Chapter

Potential and Opportunities of Agroforestry Practices in Combating Land Degradation

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Abstract

Agroforestry an established practice for centuries is the deliberate combination of perennials with food crops and/or livestock either simultaneously or sequentially. Agroforestry systems are bio-diverse and are associated in numerous ways for combating desertification and mitigating climate change. Agroforestry practice is a possible way of reducing deforestation and forest degradation and can alleviate resource-use pressure on natural conservation areas. Among many other reasons responsible for climate change, our traditional approaches towards forest management have failed thereby giving way to a drastic climate change, which slowly but has indeed harbingered the cataclysmic future that awaits us if we do not act now. This paper thus acquaints the readers with the role of agroforestry in mitigating the soil erosion, rehabilitation of degraded lands, improving water conservation and replenishment of soil fertility. Besides, the role of agroforestry in improving the soil health and overall ecosystem has also been discussed. This paper furthermore, attempts to recognize the role that agroforestry can play in mitigating the repercussions of climate change apart from improving natural resource sustainability and future food security issues.

Keywords: Agroforestry, carbon, climate change mitigation, ecosystem services

1. Introduction

Population explosion worldwide is putting huge pressure on natural resources, which is creating our planet a precarious place to live. It is expected that by the end of the 21st century the world population will reach 8 billion and food required to feed the entire population will be about 120 M tons. It is estimated that by the year 2050 food demand will increase by 60% globally and 100% for the developing countries. Therefore, there is a pressing need to conserve natural resources like soil, water, and vegetation for future demands to accommodate the ever-increasing population growth. Climate change is threatening our very existence and is accepted as a vital issue in the 21st century. Increased emissions of greenhouse gasses due to anthropogenic factors are responsible for average increase in earth temperature and global climate change. Agroforestry has immense potential in mitigating climate change concerns by lessening global warming since vegetation assimilates the CO_2 gas in the process of photosynthesis which is one of the main contributors to greenhouse gases.

Agroforestry is a farming system that integrates crops and or livestock with trees and shrubs [1]. Agroforestry provides many benefits that includes favorable microclimate, reduction in erosion, enhanced biodiversity, increased water quality, more infiltration leading to effective groundwater recharge, enhanced and elongated dry flow, improvement in habitat, soil fertility, etc. Agroforestry is promising for a sustainable solution in response to soil conservation, land degradation, and also can bridge the gaps between climate change and mitigation strategies. Agroforestry has the immense capacity to provide sustainable agricultural benefits and approximately 1.2 billion people of the world is practicing agroforestry one way or the other way [2]. It has high potential to balance between the demands and requirements of population growth and natural degradation. The present review investigated the potential and opportunities of agroforestry in combating soil and water degradation and the role of agroforestry in climate change mitigation.

2. Mitigation of soil erosion through agroforestry

Topsoil on earth is the most productive, as essential macronutrients (N, P, K, Ca, Mg and S) and micronutrients (B, Cl, Fe, Cu, Zn, etc.) for plants are mostly found in topmost layers of the soil. These essential nutrients are required for completing the life cycle of plants. Soil erosion is a process in which topsoil is displaced from its location by different agents mainly water and wind. Globally, about 24 billion tonnes of fertile soil is lost annually through water erosion [3]. The soil pool loses 1100 Mt. C into the atmosphere as a result of soil erosion and another 300–800 Mt. C annually to the ocean through erosion-induced transportation [4].

It is expected that rainfall pattern will vary greatly due to global climate change and the effect of climate change will increase soil erosion. In India, the annual rainfall amount along with the frequency of high-intensity storm events will increase by 2030 compared to the baseline i.e. 1970 which will accelerate erosion and runoff. Nearing et al. [5] reported that an increase of soil erosion and rainfall amount is of the order of 1.70. Lee et al. [6] reported 2°C increase in annual temperature which will increase wind erosion by 15–18%. Therefore, without some improved practices like agroforestry, wind erosion is expected to accelerate in arid and semiarid regions. Windbreaks, alley cropping, and riparian buffers are especially designed to reduce wind erosion [7]. Thus, agroforestry will give more flexibility in socioeconomic and environmental service perspective in changing climatic situations. Vegetation with its canopy cover reduces the kinetic energy of the rainfall. The energy left with the falling raindrops depends on the height of canopy cover from the ground surface. It is reported that 4-meter canopy height decreases the kinetic energy by 80% [8]. Plant litter absorbs the rest of the energy of the falling rainfall which reduces the soil erosion to a certain level. The plant litter reduces the runoff by improving the infiltration and water holding capacity of the soils. The decomposition of plant litter, root decay, and exudation from the rhizosphere increases the organic matter content in soil and enhances the soil structure which is less prone to erosion.

Protecting the topsoil from erosion is of high priority for ensuring sustainable food production and food security. Agroforestry systems are widely accepted and agreed around the globe due to its influence on soil erosion control. Studies reported in the past concluded that developing countries have well-adopted agroforestry systems for controlling soil erosion from the steep slopes [9–14]. Alley cropping reduces soil loss to a great extent mainly due to its dense canopy cover which reduces the kinetic energy of falling rain. Alley cropping system is very effective in absorbing almost the entire energy of rain as the trees used in this system are mostly of short stature or shrubby. The shrubs form a barrier to runoff and take more time to infiltrate into the soil and thus less runoff. Soil loss is proportional to the square root of runoff volume, the less the volume of the runoff, the less is the transportation power of the runoff [15].

In Nigeria in an alley cropping system consisting of maize with Leucaena hedge results in soil loss only 76 kg ha^{-1} in comparison to No-till condition without Leucaena where soil loss was 10737 kg ha^{-1} [16]. In an experiment in north-western Himalaya at Dehradun, India (rainfall 1740 mm), the effectiveness of different barrier hedges, trees, and grasses on runoff and soil loss at 4% slope was studied (**Table 1**). Grasses were very effective in reducing soil loss despite with higher runoff (**Table 1**). Tree alleys are also effective in reducing the soil loss and runoff. Soil deposited in front of Leucaena based agroforestry system and Eucalyptus based system is represented in **Figure 1**, which represents that average deposition ranged from 15.77–28.5 t ha^{-1} in front of Leuceana hedges [17]. In Rwanda and Burundi

Treatment	Runoff (%)	Soil loss (t ha^{-1} yr.$^{-1}$)
Corn on contour	40	21
Leucaena hedges	21.3	12.1
Panicum (0.75 m wide)	36.7	7.0
Eulaliopsis (0.75 m wide)	42.7	10.0
Veteveria (0.75 m wide)	39.6	8.1
Leucaena trees (6–8 years)	20.4	8.4
Eucalyptus trees (6–8 years)	16.3	5.8

Table 1.
Effect of different barrier hedges, trees, and grasses on runoff and soil loss.

