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The role of Agroforestry system as strategy to adapt and mitigate climate change: A review with examples from Tropical and Temperate regions

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ABSTRACT
Agroforestry is an integrated approach to sustainable land use that is aimed to maximize production and productivity of the land. Its environmental benefit is now days highly recognized especially in adapting and mitigating the current global challenge, climate change through biological carbon (C) sequestration. This approach is highly beneficial in efficient utilization of resources such as nutrients, light, and water capture that will result in greater net C sequestration. C-sequestration potential of agroforestry systems are derived by combining information from both above and below ground carbon stock. However, in estimating C stock of biomass and the extent of soil C storage under varying conditions are very challenging due to the lack of reliable estimates of area under agroforestry. The extent of C sequestered in agroforestry system also varies depending on species composition, type of agroforestry, climate, soil and land management practices. It was estimated that globally the area currently under agroforestry is around 1,023 million ha.

Key words: Agroforestry, carbon-sequestration potential, SOC, climate change

1. INTRODUCTION

In humid tropical countries, Agro forestry systems are the most important farming activity in providing economic, social and environmental benefit to the local peoples (Haile et al. 2008). It is part of a continuum of landscapes ranging from primary forests and managed forests to row crops or grasslands. It is considered to be important opportunities for improving rural livelihoods by turning unproductive land into productive land that can produce food, wood and other tree products, and generate income for poor farmers in developing countries Albrecht and Kandji (2003). Agroforestry is also important in enhancing farmers' adaptive capacity in reducing the vulnerability of agricultural systems to climate change or climate variability (Boye and Albrecht, 2005). According to this study, integration of trees on farms in agricultural landscapes often results in diversified and sustainable crop production in addition to providing a wide range of environmental benefits such as erosion control and storing substantial amount of carbon on both above and below grounds in the form of soil organic carbon.

The role of agroforestry with regards to carbon sequestration is widely recognized throughout the world. Many studies have investigated that inclusion of trees in the agricultural landscapes is an opportunities to store carbon (Dixon, 2005). However, the amount of carbon sequestered largely depends on the type of agroforestry system, environmental, socio-economic factors, and tree species (Albrecht et al., 2003).

Many studies have indicated that, even if agroforestry systems are not primarily designed for carbon sequestration, it is a unique opportunity to increase carbon stocks in the terrestrial biosphere (Albrecht and Kandji, 2003; Palm et al. 2005). These studies also indicated that, agroforestry systems contain less carbon than primary or managed forests but they contain significantly higher carbon stocks than row crops or pastures. They suggested that the introduction and proper management of trees in crop lands and grasslands has a great potential for carbon sequestration, in addition to rehabilitating degraded land and improving the livelihood of the rural communities. Agro forestry has also a potential to store carbon belowground for a long period of time due to the fact that soil is relatively stable or undisturbed and there is large biomass turnover as compared with carbon under agricultural crop land (Palm et al. 2005). Currently, Soil-carbon-sequestration potential of agro forestry has got significant attention in climate change mitigation strategy (Haile et al. 2008). The contribution of agro forestry system in storing carbon and mitigating climate change is expected to increase for the next 40 years (IPCC, 2000). However, little information is available on soil carbon sequestration potential of agro forestry systems in both temperate and the tropical regions even though agroforestry is most commonly practiced in both regions (Bayla et al. 2006).

Objective

1. To provide information on the role of tropical and temperate agroforestry system to adapt and mitigate climate change
2. To offer an attractive economic opportunity for subsistence farmers in developing countries through selling the Carbon sequestered through agroforestry activities to industrialized countries.

2. METHODOLOGY

In addition to primary data from research work (my MSc thesis in UK), different internationally recognized published literatures and proceedings were reviewed to generate valuable information.

3. RESULT AND DISCUSSION

3.1. Carbon pool potential in tropics and temperate agroforestry

Agroforestry practices are commonly known in the tropical regions where agricultural practices are less intensive. However, in some the temperate regions, there are few agroforestry practices with the aim to biodiversity conservation, and for other socioeconomic benefits. Major Agroforestry practices in the tropical and the temperate regions are listed in (table 1).

