix' between habitat remnants compared with less tree-dominated land uses, which may support the integrity of these remnants and the conservation of their populations. These systems are often like small fragments of forests integrating several species in a single system consisting of a structurally complex canopy (unlike monocrop systems), capable of providing ecosystem services similar to forests. However, the extent of these services is highly variable.

Birds: McDermott et al (2014) surveyed two common AF systems, shade-coffee plantations and silvopastures, in the Colombian Andes and observed that flock activity increased with increasing canopy cover and tree density in both systems. Buck et al (2004) reviewed 12 studies that found AF systems to provide habitats for diverse populations of birds, highlighting the habitat value of shade-grown coffee and cocoa systems in Southeast Asia and Central America. Bird richness has been reported to increase in coffee plantations with increased floristic and structural diversity. This includes habitat characteristics such as canopy cover, canopy depth, canopy height, coffee plant density, tree species richness, tree density, and management intensity (Gordon et al., 2005; Philpott et al., 2007; Philpott and Bichier 2012). Ahmed and Dey (2014), studied the Rosekandy Tea Estate situated in Barjalenga in the Cachar district of Assam. They documented 88 bird species belonging to 38 families, and 48 in the tea plantation alone and concluded that the edges of the tea plantations which transitioned from shrubs to forest vegetation greatly contributed in maintaining a high diversity of animal species while also enabling their movement.

Small mammals: Small mammals play an important role in tropical ecosystems. From the handful of studies that have been published on small mammal communities in coffee AF, researchers have found that the species richness rivals or surpasses that of native forests (Cruz-Lara et al., 2004; Husband et al., 2009; Molur and Singh, 2009; Caudill et al., 2013). Cruz-Lara et al (2004), recorded 10 species of small mammals in coffee AF compared to eight species in a nearby forest in a study conducted in Mexico. Two studies in separate areas in Costa Rica reported 11 and eight small mammal species in coffee AF with 14 and 10 species in the adjacent forest remnants (Husband et al., 2009; Caudill, 2013, respectively). Molur and Singh (2009), found nine small mammal species in the coffee AF and five species in the remnant forest habitats in a small mammal study in Kodagu (Karnataka, India). Caudill et al (2013), assessed the mammal diversity within coffee AF systems in Kodagu, Karnataka, India and investigated the impacts of the non-native shade tree species - Grevillea robusta on 11 mammal species. Their abundance and richness were found to increase with increase in tree species richness, herbaceous ground cover and proximity to forest areas.

Insects and arthropods: Harvey and Villalobos (2007) compared the abundance and species richness of dung beetles and terrestrial mammals across several land use systems in the BriBri and Cabecar indigenous reserves in Talamanca, Costa Rica. Rahman et al (2012) sampled soil invertebrates in the Nilgiris, a human-dominated biosphere reserve amidst 15 land-use practices including managed AF systems. With 21 ant species, AF systems had the highest diversity of ants followed by forest ecosystems (12 species). Pollinator abundance (bumblebees and honeybees) was shown to positively correlate with the number of flowers in a Himalayan AF system with cardamom (Amomum subulatum Roxb.) and also increase the yield of the target crop (Gaira et al., 2016).

Agroforestry has also been shown to be beneficial to insects that feed on crop pests, thereby reducing the use of pesticides (Murthy et al., 2013). Variations in tree-crop combination and spatial arrangements (Jose, 2009), vegetation diversity, tree density and canopy height (Philpott et al., 2007), nearness to forests and abundant food resources (Harvey and Villalobos, 2007) such as hosts, prey and nectar are some of the factors reported to have positive impacts on insect diversity. These studies demonstrate the arthropod conservation potential of heterogenic AF systems that do not destroy or drastically alter microhabitats and microclimatic conditions.

ii. *Soil fertility*

Agroforestry is shown to be an efficient land management method in order to enhance soil quality and to conserve water resources (Kumar, 2006; Murthy et al., 2013; Nair, 2004). A study (Sharma et al., 2009) at the Central Research Institute for Dryland Agriculture, Hyderabad, India, revealed that physicochemical properties such as soil pH and organic carbon were significantly influenced by different land-use systems. The tree shade can reduce evapotranspiration from understory plants resulting in a likely increase in soil water content compared to open pastures (Joffre and Rambal, 1993). The incorporation of trees and crops that are able to biologically enhance soil nutrients like nitrogen is fairly common in tropical AF systems. Even non-N-fixing trees release organic matter, recycle nutrients and thereby, significantly enhance all the properties of the soil (Jose, 2009).