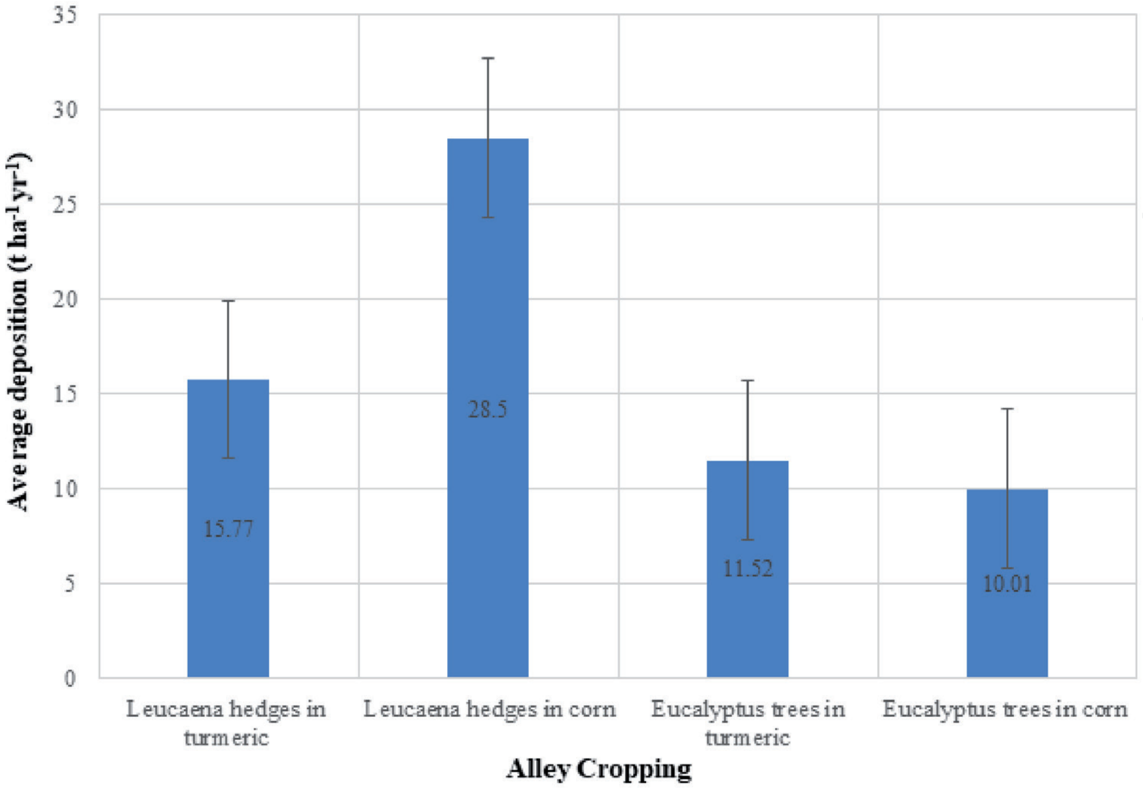

Figure 1.
Average soil deposition for different alley cropping system.

in ferrallitic soils (Ultisol) with rainfall, erosivity ranges from 250 to 700 on 20 to 60% slopes, soil loss ranges from 300 to 700 t ha^{-1} $yr.^{-1}$ in the form of sheet and rill erosion. However, surprisingly the runoff rate was only 10 to 30% of the rainfall. In these circumstances, agroforestry practices have been found suitable in reducing soil loss and produced enough biomass to mulch the surface as well as to increase soil fertility.

Numerous studies on soil loss and runoff for different agroforestry models have been carried out in Shivalik Himalayas in India. The soil loss and runoff of the agroforestry models i.e. Eucalyptus + bhabar grass, *Acacia catechu* + napier grass, Leucaena + napier grass, Teak + leucaena+ bhabar grass, Eucalyptus + leucaena + turmeric, poplar + leucaena + bhabar, Sesamum + rape seed are compared with cultivated fallow. The maximum and minimum soil loss and runoff were found in the case of Sesamum + rape seed and Eucalyptus + bhabar grass of 2.69 t ha^{-1}, 20.50% and 0.07 t ha^{-1} 0.05% respectively. For cultivated fallow land, the soil loss and runoff was 5.65 t ha^{-1} and 23% which was much more than the agroforestry models. The N loss was found minimum in Eucalyptus + bhabar grass model (0.46 kg ha^{-1}) and maximum in Sesamum + rape seed (42.50 kg ha^{-1}) whereas K loss was minimum in *Acacia catechu* + napier grass (0.52 kg ha^{-1}) and maximum in Sesamum + rape seed (3 kg ha^{-1}) respectively. In cultivated fallow land, the N and K loss was 51.30 kg ha^{-1} and 5.00 kg ha^{-1}respectively [18]. A study to understand the effectiveness of different pasture management techniques in reducing soil loss, runoff and nutrient loss (N & K) was conducted in Bundelkhand region of Central India. Runoff, soil loss and nutrient loss from pasture systems such as natural grassland, improved pasture, sown pasture and 3-tier silvopasture have been compared with respect to bare land. Results showed that among the pasture systems runoff, soil and nutrient loss was found maximum from the natural grassland i.e., 11.6%, 2.50 t ha^{-1}, 3.75 kg ha^{-1} $yr.^{-1}$ and 4.00 kg ha^{-1} $yr.^{-1}$ respectively and minimum soil and nutrient loss was found for 3-tier silvopasture system i.e., 1.27 t ha^{-1}, 1.27 kg ha^{-1} $yr.^{-1}$ and 2.10 kg ha^{-1} $yr.^{-1}$ respectively whereas runoff i.e., 9% was minimum for sown pasture.

Windbreaks/shelterbelts are very effective in arid and semi-arid regions specifically for wind erosion-prone areas. They comprised of single/multi rows/belt of trees which are planted in orientation perpendicular to the direction of wind. The belts of trees are very effective in ameliorating the microclimate and improving growth and yield of associated annual crops. Shelterbelt comprising of castor on the windward and shorter tree in leeward direction increased the yield of lady's finger and cowpea by 41% and 21% respectively than the control [19]. From different studies, it has been reported that shelterbelts reduce soil erosion by 50% [20].

Home gardens are also very effective in reducing soil erosion. Study conducted in Kerala (India) revealed that cardamom, pepper and mixed home gardens with coconut trees remarkably reduces the soil loss to 0.65, 3.55 and 1.45 t ha^{-1} respectively in comparison to soil loss 130 t ha^{-1} from land after removing forest canopy [21]. In an experiment in Nilgiris in India, runoff and soil loss was measured for 5 years (1959 to 1963) on 16% sloping land under five different vegetation cover viz., blue gum, black-wattle plantation, slola, broom, and indigenous grass. The runoff and soil loss data showed that blue gum cover produced the highest (1.08%) and grassland produced almost nil (0.018%) runoff.

3. Rehabilitation of degraded lands through agroforestry

Land degradation means the gradual deterioration of land quality in terms of agricultural productivity. An assessment by United Nations Development Programme (UNDP) showed that globally 40% of the land area comes under dryland out of which 29.7%, 44.3%, and rest falls in arid, semiarid, and dry sub-humid region respectively. The Food and Agricultural Organization (FAO) estimated that 43% of rangelands and 20% of cropping lands are degraded while Sub-Saharan Africa has the highest rate of land degradation. About 46% of land in Africa is affected by land degradation which suggests productivity loss of 20% over the last 40 years. About 68% of the land in Australia is under degradation while as in Asia about 25% of the land is vulnerable to degradation and will likely increase due to climate change issues. About 19.65 $Mkm^2$of the land worldwide is degraded out of which 10.94 Mkm^2 was caused by water. Many studies pertaining to agroforestry have been carried out in to tackle land degradation.