In temperate region, agroforestry practices have been shown to store large amount of carbon (Kort and Turlock, 1999). Potential Carbon storage from agroforestry systems in temperate regions has been estimated to range from 15-198 t C ha^{-1} with a modal value of 34 t C ha^{-1} (Nair, 2003). He also projected that, 90.3 Mt C y^{-} of carbon can be sequestered through agro forestry practices in the United States alone by 2025. In the tropics, Palm et al. (2005) reported that, agroforestry systems helped to regain 45 percent of the original carbon stock of the cleared forest compared to only 12 percent by croplands and pastures. According to these study, the total carbon emission from global deforestation at the currently estimated rate of 17 million ha y^{-1} is 1.6 Pg. It was assumed that, one hectare of agroforestry could save 5 hectares from deforestation in the low latitude (tropical) regions so that a significant portion of carbon emission caused by deforestation could be reduced by establishing agro forestry systems. In principle, therefore, agroforestry is the most important land use system to carbon sequestration due to its high rate of carbon gain (0.2 to 3.1 t ha^{-1} yr^{-1}) as compared with other land use practices (IPCC, 2001).

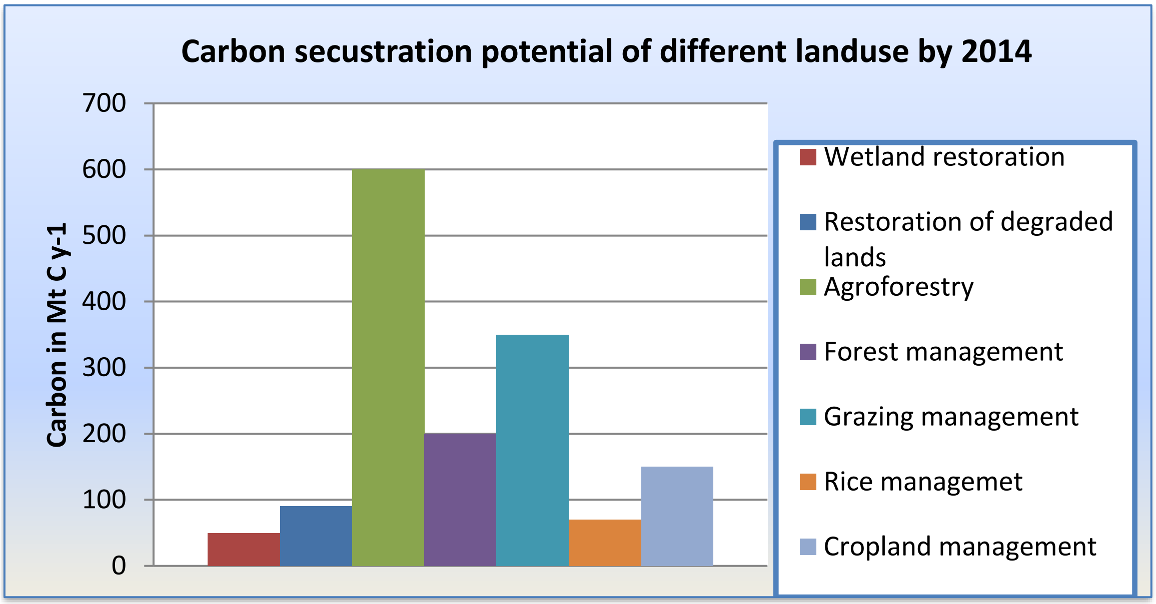

Figure 1

Carbon sequestration potential of different land use by 2040 (adopted from: IPCC, 2007)

Table 1

Major Agroforestry practices in the tropical and the temperate regions. (Source: Nair et al. 2008)