Gupta et al (2009) carried out research in a poplar (*Populus deltoides* Bartr.) based AF plantation with wheat (*Triticum aestivum*) during winters, and green gram (*Vigna radiata*) during summers at farms in Central Punjab, India. They observed that the average soil organic carbon increased from 0.36% in monocrop to 0.66% in AF soils (2.9–4.8 Mg ha-1 higher), and this was found to increase with tree age. Studies of soil enrichment services through litter fall from Ficus trees (*Ficus benghalensis*) in rainfed AF systems in Karnataka showed that approximately 20% of the required phosphorus, 77% of required nitrogen and 67% of required potassium could be delivered from the Ficus litter (Dhanya et al., 2013). Saha et al (2010), studied the effects of five multi-purpose tree species (MPTs) on soil in AF farms located in the north-eastern Himalayan region in India and found that all soil hydro-physical characteristics were greatly improved.

Agroforestry systems have also been proven to be able to reclaim polluted land and mitigate soil salinization and acidification (Murthy et al., 2013). Eco-restoration and sustenance of soil resources through AF is also one of the most viable options to manage land and soil resources (Dhyani and Chauhan, 1995). Rockwood et al (2004), documented AF systems in phytoremediation through short rotation woody crops (SRWCs) that can remediate contaminated soil and groundwater across Europe and America. Of the various tree-agronomic crop systems, it is the riparian systems and windbreaks that have the greatest potential for dendro-remediation. This could involve planting SRWCs for reclamation and restoration of disturbed land (e.g. mined surfaces, contaminated sites, degraded land, landfills, etc.) to improve soil properties, control invasive species, and even provide a transition to natives (Rockwood et al., 2004). Tassin et al (2012), have studied how farmers in highland Madagascar, the island of Re´union, the Bateke plateau near Kinshasa, Congo, and the Palani Hills of southern India have improved fallows by using invasive woody legumes (Acacia sp.) which were 'negative' plant invasions converted into productive AF systems.

Agroforestry is believed to increase the soil organic carbon (SOC) through litter fall (Young, 1989; Aldeen et al., 2013; Murthy, et al., 2013) and rhizospheric effects (Saha et al., 2010), increase land productivity (Noble, 1998; Saha et al., 2010), check soil erosion (Guevara-Escobar et al., 2002; Schultz et al., 2004), conserve moisture in the soil (Morgan, 1995; Nair, 2004), and diversify the farm income (Seobi et al., 2005). Similar observations have been reported by Young et al (1987); Reicosky and Forcella (1998); and Saikh, Varadachari, and Ghosh (1998).

iii. *Improved air quality*

Features prevalent in AF, such as windbreaks and shelterbelts, benefit air quality and aid in reducing pollution in multiple ways. They safeguard buildings and roadways from drifting snow in colder countries. They also reduce wind chills, protect crops, provide additional habitats for wildlife, remove atmospheric carbon dioxide and improve oxygen circulation, reduce wind velocity and with it, erosion and particulate matter in the air, reduce noise pollution and livestock odour. Of late, shelterbelts have gained popularity as a means to mitigate livestock odour (Tyndall and Colletti, 2007). They filter airstreams of particulates and remove odour-causing aerosols.

Another time-tested benefit of AF is its provision of clean water. Agriculture has numerous effects on water systems, changing water chemistry through eutrophication, modifying the food web, pesticide pollution, increasing sediment load from erosion and so forth (Moss, 2008). In particular, riparian buffers can be immensely beneficial to reducing pollution. Conventional agricultural systems involve a significant amount of fertilizer runoff from agricultural fields, as less than half of the applied nitrogen and phosphorous fertilizer is taken up by crops. The rest is washed away in the form of surface runoff, or leached into subsurface water supplies (Cassman, 1999).