Increase in vegetation coverage is the fundamental approach to control land degradation. UNCCD (2004) revealed that forests and tree cover have potential combat land degradation and desertification by stabilizing soils, reducing water and wind erosion and maintaining nutrient cycling in soils. Different agroforestry systems have been designed after years of research for different categories of degraded lands. These agroforestry systems not only provide higher productivity but are also capable of conserving the resources efficiently. Silvipasture systems have been found to be very successful on degraded lands. Eucalyptus trees in combination with *Eulaliopsis binnata* harnessed almost all the runoff and trapped all soil inside the field except in 1988 when rainfall was extremely high than other years (**Table 2**). In the reclamation of the salt-affected area some of the tree species such as *Acacia farenesiana*, *Tamarix articulate*, *Propsopis juliflora*, *Pithecellobium dulce* and *Parkinsonia aculeate* were found to very effective [22]. In the reclamation of alkali soil, *Prosopis juliflora* (2 mx 2 m) + *Leptochloa fusca* was found most effective alone with the production of 161 t biomass and 56 t ha^{-1} grass in six years [22]. However, in alkaline soils at Dhipura (Madhya Pradesh, India), it was found *P. juliflora* not only increased the OC content but also enhanced the essential mineral content to great extent after 9 years. *Propopis chilensis* (Mesquite) tree was found to be effective in reducing pH, EC, and exchangeable Na level and increasing infiltration characteristics, OC, total N, available P, exchangeable Ca, Mg and K levels [23, 24]. Eucalyptus tree as reported with high transpiration rates was found very effective in reclaiming waterlogged areas [24].

Natural causes like forest fire, avalanches, landslides, flooding, and anthropogenic activities such as deforestation, overgrazing, construction works, unscientific farming in hills resulted in excess soil erosion and land degradation [25, 26]. A 4 ha landslide-prone area at Nalotanala on Dehradun-Mussoorie road in India, agroforestry plantation of *Ipomoea carnea*, *Vitex negundo* and napier with *Erythrino suberosa*, *Dalbergia sissoo* and *Acacia catechu* successfully stabilized the area after 10 years of practice. [27]. Acharya and Kafle [28] reported that due to continuous soil erosion

Parameters	**Years**				
	1985	**1986**	**1987**	**1988**	**1989**
Air dry grass yield (t ha^{-1})	1.2	8.6	1.5	5.1	4.1
Mean Eucalyptus height (m)	1.5	4.7	6.7	8.4	10.5
Mean Eucalyptus DBH (cm)	1.2	4.3	5.5	6.6	7.4
Runoff (mm)	—	—	—	10.01	—
Soil loss (t ha^{-1})	—	—	—	0.17	—
Monsoon rainfall (mm)	686	905	313	1586	934

Table 2.
Different parameters related to Eucalyptus and Bhabar agroforestry system.

in up-hills in Nepal, the bed levels of *Terai* river were increasing 35–45 cm annually [29]. Govt. of Nepal has leased the degraded forest lands and the tax-free lands to families below the poverty level for the reclamation of the degraded lands [30].

4. Soil moisture conservation and water quality improvement by agroforestry practices

Trees in the agroforestry system can increase the crop yield by conserving soil moisture through mulching. Soil moisture availability is higher under trees than open areas and the agroforestry system increases the infiltration characteristics of the soil and thus, it traps more water and increases the soil water content. In the arid region, Kumar et al. [31] observed the effect of soil water availability on *Hordeum vulgare* (barley) yield is compared for various agroforestry models with *Prosopis cineraria*, *Tecomella undulate*, *Acacia albida* and *Azadirachta indica*. It was found that *P. cineraria*, *T. undulate*, *A. albida* and *A. indica* increased crop yield by 86%, 48.8%, 57.9%, and 16.8% over the control. It is well proved that the agroforestry system improves the quality of the groundwater compare to the cropping system most of the applied nutrients are leached out which pollutes the groundwater [32]. Deep-rooted trees used in agroforestry consume the excess nutrients applied in the crop field. Therefore, acts as a filter and releases water with fewer nutrients and reduces groundwater pollution.

Seobi et al. [33] studied the effect of agroforestry and grass-legume buffers on soil hydraulic retention and soil physical properties for Putnam soil (fine, smectitic, mesic Vertic) in corn (*Zea mays*)–soybean (*Glycine max*) field in northeastern Missouri in USA from 1991 to 1997. Agroforestry buffers used for the experiment were 4.5 m wide and 36.5 m apart. The trees and grasses used in agroforestry buffers were redtop (*Agrostis gigantean*), brome (*Bromus spp*.), and birdsfoot trefoil (*Lotus corniculatus*) with pin oak (*Quercus palustris*, swamp white oak (*Q. bicolor*), and bur oak (*Q. macrocarpa*). Soil samples were collected from buffers and crop fields using core samplers up to 40 cm with a 10 cm interval. Pressure starting from 0 to −33 kPa was applied to soil samples and corresponding water content was noted. Results showed the grass and agroforestry buffers can store 0.9 cm and 1.1 cm more water for top 30 cm soil in comparison to the row crop. The reason for the increased soil water content in the agroforestry and grass buffer system may be attributed to the enhanced porosity. Thus, it increases the infiltration characteristics of the soil and reduces runoff.

The land is being cleared in arid and semi-arid regions of Australia to meet agricultural development by clearing the native forests. However, gradual salinization is being a problem of those lands due to rising groundwater level. In a study in two different experiment sites in Western Australia, the reclamation of those lands is carried out by using pinus (*Pinus radiate & P. pinaster*) - pasture and eucalyptus (*E. sargentii*, *E. wandoo, E. camaldulensis and E. calophylla*) -pasture agroforestry measures. Site 1 has an area of 76 ha out of which agroforestry covers 47 hectares whereas site 2 has an area of 30.25 ha out of which 17.24 ha covered with agroforestry. The long-term annual rainfall and pan evaporation for site 1 were recorded as 717 mm and 1800 mm respectively whereas for site 2, annual rainfall and pan evaporation was 713 mm and 1613 mm respectively. Results showed that groundwater level in site 1 was decreased by 1 m relative to the groundwater level in pasture land whereas in site 2 decreases in groundwater level were 2 m over the period 1979–1989. The salinity level is also found decreased by 9% and 6% for site 1 and site 2 respectively in comparison to the initial stage [34]. It is expected that due to less water availability caused by climate change will affect 2.7 to 4 billion people worldwide by 2050 [35]. Climate change will affect the water quality in terms of sediment, nutrients, dissolved organic carbon, pathogens, pesticides, and salt content in water [36]. In this scenario of changing climate, agroforestry practices will act as a remedy and will enhance the micro-climate, reduce runoff and evaporation, and also increase the soil moisture content and groundwater level and thus agroforestry practice will increase the water availability and food security guarantee.