Agroforestry practices	Description
A. Tropical agroforestry practices	
Alley cropping	Fast growing preferably leguminous, woody species grown in crop fields that is periodically pruned at low height (<10m) to reduce the shading effect on crops. The prunings are applied as mulch as source of organic matter or as source for animal fodder
Homegardens	Multistories of various trees and crops in homestead
Improved fallow	Fast growing preferably leguminous, Woody species planted and left to grow during fallow phase between cropping years for site improvement; woody species my yield economic products
Multipurpose trees on farms and rangelands	Fruit trees or other multipurpose trees planted in systematic arrangements in crops or range lands for diversified benefits.
Silvopasture	Integrating trees in animal production system
Grazing system	Cattle grazing on pasture under widely spaced or scattered trees
Cut and carry system	Feeding animals with high quality fodder from tree or grass grown in protected areas
Shaded perennial-crop system	Growing shade tolerate species such as cacao and coffee under or in between overstory
Shelterbelts and wind breaks	Use of trees to protect fields from wind damage.
Taungya	Growing agricultural crops during the early stages of establishment of forestry plantations
B. Temperate agroforestry system	
Alley cropping	Trees planted in single or grouped rows in herbaceous (agricultural or horticultural) crops in the wide alleys between the tree rows
Forest farming	Utilizing forested trees for producing specially crops that are sold for medicinal, ornamental or culinary uses
Riparian buffer strips	Strips of perennial vegetation planted between croplands/pastures.
Silvopasture	Combining trees with forage and livestock production
Wind breaks	Row trees around farms and fields, planted and managed as part of crop to protect crops, animals and soil from wind hazards.