Agroforestry has been shown to reduce non-point source pollution from agricultural land in five key ways (Dosskey, 2001), namely: (i) reducing surface runoff from fields; (ii) filtering surface runoff; (iii) filtering groundwater runoff; (iv) reducing bank erosion, and (v) filtering stream water. AF vegetative buffers have been shown to reduce non-point source pollution from row crop agriculture (Udawatta et al. 2002; Anderson et al. 2009). Trees with deep roots provide a safety net of sorts by recycling excess nutrients back into the system and improving nutrient use efficiency (van Noordwijk et al. 1996).

iv. *Reduced reliance on fossil fuels and forests for fuelwood*

In a time of mounting concern about the long-term availability of oil, AF systems have the potential to reduce reliance on fossil fuel consumption in a number of ways. For instance, AF plantations have the potential to provide fuelwood (Smith, 2010), which could reduce reliance on fossil fuels significantly. A study of the impact of community AF on households in Bangladesh by Chakraborty et al. (2015), also showed that AF was an important source of fuelwood, which reduced household expenditure on conventional fossil fuels. Similarly, Bugayong (2003) discovered that AF significantly reduced the reliance of communities on nearby forests for fuelwood. Also, AF systems, through production of renewable energy, coppice systems or as a by-product of timber production, can reduce the use of fossil fuels for heating and cooking. Furthermore, internal nutrient cycling and enhanced pest and disease control can reduce the need for oil-based agrochemicals. Localized production of multiple outputs can avoid the need for long-distance transportation of goods and therefore reduce fuel use.

v. *Aesthetics and Culture*

Traditional AF systems such as orchards, parkland and wood pastures are valued for their visual appeal. Integrating trees into landscapes can increase the attractiveness of the landscape (McAdam et al., 2009). Franco et al (2003) note that there is a need to consider the values that society places on non-market aspects such as beauty. This tends to maximize the efficiency of resource allocation in a landscape management setup.

Cultural aspects of traditional AF systems, particularly in temperate regions, are often overlooked, despite long histories of woodland and orchard grazing, alpine wooded pastures, pannage, the dehesa and parklands (McAdam et al., 2009). Lifestyles such as nomadism, transhumance (seasonal movement of people with their livestock) and traditional techniques such as pollarding and hedge-laying are integrated within such systems. The symbolic and cultural perceptions of these landscapes are shaped by local practices, laws and customs (Ispikoudis and Sioliou, 2004). While only remnants of these traditional landscapes exist today, the significance and value of these cultural landscapes have been recognized at the international level by UNESCO.

In India, as in other countries with indigenous cultures such as Brazil, Bangladesh, etc., traditional AF systems have been in place for generations. In Rajasthan, fodder and grain crops have long been intercropped with Prosopis cineraria. Prosopis guards against crop failure by acting as the primary source of fodder during such times. Its leaves and seeds are stored in anticipation of lean periods. Its wood is used to make charcoal and fuelwood, as well as agricultural tools (Paroda and Muthana, 1981). A study in the West district of Tripura found an interesting difference in the participation of women from different sociocultural groups, which it attributed to belief systems and traditions. In the study, women's participation in tribal and non-tribal communities practicing AF was compared. It was found that the latter participated more in marketing activities than the former, who were more involved in production, management and harvesting (Jaba et al., 2015). In the flood-prone, fertile alluvial soils of Bangladesh, multi-storey plants, shrubs, bamboos, palms and other trees that can withstand flooding are grown together (Douglas, 1981). AF thus has a huge potential to conserve traditional knowledge and practices that have existed for centuries.