5. Agroforestry promising for soil fertility replenishment

The role of the agroforestry system in enhancing and maintaining soil fertility and productivity and sustainability has been well documented [37]. Even those trees which do not fix N, enhance soil physical properties which helps in crop growth. Maintenance and enhancement of soil fertility levels are necessary for regional and global food security purposes. Several studies are reported and proved that from agroforestry system nutrient loss is less as compared to the agriculture farming. Grewal et al. [38] have reported that leucaena-napier grass allowed less nutrient loss compared to the traditional agricultural system. There was net gain of 38 kg N, 10 kg P, and 20 kg K as compared to the net loss of 15 kg N, 2 kg P and 14 kg K ha^{-1} in the traditional agricultural system. In a study with *Acacia nilotica* + *Saccharum munja* and *Acacia nilotica* + *Eulaliopsis binate* the soil organic carbon was found 0.91% and 0.99% after 5 years [39]. Tomar et al. [40] reported the effect of green manuring with different agroforestry tree species on dry matter yielding and production as well as post-harvest fertility of low land rice (*Oryza sativa*) in India. The green leaves of the tree species viz., *Erythrina indica*, *Acacia auriculiformis*, *Alnus nepalensis*, *Parkia roxburghii* and *Cassia siamea* at 10 t ha^{-1} were applied in rice fields during the rainy season of 2008 to 2010. The dry matter and paddy yield from those fields were compared with the fields which were treated with recommended N-P_2O_5-K_2O (80:60:40 kg ha^{-1}) and control (no fertilizer and manure). The soil of the field was sandy clay loam, acidic, low in P content (6.95 kg ha^{-1}), medium in N (277 kg ha^{-1}), high in K (258 kg ha^{-1}), and OC (2.56%) respectively. In 1st and 2nd year of study, the grain and straw yield was higher in NPK plot (**Table 3**). However, in 3rd-year grain and straw yield was higher in green-leaf manure plots. *Erythrina* tree leaf manure was found superior among the other tree leaf manures. Application of green leaf manure increased the available soil NPK increased more compared to recommended N-P_2O_5-K_2O dose and control. Therefore, based on the above observation, it could be said that plant residues can have long term implications in maintaining soil fertility without decreasing the crop yield. In arid and semi-arid regions, *Prosopis cineraria* in low intensity about 120 trees ha^{-1} increases the N level of soil. It is also used as a source of animal feed, fuel, timber and intercropping with millet and legumes increase the grain yield [41].

In an alley cropping system red alder (*Alnus rubra*) in maize experiment at Oregon in the USA, it was found that 32–58% of total N in maize was transferred from N fixed by red alder and more transfer obtained when the distance between red alder and maize is less [42]. Avasthe et al. [43] reported that large cardamom (*Amomum subulatum* Roxb.) based agroforestry practice was found effective in conserving soil, water, and nutrients in the fragile mountain ecosystem of Sikkim Himalayas in India in comparison to a mixed forest and traditional maize-soybean-mustard cropping sequence. In this agroforestry system, cardamom is grown under the shade tree *Alnus nepalensis* which fixes atmospheric N. OC, available N, K except P was found higher in the soil in cardamom based on agroforestry system compared to maize-soybean-mustard cropping sequence. On the other hand, soil loss and nutrient loss in the soil also found less in large cardamom based

Treatments	**Grain yield(t ha^{-1})**			**Straw yield(t ha^{-1})**			**Organic carbon (%)**		**N (kg ha^{-1})**		**P (kg ha^{-1})**		**K (kg ha^{-1})**	
	2008	**2009**	**2010**	**2008**	**2009**	**2010**	**2009**	**2010**	**2009**	**2010**	**2009**	**2010**	**2009**	**2010**
Erythrina	4.48	4.83	5.67	6.55	7.12	7.77	2.98	3.15	320.1	323.3	12.18	13.06	292.7	294
Alnus	3.50	4.10	4.67	5.66	6.11	6.45	2.95	3.06	295.3	309.7	9.42	11.72	296.0	295
Parkia	4.13	4.40	5.24	6.20	6.85	7.16	2.90	3.00	288.7	314.1	10.67	12.85	271.4	282
Acacia	3.92	4.66	5.30	5.83	6.90	7.49	3.05	3.18	299.3	307.5	11.20	12.31	274.8	278
Cassia	3.99	4.55	5.58	5.83	6.69	7.46	2.90	3.12	318.8	322.5	12.37	13.20	280.2	298
N-P_2O_5-K_2O	4.82	5.08	5.13	6.88	7.34	7.05	2.90	2.91	281.0	297.0	8.56	10.25	273.9	277
Control	2.80	3.13	3.35	4.18	4.75	5.04	2.80	2.80	269.4	270.7	7.39	7.20	253.8	265

Table 3.
Paddy grain and straw yield and post fertility status of the soil due to the application of tree leaves and N-P2O5-K2O fertilizer in compared to control.

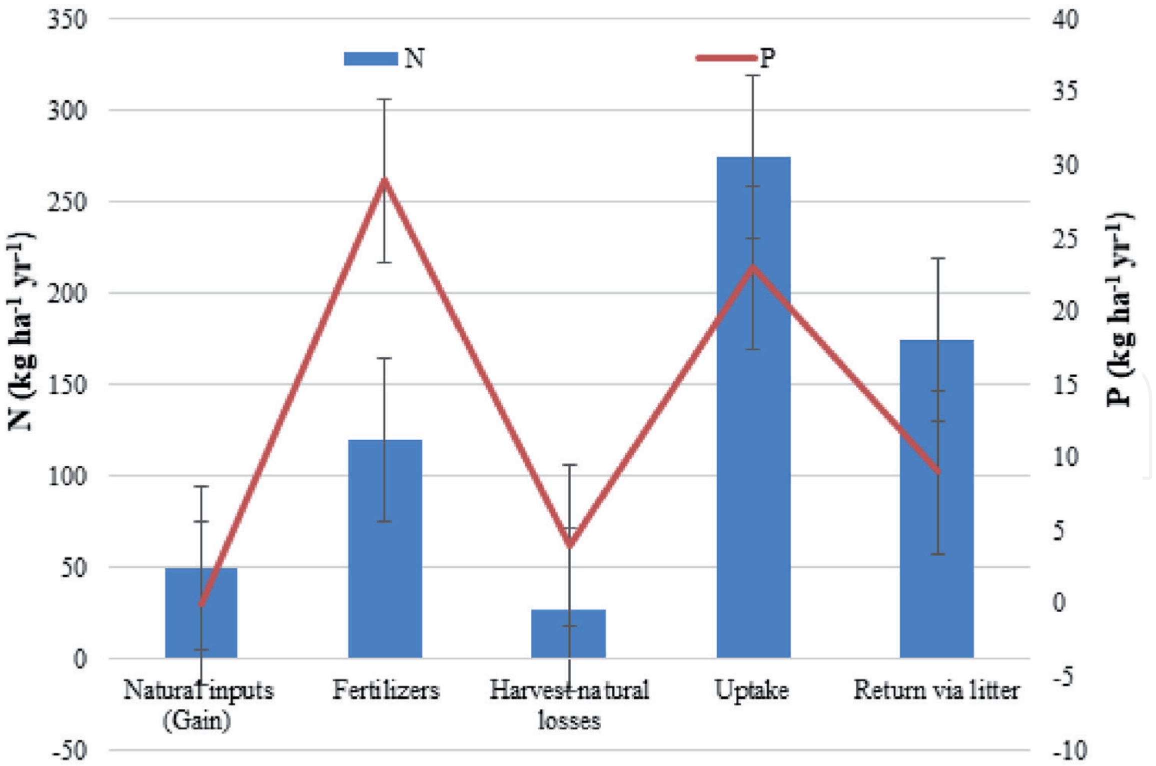

Figure 2.
Nutrient cycling in Coffee-Erythrina-Inga agroforestry.

agroforestry system than maize-soybean-mustard cropping sequence. In a study N and P gain, loss, uptake and return via litter in coffee-Erythrina-Inga agroforestry system was estimated [44] as shown in **Figure 2**.