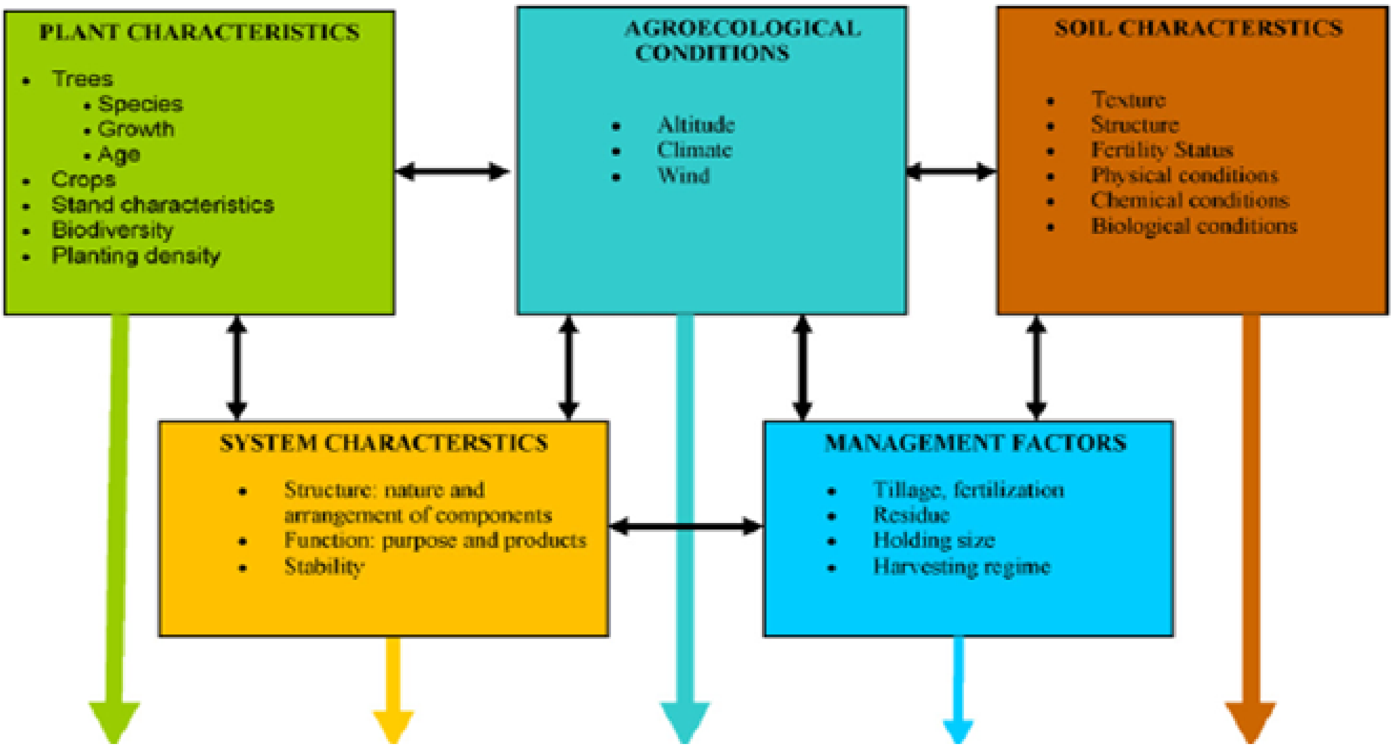

Figure 2: Factors affecting Soil organic carbon (SOC) pool and its dynamics

3.2. Comparison of Soil carbon pool between different agroforestry systems

Reviewing SOC content in agroforestry system in comparison with other land-use systems; Nair et al. (2008) tried to rank the land-use systems in terms of their SOC content in the order: forests > agroforestry> tree plantations > arable crops including grasslands. In addition, IPCC report in 2001 also predicted the Carbon sequestration potential of different land use and management options up to 2040's (Figure 1 and Table 2). According to the report; agroforestry was the promising land use system to sequester high carbon to mitigate the climate change as compared with other land use practices.

Table 2

Value on soil carbon stock under tropical agroforestry system (Adopted from Nair et.al 2009)

Agro ecological zone	Major Agroforestry system	Reported values of soil C stock (Mg ha^{-1})
Humid lowlands	Shaded perinial system	21-235
	Alley cropping	10-25
	Improved fallow	123-149
	Homegardens	108-119
	Tree intercropping	27-78
	Silvopasture	96-173
	Woodlots	61-75
Tropical highlands	Shaded perennial system	21-97
	Silvopastorial system	132-173
Arid and semi-arid lowlands	Fodder banks	33
	Live fences	24
	Grazing system	27-33

3.3. Carbon sequestration potential of agroforestry systems

3.3.1. Aboveground (vegetation) carbon sequestration potential of agroforestry systems

Due to the complex relationshipsbetween aboveground and belowground Carbon sequestration, it is usually difficult to consider one in isolation from the other. It was estimated that aboveground carbon storage potential of agroforestryis 45–50% of branch and 30% of foliage dry weight constituteC (Shepherd and Montagnini, 2001; Schroth et al., 2002); theseestimates are highly variable, ranging from 0.29 to15.21 Mg ha_1 yr_1. Since these estimates are directly relatedto the estimated production potential of the system, theydepend on a number of factors including site characteristics,land use types, species involved, stand age, and managementpractices (see fig. 2). Agroforestry systems in the arid, semiarid, anddegraded sites have a lower carbon storage potential than those in fertile humidsites; and the temperate agroforestry have relatively lower vegetationcarbon storage potential than the tropical ones (Nair et al. 2009); (see table 3).