vi. *Economic and social benefits of agroforestry*

A very important marker of the social benefits of a system such as AF is its effect on the conditions of the more vulnerable sections of society, in particular, women, children and marginalized groups. A study conducted over a decade in the Banswara district in Rajasthan and Dahod district in Gujarat in semi-arid western India where wadi AF was introduced found that AF had numerous benefits to the condition of women in the study group. The study determined that institutional arrangements were necessary for the continued inclusive upliftment of the marginalized sections of these societies (Bose, 2015). Chakraborty et al., (2015) compared the socio-economic conditions of farmers who adopted AF and those who did not in Manirampur and Baghepura of Jessore district in Bangladesh and report that farmers practicing AF better off than those not practicing AF, both socially and economically. Bugayong (2003) in a study in the Philippines, show that nearly 80% of participants report medium to high income change as a result of AF. Similarly, a study of AF implementation in the Attappady block of Kerala, in the Nilgiri biosphere Reserve, reported significant improvements in the socio-economics, food and livelihood security of those involved (Kumar, 2006).

Saha et al. (2010) rightly argue that the economic and social benefits of AF are vital in ultimately determining whether a farmer will consider it a viable alternative to conventional 'modern' agricultural practices. Agroforestry systems are an investments of sorts – planting timber species such as teak (*Tectona grandis*) or Silver Oak (*Grevillea robusta*) may not generate many benefits in the initial stages, but do so significantly when they are logged two decades later (Dagar et al. 2014). AF has the potential to provide multiple harvests in a year, thus evening out both labour as well as income through the year. This leads to increased financial resilience and reduced vulnerability to crop failure, which is all too common a phenomenon with single-cropping or monoculture practices (Kumar, 2006; Murthy et al. 2013). The NRCAF (2007) estimated that there was potential for employment under improved AF systems, amounting to 943 million person-days annually from 25.4 million ha (Table 2).

Table 2: Employment generation potential of agroforestry in India and rates of return from investment in agroforestry system

Agroforestry System	Area (million/ha)	Additional employment (persons/ha/year)	Total employment (million/days)	Ratio of rate of investment (%/year)
Silviculture	1.8	30	53.3	126
Agrisilviculture (irrigated)	2.3	40	91.3	150
Agrisilviculture (rainfed)	1.3	30	38.0	157
Agrihorticulture (irrigated)	1.5	50	76.1	129
Agrihorticulture (rainfed)	0.5	40	20.3	131
Silvipasture	5.6	30	167.4	89
Tree borne oilseeds	12.4	40	497.1	38
Total	25.4	--	943.4	117

Source: NRCAF 2007

The productivity of the land increases as well, since AF often improves soil properties. This further improves the earning potential of the farmer (Murthy et al. 2013). In addition to higher yield potentials of AF, product diversification increases the potential for economic profits by providing annual and periodic revenues from multiple outputs throughout the rotation and reducing the risks associated with farming single commodities (Benjamin et al. 2000).

Bhattacharya and Mishra (2003) conducted a study to understand the potential, costs and benefits of agrihorticulture systems in north eastern India. According to this study, agrihorticultural systems with Psidium spp. yielded a net return 2.96 times greater

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than similar systems without trees. Similarly, Singh and Pandey (2011) report that in traditional systems of AF that used Acacia species with Oryza species, the benefit to cost ratio was found to be 21.47. Jaba et al., 2015 conducted a study in Tripura West district and analysed the sources of income of tribal and non-tribal communities. Their findings demonstrate that earnings from tree crops (through AF) were significant at INR 24,075 in tribal communities. Compared with exclusive forestry land use, AF practices are able to recoup initial costs more quickly due to the income generated from the agricultural component (Rodríguez et al. 2009; Grado, Hovermale and Louis, 2001), and studies have shown increased profitability of silvo-arable (Yates et al. 2007; Benjamin et al. 2000) and silvopastoral (Benavides, Douglas and Osoro, 2009; Brownlow, Dorward and Carruthers, 2005) systems compared to agricultural monoculture systems.