In semi-arid region of India for neem-based agroforestry system, the annual litterfall was estimated as 6059 kg ha^{-1} from 400 neem trees which returned 98, 2.25, 3.2, and 131 kg ha^{-1} of available nitrogen, phosphorous, potassium, and calcium to soil [45]. Kang et al. [46] reported the comparative efficiency of pruning of *Gliricidia sepium* and *Leucaena leucocephala* in increasing the nutrient level in the soil. They found that *Leucaena* pruned compost is more efficient in increasing the nutrient level of soil compared to *Gliricidia*. Singh et al. [47] reported that the agroforestry system is more effective in increasing soil fertility than crop-based system. Patel et al. [48] reported that *Sesbania rostrata* fixed 307 kg N ha^{-1} whereas *S. cannabina* fixed only 209 kg N ha^{-1} in a shifting cultivation discarded area. In the north-eastern region of India, *Bambusa nutans* trees found effective in binding the soil nutrient in abandoned *Jhum* cultivated land [49, 50]. In arid region in Rajasthan in India, the soil microbial biomass C, N and P were found more in the agroforestry system than in soil with no tree [51].

6. Interference of agroforestry in soil health management

The agroforestry system increases the soil infiltration capacity. In an experiment, it was reported that the infiltration capacity of soils which were mostly clay to silt clay in texture and acidic in nature were in the order of Eucalyptus, Bhabar, Eucalyptus + Bhabar, and agricultural plot. The infiltration rate was about 3 times in Eucalyptus + Bhabar than the agricultural plot [52]. The effects of five agroforestry systems on soil physical properties have been investigated in the ICAR complex for the north-east region in India. The name of the agroforestry systems are Khasi mandarin (*Citrus reticulate* Blanco.) + annual agricultural crops;

Assam lemon (*Citrus lemon* L.) + annual agricultural crops; Arboretum (Mixed multipurpose tree species) + annual agricultural crops; Silvi-hortipastoral [alder (*Alnus nepalensis*) + pineapple (*Ananus sqennnsa* L.) + fodder and multistoried AFS [alder +tea (*Camellia sinensis*) + black pepper + annual agricultural crops]. The soil physical properties such as bulk density (BD), mean weight diameter (MWD) and apparent saturated hydraulic conductivity (AHC) were compared with the soil from the adjoining area of natural forest soils of same age. The mean bulk density of soil from natural forest was least (0.94 Mgm^{-3}) and highest for Khasi mandarin and Assam lemon (1.19 Mgm^{-3}). The bulk density was less for natural forest and other agroforestry systems due to heavy litter fall and decay of dead roots resulting in high organic carbon content [8]. Soil aggregates were represented with MWD which was observed highest for natural forest i.e., 3.13 and lowest in case of Assam lemon i.e., 1.39. The value of MWD is in the order as natural forest>multistoried AFS > Silvi-hortipastoral>Arboretum>Khasi mandarin>Assam lemon. The value of MWD was highest for natural forest due to more availability of organic matter content which helps in forming the aggregates. The reason for being a low value of MWD for Arboretum, Khasi mandarin and Assam lemon may be attributed to the frequent use of agricultural implements that disintegrate the soil structure. In all agroforestry systems, hydraulic conductivity was inversely related to soil depth. AHC signifies the rate of water movement through the soil profile. AHC was found rapid in natural forest (1.84×10^{-4} m/s) and least in case of Khasi mandarin system (0.38×10^{-4} m/s). AHC varied for different agroforestry systems as Natural forest>multistoried AFS > Silvi-hortipastoral>Arboretum>Assam lemon> Khasi mandarin. This study concludes among the agroforestry system, multistoried AFS and Silvi-hortipastoral improves more soil moisture conservation capability, soil structure, and pore size distribution [53].

An increase in porosity was reported by Udawatta et al. [54] in the Midwest Region of the United States in maize-soybean field in conjunction with using agroforestry buffers. In grass and agroforestry buffer strips pore path was observed three and five times higher than in soil of maize-soybean field which may be a reason for increased infiltration rate. Pandey et al. [55] reported that the sand particles declined by 10% and 9%; clay particle increased by 14% and 10% under mid-canopy and canopy edge respectively compared to under canopy gap position. Silt particles quantity was not influenced by canopy position. Soil organic carbon, total N, total P were more under mid-canopy and canopy edge compared to the canopy gap. Seobi et al. [33] observed improved soil physical properties in agroforestry and grass buffer system in comparison to the row crop system.

7. Agroforestry in climate change mitigation potential

Agroforestry system acts as an atmospheric carbon sink and in carbon sequestration process, carbon is captured from the atmosphere and stored as carbon sink such as by oceans, vegetation and soils through certain biological and physical processes. Agroforestry system traps more atmospheric carbon compared to crop plants or pastureland [56, 57]. The capacity of agroforestry systems to sequester carbon depends on different factors such as tree species, age of tree, tree density, climate, geographical location, and management practices. In general, tropical humid climate sequestrates more carbon than arid, semi-arid, temperate region. On an average soil organic carbon pool in the soils of arid climate and cold region below 1 m depth is 30 and 800 tons ha^{-1} respectively. The total worldwide land area under agroforestry system is 1023 Mha which has potential to sequester carbon approximately 1.9 Pg over 50 years [58]. By improving the present management practices involved in agroforestry system, additional 17000 Mg year^{-1} carbon can be sequestrated by 2040 [59]. In another estimate, the area under agroforestry in world is 8.2% of total reported geographical area (305.6 m ha) and contributes 19.3% of total C stock under different land uses (2755.5 m t C) [60–62]. If worldwide present area of unproductive cropland and grassland of 630 Mha is converted to agroforestry which can harness additional 586000 Mg year^{-1} carbon by 2040. Riparian buffer, alley cropping and silvipasture system can sequester 4.7, 60.9, and 474 Tg C year^{-1}, respectively. Additional protection of farmland and cropland with windbreak can sequester additional 8.79 Tg C year^{-1}. Therefore, the agroforestry system in USA has a potential to sequester C as 548.4 Tg year^{-1}. By this way, agroforestry system in USA can trap 34% of greenhouse gas in the form of CO_2 [63]. In India, degraded land amounts over 100 Mha where only bushes and grasses grow only in monsoon season [64]. These lands are low in soil carbon and have ample scope to increase the soil carbon by planting proper tree species and grasses with proper management practices. In India, potential of agroforestry system in storing C is estimated 2400 m tons. It is estimated that the total area under agroforestry in India is 8.2% which contributes 19.3% of total carbon under different land uses [20]. Newaj et al. [65] found that *Albizia procera* under agro-silviculture system sequestered C more than in a pure tree. In this system, 2 crop rotations i.e. black gram-mustard and green gram-wheat were used. Three pruning treatments (70% canopy pruning, 50% pruning, and un-pruned) have been applied. After 3 years, it was found that sequestered carbon amounts 27.97, 22.96, and 21.33 t ha^{-1} in the un-pruned tree, 70% and 50% canopy pruning in agro-silvicultural system. In a homegarden with bamboo farming system in Assam India, the aboveground average carbon sequestration estimated as 1.32 Mg ha^{-1} yr.$^{-1}$ [66], while the presence of organic C was 30% and 114% greater in home gardens in comparison to the coconut plantations and rice fields [67]. Howlett et al. [68] found in a silvipastoral system in northeast spain a greater level of organic C in birch (*Betula pendula*) in comparison to pine (*Pinus radiata*). The reason is attributed to the fact that the subsoil environment created by pine is less conducive for plant growth and decomposition is reduced and the organic C built over time is less. In a study at Bahia, Brazil aboveground and below ground C sequestration had been studied under cacao (*Theobroma cacao* L.) based agroforestry system (AFS). In this cacao-based AFS, cacao was planted with woody species for shade such as *Erythrina spp.* and *Gliricidia spp.* or under these in natural forests. Cacao cultivated under natural forest trees is known as cabruca. The huge amount of belowground C accumulation is due to a large amount of leaf litter, decomposition roots of both cacao and woody trees. It is estimated that total amount of C stored in cacao based AFS in Bahia below 1 m depth was 302 Mg ha^{-1}. It has been reported that shade trees (55 trees ha^{-1}) in cabruca system stores 44% more carbon than the Erythrina trees (35 trees ha^{-1}) though the mean C stored by cacao + Erythrina and cabruca system was similar with a mean of 39.27 Mg ha^{-1} [69].