3.3.2. Belowground (soil) carbon sequestration potential of agroforestry systems

Carbon is sequestered in soils directly and indirectly (Soil Science Society of America, SSSA, 2001). Direct soil carbonsequestration is by inorganic chemical reactions thatconvert CO_2 into soil inorganic carbon compounds such as calciumand magnesium carbonates. Indirect plant carbon sequestrationoccurs as plants photosynthesize atmospheric CO_2 into plantbiomass. Some of this plant biomass is indirectly sequesteredas SOC during decomposition processes (Fig 2). Itis estimated that historically soils account for about 58% of thegross emission of CO_2-C into the atmosphere from theterrestrial ecosystems (Lal and Bruce, 1999; Lal, 2008).The literature on soil carbon sequestration (SCS) potentialof agroforestry is scanty although rather plentiful reports are availableon the potential role of agricultural soils to sequester carbon.Reviewing the SCS in agroforestry in comparison with other land-usesystems, Nair et al. (2009) noted a general trend of increasingsoil organic carbon (SOC), an indicator of SCS, in agroforestry,and ranked the land-use systems in terms of their SOC contentin the order: forests >agroforests> tree plantations > arablecrops. They further noted that the estimated values of SCS in agroforestry varied greatly based on biophysical andsocioeconomic characteristics of the system (see table 4). The impact of any agroforestry system on soil C sequestrationdepends largely on the amount and quality of biomassinput provided by tree and non-tree components of thesystem, and on properties of the soils, such as soil structureand their aggregations (Schlesinger et al., 1990; Ojima et al., 1999).

Table 3

Mean vegetation (above and belowground) carbon sequestration potential of prominent agroforestry system

Agroforestry/land-use system	Age (year)	Mean vegetation carbon(Mg ha^{-1})	Source
Fodder bank in Mali	7.5	0.29	Takimoto et al. (2008)
Live fence in Mali	8	0.59	Takimoto et al. (2008)
Tree based inter cropping in Canada	13	0.83	Peichl et al. (2006)
Park land AF in Mali	35	1.09	Takimoto et.al (2008)
Agrisilviculture in India	5	1.26	Kumar et al. (2005)
Silvopasture in USA	11	2.11	Sharrow and Ismall (2004)
Shaded coffee in Togo	13	6.31	Dossa et al. (2008)
Agroforestry woodlots in India	9	6.50	Kumar et al. (2005)
Home garden AF in Indonesia	13	8.00	Roshetko et al. (2002)
Mixed species stand in Peru	4	15.21	Parrotta (2006)

Table 4

Summary of the estimates on the extent of agroforestry practices in the world and their carbon sequestration potentials

Region/practice	Estimated area(Million ha)	Potential for carbon sequestration in above and below ground (Pg C y^{-1})	Source	Remark
Africa and Asian agro-silvopastoral	585-1215	1.1-2.2	Dixon (2003)	Over 60 year's period an additional 630 Mil. Ha of

				crop and grassland that are currently fallowed could be converted in to agroforestry.
World all agroforestry system	400	0.26	Watson et al. (2009)	Estimate for 2010 carbon gain of 0.72 Mg C $ha^{-1}y^{-1}$
USA alley cropping, silvopasture, wind break and riparian buffers	235	0.1	Nair (2006)	Excludes the conservation buffer including the short rotation woody crops on which area estimates are not available
Asian home garden AF	8.0	0.064	Kumar (2006)	Home garden AF average age is 13 years
European silvoarable agroforestry	65.2	2.5	Reisner et al. (2007)	Silvoarble agroforestry accounts 40% of the European arable land

4. CONCLUSION

Agroforestry systems that integrate tree production with crop and animal production systems are believed to have a higher potential to sequester C than pastures or field crops. This conjecture is based on the notion that tree incorporation in croplands and pastures would result in greater net aboveground as well as belowground C sequestration. Although some estimates of so-called "C-sequestration potential" of agroforestry systems are available, these are mostly estimates of C stocks and, overall, the data are not rigorous. Methodological difficulties in estimating C stock of biomass and the extent of soil C storage under varying conditions and the lack of reliable estimates of area under agroforestry systems are serious limitations in exploiting this low-cost environmental benefit of agroforestry. Globally, C trading is rapidly expanding, and the CDM of the Kyoto Protocol offers attractive economic opportunity for subsistence farmers in developing countries, the major practitioners of agroforestry, for selling the C sequestered through agroforestry activities to industrialized countries. It will be an environmental benefit to the global community at large as well. The political environment should give attention for enhancing smallholder involvement in GHG-mitigation projects. The success in the implementation of such projects will also depend on the farmers' awareness and willingness to participate in the project.

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