vii. *Climate change mitigation-adaptation*

Globally, climate change is the prevalent environmental and developmental challenge endangering natural resources and humanity. The AFOLU (Agriculture, Forestry and Other Land Use) sector accounts for about a quarter (~10–12 $GtCO_2$-eq/year) of net anthropogenic GHG emissions, mainly from deforestation, agricultural emissions from soil, nutrient and livestock management (IPCC, 2014). Climate mitigation efforts in land use sectors like agriculture and forestry, especially in the developing countries, can play a significant role in the global efforts to address climate change. The potential of AF as a management practice which increases aboveground and belowground carbon stocks to mitigate greenhouse gas emissions is highlighted progressively in contemporary research. The principle behind it rests in the fact that trees have the capability of sequestering a relatively large quantity of carbon for longer periods, as compared to other vegetation. Harvesting followed by long term locking, fossil fuel substitution, and soil carbon also contribute to enhanced carbon sequestration (Sharma, et al, 2015). The total carbon storage capacity of an AF system depends on the growth and nature of the tree species, and varies from region to region (Newaj and Dhyani, 2008).

Increased growth and assimilation rates of intercropped tree components in AF have higher carbon storage capacity than mono-cropping systems. This may be attributed to the additional carbon pool in the trees, along with litter fall and fine root turnover, which result in increased soil carbon pools (Chauhan et al., 2010). Pandey (2007) highlight that AF for carbon sequestration is additionally attractive as the need for slash-and-burn or shifting cultivation is significantly reduced, due to intensive use of the land for agricultural production. Further, unsustainable harvest of wood products from natural forests is considerably reduced as a result of their continued supply from AF systems.

The average carbon storage potential of Indian AF is estimated to be 25 tC/ha over 96 million ha (Sathaye and Ravindranath, 1998). However, this potential is dependent on the ecosystem, species, growth rate and management involved (Pandey, 2007). FSI (2013) reports that AF systems in India store about 279 MtC (Table 3); the East Deccan zone is estimated to store a whopping 53 MtC in its AF systems while the west coast and South Deccan regions store almost 33 and 23 MtC, respectively. In the agroecosystems of Indo-Gangetic Plains, about 69% of soil carbon in the soil profile is confined to the upper 40 cm soil layer where carbon stock ranges from 8.5 to 15.2 tC/ha, while the agricultural soils contain 12.4 to 22.6 tC/ha of organic carbon in the top 1 m soil depth (Singh et al., 2011).

Table 3: Physiographic zone-wise growing and carbon stock estimate under agroforestry

Physiographic zone	Geographical area (sq. km)	Carbon stock in million tonnes
Western Himalayas	329,255	15.47
Eastern Himalayas	74,618	2.98
North East	133,990	9.51
Northern plains	295,780	22.66
Eastern Plains	223,339	19.86
Western Plains	319,098	10.42
Central Highlands	373,675	22.85
North Deccan	355,988	14.91
East Deccan	336,289	53.30
South Deccan	292,416	23.74
Western Ghats	72,381	22.57
Eastern Ghats	191,698	9.64
West Coast	121,242	33.33
East Coast	167,494	18.60
Total	**3,287,263**	**279.83**

Source: FSI, 2013

On a species system scale, Koul et al. (2011) reported that soil organic carbon was found to be the highest (17.69 t/ha) in natural forest of *Shorea robusta* followed by pure plantations of *Terminalia arjuna* (13.29 t/ha). Agri-horticulture AF systems (12.14 t/ha), pure plantations of *Dalbergia sissoo* (10.66 t/ha) and tea (*Camellia* spp.) gardens (10.45 t/ha) were also found to have significant carbon sequestration potential. Poplar-based AF systems have also been adopted extensively for carbon farming (Chauhan et al., 2010). This short rotation AF crop has been reported to sequester around 8 MgC/ha/yr. Poplar can be considered a major carbon assimilator, as it locks up carbon in its wood products for longer periods. Thus, traditional agricultural systems intermixed with poplar provide the best land use option for increased carbon sequestration.