8. Ecosystem services from agroforestry systems

According to the 2005 Millennium Ecosystem Assessment, human beings are relished by supporting, regulating, provisioning, and cultural services from the ecosystem. They have become the most widely used framework to study the relations between ecosystems (including natural and human-modified ecosystems) and people [70]. Agroforestry has been demonstrated to combine production with multiple ecosystem services and goods [71] it provides multiple ecosystem services, combining the provision of agricultural, livestock and forestry products with regulating services, cultural services and supporting services. In this context, there is a general need to gain more insight into the overall, total functioning of an agroforestry system i.e., a broad picture of the simultaneous and multiple services provided by such a system.

Agroforestry is a viable land-use option that, in addition to the socio-economic benefits, offers several ecosystem services in the face of different environmental and social challenges [37, 72]. Agroforestry promotes multiple ecosystem services like improvement in soil quality, water conservation by slowing down surface run-off, reducing sediment transportation, soil biodiversity, enhances carbon sequestration, and increases diverse food and cover for wildlife habitat [73, 74]. However, being these services much interlinked so are difficult to measure autonomously but agroforestry has the potential to promote economic, environmental, social vitality, and land stewardship [73]. Sileshi et al. [75] while working in eastern and southern Africa reported that when agroforestry properly designed and strategically located, and the practices of agroforestry can contribute to ecosystem services by mitigating land degradation, climate change, and desertification while adding structural and functional diversity to the agricultural landscapes in the Miombo eco-region. Trees on farms can prevent environmental degradation and provides healthy system for human welfare [76]. However, agriculture has changed enormously in the second half of the last century, driven by agricultural policy and technological progress. Trees that characterized many agroecosystems across the globe have been lost to a large extent [77, 78]. Although, promoting the concept of ecosystem services, to better understand the diverse ecosystem services provided by agroforestry is very important to know. In Ethiopia, agroforestry was credited as a sustainable farming practice that uses and conserves biodiversity and limits agricultural expansion into natural forests [79]. However, this farm-based conservation of biodiversity was only recently advocated by the Convention on Biological Diversity [80–82]. If managed properly, agroforestry holds promise for ecosystem services and environmental benefits. The practices of agroforestry can be considered an adaptive strategy in areas with increasing climate variability and can serve as viable carbon sinks as they trap and store carbon.

9. Conclusion

Agroforestry provides goods and services from trees and reinstates degraded lands. The agroforestry system has the potential for making habitats for edge species conservation of remnant intrinsic species and their gene pools. In the wake of food scarcities and predictable climate change, the practices of agroforestry are gaining attention from the researchers and policymakers as a lucrative approach to develop food security, while at the same time backing to climate change adaptation and mitigation. However, to achieve the target of sustainability, we need to practice agroforestry with improved water management and innovative practices. Climate change will intensify constraints by creating weather more inconstant and will influence the yield by a further decrease in average yields worldwide. Changing food habits with an increase in population and water and land scarcity are also long-term trends that threaten our shared vision of a more prosperous future in which well-fed people everywhere can achieve their full potential without damaging their environment. Agroforestry can improve the resilience of agricultural production to current climate variability as long-term climate through the use of trees for intensification and diversification and buffering of farming systems.

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References

[1] Alice B (2002) Agroforestry Overview Horticulture systems guide, Appropriate Technology Transfer for Rural Areas,1-10pp

[2] World Bank. Sustaining forests: a development strategy. ISBN 0-8213-5755-7 (The World Bank, Wash., D.C., 2004).

[3] Young R, Orsini S, Fitzpatrick I (2015) Soil degradation: a major threat to humanity. Sustainable Food Trust. UK. http://assets.fsnforum.fao.org.s3-eu-west 1.amazonaws.com/public/discussions/contributions/Soil-degradation-Final-final_0.pdf

[4] Lal R (2011) Soil Carbon Sequestration. SOLAW Background Thematic Report- TR04B, Food and Agriculture Organization of the United Nations, Rome, 36p.

[5] Nearing MA, Pruski FF and O'Neal MR (2004) Expected climate change impacts on soil erosion rates: a review. Journal of Soil and Water Conservation 59: 43-50.

[6] Lee JJ, Phillips DL, Dodson RF (1996) Sensitivity of the US Corn Belt to climate change and elevated CO2: II. Soil erosion and organic carbon. AgriSyst 52: 503-521

[7] Garrett HE, ed. (2009) North American Agroforestry: An Integrated Science and Practice, 2nd ed., Madison, WI: American Society of Agronomy, Inc.

[8] Young A (1989) Agroforestry for Soil Conservation. CAB International, Wallingford, UK, pp101

[9] Lal R (1989) Agroforestry systems and soil surface management of a tropical Alfisol. II. Water runoff, soil erosion and nutrient loss. AgroforSyst 8: 97-111

[10] Pacardo EP, Montecillo L (1983) Effects of corn/ipil-ipil cropping systems on productivity and stability of upland agro-ecosystems. Annual Report, UPLB PCARRD Res. Project, Philippines

[11] Raintree JB, Torres F (1986) The agroforestry research in farming systems perspectives: The ICRAF approach. IARC's workshop on FSR, 17-21 Feb. 1986, ICRISAT, Hyderabad, India

[12] Sukmana S, Suwardjo H, Abdurachman A, Dai J (1985) Prospects of Flemingiacongesta for reclamation and conservation of volcanic skeletal soils. Pembr. Pen. Tanah Dan. Pipuk 4: 50-54

[13] Wiersum KF (1981) Observations on Agroforestry in Java, Indonesia. Agric. Univ. Wageningen, pp131

[14] Wiersum KF (1984) Surface erosion under various tropical agroforestry systems. In C. L. O'Loughlin and A. J. Pearce (eds) Effects of forest landuse on erosion and slope stability, Univ. of Hawaii, Honululu

[15] Phoung TT, Shrestha RP, Choung HV (2017) Simulation of soil erosion risk in the upstream area of Bo River watershed. In redefining diversity and dynamics of natural resources management in Asia- Elsevier. 3: 87-99

[16] Lal R (1990) Agroforestry systems to control erosion on arable tropical steeplands, IAHS-AISH Publ. No.192

[17] Narain P, Singh G, Joshie P (1992) Technological needs of vegetative land protection measures, Proc 7th ISCO Conf, Sydney Australia, pp 638-643

[18] Grewal SS (1993) Agroforestry systems for soil and water conservation

in Shivalik. In: Agroforestry in 2000 AD for semi-arid and arid tropics, NRC for Agroforestry, Jhansi, India, 82-85pp

[19] Venkateswarlu J (1993) Problems and prospects in desertification control: Role of Central Arid Zone Research Institute. In: Desertification and its Control in the Thar, Sahara and Sahel Regions (Sen, A.K. and Kar, A. Eds.). pp. 249-267. Jodhpur, India: Scientific Publishers

[20] Fanish SA, Priya RS (2013) Review on benefits of agro forestry system. International J Edu Res 1(1), 1-12.

[21] Moench M (1991) Soil erosion under a successional agroforestry sequence: a case study from Idukki District, Kerala, India. Agroforestry Systems 15(1):31-50

[22] Singh G, Singh NT, Tomar OS (1993) Agroforestry in salt-affected soils. Technical Bulletin No. 17, CSSRI, Karnal, pp65

[23] Bhojvaid PP, Timmer VR, Singh G (1996) Reclaiming sodic soils for wheat Production by Prosopisjuliflora (Swartz) DC afforestation in India. Agroforest Syst 34(2):139-150

[24] Singh GB (1999) Agroforestry research in India-issues and strategies. Indian J Agroforestry 1: 1-14.

[25] Karkee K (2004) Land degradation in Nepal: A menace to economy and ecosystems international Master's Programme in environmental science, University of Lund, Sweden

[26] Neupane RP, Thapa GB (2001) Impact of agroforestry intervention on farm income under the subsistence farming system of the middle hills, Nepal. Agroforest Syst 53: 31-37

[27] Sastry G, Husenappa V, Bansal RC, Tejwani KG (1981) Hydrological aspects of farm ponds in Doon Valley. Research Bulletin No. 6, CSWCRTI, Dehradun. pp15

[28] Acharya, Kafle (2009) Land degradation in Nepal and its management through agroforestry. J Agri Environ 10:115-123

[29] Dent FR (1984) Land degradation: present status, training and education needs in Asia and Pacific. UNEP investigations on environmental education and training in Asia and Pacific: FAO, Regional Office, Bangkok

[30] Gautam MK, Robert EH, Singh BK (2003) Report on community based leasehold approach and agroforestry technology for restoring degraded Hill Forests and proving rural livelihoods in Nepal, Forest and Biodiversity Conference, Kathmandu, Nepal

[31] Kumar A, Hooda MS, Bahadur R (1998) Impact of multipurpose trees on productivity of barley in arid ecosystem. Ann. Arid Zone 37: 153-157

[32] Cassman KG (1999) Ecological intensification of cereal production systems: yield potential, soil quality, and precision agriculture. Proc Natl Acad Sci 96: 5952-5959

[33] Seobi T, Anderson SH, Udawatta RP, Gantzer CJ (2005) Influence of Grass and Agroforestry Buffer Strips on Soil Hydraulic Properties for an Albaqualf. Soil Sci Soc Am J 69: 893-901

[34] Bari MA, Schofield NJ (1991) Effects of agroforestry-pasture associations on groundwater level and salinity. Agrofor Syst 6: 13-31

[35] Diop S, Ed. (2008) Vital Water Graphics – An Overview of the State of the World's Fresh and MarineWaters. Nairobi: United Nations Environmental Programme. DOI 10.1007/s10457-009-9229-7

[36] IPCC (2013) Intergovernmental Panel on Climate Change. Regional

Impacts of Climate Change. Special Reports. 28 May 2013 <http://www.ipcc.ch/ipccreports/sres/regional/index.php?idp=30

[37] Jose S (2009) Agroforestry for ecosystem services and environmental benefits: an overview, Agroforest Syst 76: 1-10

[38] Grewal SS, Juneja ML, Singh K, Singh S (1994) A comparison of two agroforestry systems for water and nutrient conservation on degraded land. Soil Technology 7: 145-153

[39] Samra JS, Singh SC (2000) Silvipasture systems for soil, water and nutrient conservation on degraded lands of Shivalik foot hills (subtropical northern India). Ind J Soil Conser 28(1): 35-42

[40] Tomar JMS, Das A, Lokho Puni Chaturvedi OP, Munda GC (2012) Shifting Cultivation in North Eastern Region of India – Status and Strategies for Sustainable Development. The Ind Fores 137 (9): 52-62

[41] Singh GB (1987). Agroforestry.in the Indian subcontinent: past, present and future. In: Steppler, HA and Nair, PKR (eds.), Agroforestry: a decade of development, pp. 117-138, ICRAF, Nairobi, Kenya

[42] Seiter S, Ingham ER, William RD, Hibbs DE (1995) Increase in soil microbial biomass and transfer of nitrogen from alder to sweet corn in an alley cropping system. In: Ehrenreich JH, Ehrenreich DL, Lee HW (eds) Growing a sustainable future. University of Idaho, Boise, ID, pp. 56-158

[43] Avasthe RK, Singh KK, Tomar JMS (2011) Large cardamom (*Amomumsubulatum*Roxb.) based agroforestry systems for production, resource conservation and livelihood security in the Sikkim Himalayas,Indian J soil Conser 39(2): 155-160

[44] Young A (1997) Agroforestry for soil management, 2nd edn. CAB International, Wallingford, vii + 320 pp

[45] Pandey AK, Gupta VK and Solanki KR (2010) Productivity of neem based agroforestry system in semi-arid region of India. Range Management and Agroforestry, 31: 144-49.

[46] Kang BT, Reynolds L and Atta-Krah AN (1989) Alley farming. Advances in Agronomy 43: 315-359

[47] Singh G, Singh NT, Dagar JC, Singh H, Sharma VP (1997) An evaluation of agriculture, forestry and agroforestry practices in a moderately alkali soil in northwestern India. Agrofores syst 37(3):279-295

[48] Patel LB, Sidhu BS, Beri V (1996) Symbiotic efficiency of Sesbaniarostrata and S. cannabina as affected by agronomic practices. BiolFert Soils 21: 149-151

[49] Arunachalam A, Khan ML, Arunachalam K (2002) Balancing traditional jhum cultivation with modern agroforestry in eastern Himalaya - A biodiversity hot spot. CurrSci 83:117-118

[50] Tomar JMS, Upadhaya K, Tripathi OP, Pandey HN (2007) Agroforestry Systems and Practices Prevailing in Meghalaya. In: Puri and Panwar (eds.) "Agroforestry Systems and Practices"357-366

[51] Yadav RS, Yadav BL, Chhipa BR (2008) Litter dynamics and soil properties under different tree species in a semi-arid region of Rajasthan, India, Agroforest Syst 73(1): 1-12

[52] Grewal SS, Samra JS, Mittal SP, Agnihotri Y (1995) Sukhomajri concept of integrated watershed management. Chandigarh, India: Central Soil and Water Conservation Research and Training Institute. X, 157pp

[53] Saha R, Mishra VK, Tomar JMS (2005) Effect of agroforestry systems on erodibility and hydraulic properties of Alfisols in eastern Himalayan region. Ind J Soil Conser 33:251-253

[54] Udawatta RP, Gantzer CJ, Anderson SH, Garrett HE (2008) Agroforestry and grass buffer effects on high resolution X-ray CT-measured pore characteristics. Soil Sci Soc Am J 72:295-304.