Studies in Khammam district, Andhra Pradesh, on technical potential for afforestation on cultivable wastelands, fallow, and marginal croplands with Eucalyptus clonal plantations found baseline carbon stock to be 45.3 tC/ha, mainly in soils (Sudha et al., 2007). Although most AF systems sequester a lot of carbon, home gardens are argued to be particularly effective. This is due to the fact that they can provide fuelwood to alleviate the pressure on natural forests, as well as biofuel-products which may reduce the need for fossil fuel burning (Kumar, 2006). Nair et al. (2009) estimated that tropical home gardens have particularly high carbon sequestration potential (16-36 Mg/ha/year). Tropical home gardens of Kerala, exhibit an average aboveground standing stock of 16 to 36 Mg/ha; small home gardens are often found to have higher carbon stocks on per unit area basis, compared to large- and medium-sized ones (Murthy, 2013; Sahoo, et al, 2007).

Negash and Starr (2015) presented and evaluated the biomass carbon and soil organic stocks in three indigenous AF systems (Enset - Ensete ventricosum, Musaceae, Enset-Coffee and Fruit-Coffee) practiced on the Rift Valley escarpment of Ethiopia. The total biomass carbon stocks of the small holdings in their study were within the range reported for AF systems globally (12–228 Mt/ha).

Integration of climate change mitigation and adaptation strategies to promote sustainable development and moderate the ensuing impacts of climate change is being advocated in the recent times and AF is one among these strategies. It provides a particular example of an innovative practice which represents synergy between mitigation and adaptation options, alongside providing multitudes of socio-economic and ecological benefits (Ekpo and Asuquo, 2012). It is designed to enhance productivity in a way that contributes to climate change mitigation through enhanced carbon sequestration. It can also strengthen the ability to adapt to adverse impacts of changing climatic conditions (IPCC, 2001; Ekpo and Asuquo, 2012; Verchot et al. 2007; Roy et al. 2011).

Matocha et al. (2012) highlight nine key interventions which have the potential for obtaining synergies between adaptation and mitigation in AF systems. Income diversification is highlighted to be one of the most effective of these interventions. Tree and forest products provide multiple raw materials, thus increasing options available for income. This reduces the vulnerability of resource-poor farmers to climate and market shocks (adaptation), while increasing landscape carbon stocks (mitigation). The range of benefits accrued can further be enhanced through the incorporation of trees with either crops or silvo-pastoral lands, or even the introduction of livestock into mixed land uses. Charles et al. (2013) conducted a study in Tanzania and concluded that products from AF practices improved the resilience of smallholder farmers against the impact of climate changes. In particular, they improved farm production (food, fodder, timber, fuelwood and manure), ecosystem services (soil improvement, climate amelioration, wind break, erosion control, and disease and pest control) and household income.

Apart from benefits to the immediate micro environment in which AF systems thrive, the surrounding ecosystems and their components also incur some benefits. AF systems act as corridors connecting fragmented forest lands and facilitate the movement of wildlife through a landscape that may otherwise be too hostile. This role of AF in providing corridors that allow movement of species through landscapes will increase in importance under predicted climate change scenarios, by allowing species to adapt their distributions in response to the shifting climate (Manning et al., 2009).

Thus, combining adaptation with mitigation has been recognized as a necessity in developing countries, particularly in the AFOLU sector. In reality, there is no dissociation between crop production and other ecosystem services from land use (Mbow et al. 2014). AF systems help farmers adapt to changing socio-economic and climatic conditions (McNeely and Schroth, 2006). In order to optimize AF for adaptation and mitigation to climate change, there is a need for more integrated management to increase benefits and reduce negative impacts on climate (Table 4).

Table 4: Examples of positive or negative implications of agroforestry practices for adaptation or mitigation to climate change (adapted from Mbow et al. 2014)

		Mitigation	
		Positive	Negative
Adaptation	*Positive*	Soil carbon sequestration, improved water holding capacities, use of manure instead, mixed AF 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 products, timber extraction.
	Negative	Integral protection of forest reserves, limited rights to AF trees, Forest Plantation excluding harvest.	Use of forest fires for pastoral and land management, tree exclusion in farming lands.