[55] Pandey CB, Singh AK, Sharma DK (2000) Soil properties under Acacia nilotica trees in a traditional agroforestry system in central India. Agrofores syst 49(1):53-61

[56] Kirby KR, Potvin C (2007) Variation in carbon storage among tree species: implications for the management of a small scale carbon sink project. For Ecol Manage 246: 208-221

[57] Sharrow SH, Ismail S (2004) Carbon and nitrogen storage in agroforests, tree plantations, and pastures in western Oregon, USA. Agroforest Syst 60:123-130

[58] Nair PKR, Mohan Kumar B and Nair VD (2009) Agroforestry as a strategy for carbon sequestration. Journal of Plant Nutrition and Soil Science, 172:10-23.

[59] IPCC (2000) Land use, land-use change, and forestry. A special report of the IPCC. Cambridge University Press, Cambridge, p 375

[60] Dixon RK, Brown S, Houghton RA, Solomon AM, Trexler MC, Wisniewski J (1994) Carbon pools and flux of global forest ecosystems. Science 263: 185-190.

[61] Krankina ON, Dixon RK (1994) Forest management options to conserve and sequester terrestrial carbon in the Russian Federation. World Resour. Rev. 6: 88-101.

[62] Winjum JK, Dixon RK, Schroeder PE (1992) Estimating the global potential of forest and agroforest management practices to sequester carbon. Water, Air and Soil Poll 64: 213-228.

[63] Udawatta RP, Jose S (2011) Carbon sequestration potential of agroforestry practices in temperate North America. In: Kumar BM, Nair PKR (eds.) Carbon sequestration potential of agroforestry Systems: opportunities and challenges. Springer, Dordrecht, pp. 17– 42

[64] Bhumbla DR, Khare A (1984) Estimate of wastelands in India. Society for Promotion of Wastelands Development (SPWD), New Delhi, India.

[65] Newaj R, Dar SA, Bhadur R (2008) Carbon sequestration in agrisilviculture as affected by canopy pruning of *Albiziaprocera* under irrigated ecosystem. In: Abstracts, National Symposium on Agroforestry Knowledge for Sustainability,Climate Moderation and Challenges ahead, 15-17 Dec, 2008, NRCAF, Jhansi, India, pp. 182

[66] Nath AJ and Das AK (2011) Carbon storage and sequestration in bamboo-based smallholder homegardens of Barak Valley, Assam. Current Science, 100:229-233.

[67] Saha R, Mishra VK (2009). Effect of organic residue management on soil hydro-physical characteristics and rice yield in eastern Himalayan region, India. J Sustain Agri 33 (2): 161-176

[68] Howlett DS, Mosquera-Losada MR, Nair PKR, Nair VD, Rigueiro-Rodrigues A (2011) Soil carbon storage in silvopastoral systems and a treeless pasture in northwestern Spain. J Environ Qual 40(3) 825-832

[69] Gama-Rodrigues EF, Nair PKR, Nair VD, Gama-Rodrigues AC, Baligar V, Machado RCR (2010) Carbon storage in

soil size fractions under two cacao agroforestry systems in Bahia, Brazil. Environ Manag 45: 274-283

[70] Fagerholm, Nora, Torralba M, Burgess PJ, Plieninger T (2016) A systematic map of ecosystem services assessments around European agroforestry. EcolIndicat 62: 47-65

[71] McAdam JH, Burgess PJ, Graves AR, Mosquera-Losada MR, Rigueiro Rodriguez A (2009) Classifications and functions of agroforestry systems in Europe. In: Rigueiro-Rodríguez A, McAdam JH, Mosquera-Losada MR (eds) Advances in agroforestry, vol 6, Agroforestry in Europe: current status and future prospects. Springer, New York, pp. 21-41. doi:10.1007/978-1-4020-8272-6_2

[72] Adhikari S, Baral H (2018) Governing Forest Ecosystem Services for Sustainable Environmental Governance: A Review. Environments. 5: 53. doi:10.3390/environments5050053

[73] Ranjith P, Udawatta RP, Clark J, Gantzer, Jose S (2017) Chapter 14 - Agroforestry Practices and Soil Ecosystem Services, Editor(s): Mahdi M. Al-Kaisi, Birl Lowery, Soil Health and Intensification of Agroecosytems, Academic Press, Pages 305-333, ISBN 9780128053171

[74] UMCA (2011) Annual Report: Agroforestry for Ecosystem Services, The Center for Agroforestry at the University of Missouri, pp. 36 Columbia, USA

[75] Sileshi G, Festus K. Akinnifesi , Oluyede C. Ajayi, Sebastian Chakeredza, Martin Kaonga, Matakala PW (2007) Contributions of agroforestry to ecosystem services in the miombo eco-region of eastern and southern Africa. Afri J Environ Sci Tec 1(4): 068 -080

[76] Brown D, Boyd DS, Brickell K, Ives CD, Natarajan N, Parsons L (2019) Modern slavery, environmental degradation and climate change: Fisheries, field, forests and factories. Environment and Planning E: Nature and Space: 2514848619887156

[77] Kumar BM, Nair PKR (2006) Tropical home gardens: a time-tested example of sustainable agroforestry. Springer, Dordrecht

[78] Palang H, Fry G (eds) (2003) Landscape interfaces: cultural heritage in changing landscapes. Kluwer, Dordrecht, pp. 420

[79] Khumalo S, Chirwa PW, Moyo BH, Syampungani S (2012) The status of agrobiodiversity management and conservation in major agroecosystems of Southern Africa. Agric. Ecosyst Environ 157: 17-23

[80] Balmford A, Bennun L, Ten Brink B, Cooper D, Côté IM, Crane P, Dobson A, Dudley N, Dutton I, Green RE, et al. (2005) The convention on biological diversity's 2010 target. Sci 307: 212-213

[81] Boshier DH, Gordon JE, Barrance AJ (2017) Prospects for Agro-Ecosystems: Mesoamerican Dry-Forest. Available online: http://forest-genetic-resources-training-guide.bioversityinternational.org/fileadmin/bioversityDocs/Training/FGR_TG/additional_materials/BoshierGordonBarrance2004.pdf (accessed on 22 September 2017)

[82] McNeely JA, Schroth G (2006) Agroforestry and biodiversity conservation-traditional practices, present dynamics, and lessons for the future. Biodivers Conserv 15: 549-554