Thus, AF systems have the ability to enhance the resilience of a system for coping with the adverse impacts of climate change, and provide a unique opportunity to combine the twin objectives of climate change adaptation and mitigation.

b) Negative impacts of agroforestry

Although there are numerous benefits to establishing an AF system, there are also certain trade-offs. Three aspects of Leakey's (1996) definition, used very frequently, are important for the value of AF. Firstly, AF involves deliberate integration of trees with farms and landscapes, which may have direct and indirect effects on farm and landscape biodiversity. Secondly, there are trade-offs and complementarities between the social, economic, ecological and biodiversity benefits of AF compared to other land use systems. Finally, while some AF practices in certain circumstances contribute greatly to diversification and sustainability, there are other circumstances where they contribute very little.

Increased shade in AF systems reduces yield by reducing the amount of direct light, which is usually the limiting resource in northern temperate regions (Benavides, Douglas, and Osoro, 2009; Chirko et al., 1996; Reynolds et al., 2007; Smith, 2010). Similarly, competition for water is likely to limit productivity in semiarid regions such as the Mediterranean, although it is difficult to quantify it separately from nutrients and other requirements (Chirko et al., 1996; Reynolds et al., 2007). Competition for water, sunlight and nutrients may affect grain yield and total biomass of agricultural crops but the magnitude depends on the species used in the AF system (Singh et al., 2013). This 'weedy' nature of AF trees also makes cultivation more tedious and labor-intensive (Tassin et al., 2012). A common problem is that the positive effects for some tree species are accrued over a longer period of time while the negative effects such as competition for resources are immediately apparent (Nair, 2004). Soini (2004) reported that AF systems have created an inhospitable habitat for most bird species in Kilimanjaro, Tanzania, owing to very high levels of interference from the human population.

There are also a few studies that discuss and highlight the major constraints with respect to implementation of AF (Devaranavadgi, 2010). Garcia et al (2010) considered challenges to the strategies proposed by Harvey et al (2007), in coffee AF landscapes in South India and drew insights from the ground realities in Kodagu District (Karnataka). For example, multipurpose AF trees on farms that aimed to serve as alternative sources of fuelwood were often not accessible to the poor. The landless population (tribal groups, migrants, labourers, etc.) neither had legal access to fuelwood from state-controlled forests nor from private lands. Another example was that the forest patches were a source of "nuisance" to nearby plantations as they attracted elephants and other wildlife that destroyed plantation crops.

It must also be recognized that AF has potential to threaten native biodiversity. The introduction and colonization of invasive alien tree species can replace valuable indigenous species which are comparatively less aggressive. Domination of local pastures and altering catchment hydrology are landscape level examples of the consequences (Tassin et al., 2012). Ultimately, however, Tassin et al (2012), argue that given the properties (resilience, fast growth, etc.) of AF tree species that lead to their selection in the first place, acceptability becomes a broader social and political debate.

IV. Conclusions

It is evident from the review that AF systems by and large across the world have several positive impacts and have a two-way relationship with livelihood and biodiversity in multi-functional landscapes. They help maintain and contribute to tree and animal diversity and also help improve livelihoods through increased flow of products that could generate income. However, it is important to note that the impacts of agroforestry are dependent on varied factors and even those that have been reported have been at different scales, for different systems and for different regions. Further, the impacts of agroforestry systems would be very specific and would also depend on management practices adopted by individual farmers. It is also pertinent to note that the impacts reported are standalone cases and many have no systematic control or reference plots for comparison. However, AF is one of the key strategies that will help design multifunctional landscapes that can deliver multiple ecosystem services. But, AF is not a stand-alone conservation measure, additional measures to minimize disturbance from a rising human population are required, thus making AF an integral part of a mosaic of strategies. Given the potential of AF to contribute positively towards climate change mitigation as well as adaptation synergistically, it is gaining importance as a land-based mitigation option and as a reliable coping strategy or adaptation measure, particularly in regions with large rainfed agriculture dependent farming communities. This is because of the potential of agroforestry to generate income during agriculture lean or agriculture failure periods. Countries such as India have formulated targeted agroforestry policy in addition to including it as one of the key mitigation and adaptation measures in the National Action Plan on Climate Change. Finally, there also remains a future prospect of carbon trading and payments through implementation of payment for environmental services and REDD+ programs which could serve as added incentive to local communities to promote AF systems.

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