



## Role of agroforestry in climate change mitigation and adaptation through carbon sequestration: A review

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### ABSTRACT

The rising demand on the world's natural resources brought on by economic and demographic pressure has resulted in an unsustainable usage of resources and environmental instability. This shifting character of the world climate has generated lot of environmental difficulties. This harmful impact on the global ecosystem necessitates urgent attention. The management of carbon is a serious issue that faces the globe today. Concerning this issue, a number of summits have been organised. The current level of carbon in the atmosphere is about 416 ppm. It is estimated that if the carbon increases in the atmosphere at the present rate and no constructive efforts are pursued to lessen the same, the level of carbon in the atmosphere would go upto 800-1000 ppm by the end of year 2100 which may create havoc for all living creatures on earth. In the overall strategy and planning for the country's balanced development, the issues relating to environmental management have received the necessary attention. The conservation and improvement of the environment, as well as the preservation of forests and wildlife, are mandated by Article 48 A of the Constitution under Part IV-Directive Principles of State Policy. Through carbon absorption, agroforestry is crucial in lowering greenhouse gas emissions relative to atmospheric CO<sub>2</sub>. Following its inclusion in the Kyoto Protocol as a method for reducing greenhouse gas emissions, agroforestry has gained attention for its potential to sequester carbon. Because it enhances microclimate, guards against soil erosion, boosts soil fertility, lowers carbon emissions, and increases carbon absorption, agroforestry can play a noteworthy part in the adaptation to climate change. Hence Agroforestry systems are highly recommended as solution to environmental problem and to promote the mitigation and adaptation synergy in addressing climate change.

**Keywords:** Agroforestry, carbon sequestration, climate change, environment, role, sustainability.

It is common knowledge that the world is experiencing a climate emergency due to climate change. Due to increased exposure to climatic dangers, preexisting vulnerabilities, and reduced adaptation ability, climate change consequences have been more catastrophic and harmful in some locations (Ripple *et al.*, 2020). Current global issues include reducing climate change, ensuring food security, protecting biodiversity, restoring ecosystems, and localising sustainable development goals (Feliciano *et al.*, 2018). It is becoming more urgent to acknowledge and encourage initiatives for climate adaptation and mitigation as natural disasters and climatic instability increase. The capability to increase overall resilience to climate vulnerability has been highlighted as being mostly dependent on adaptation activities to improve land and water management related practises (Turrall *et al.*, 2011).

Under the current climate change scenario, adaptation becomes the most important requirement, especially in poor and undeveloped countries, which are exposed to the adverse repercussions of climate extremes. Growing tree crops alongside annual crops can be seen as a combination of innovative techniques designed to increase productivity while reducing the effects of climate change and, at the same time,

buffering the capacity of the systems from the damaging effects of excessive temperature (Verchot *et al.*, 2007). In light of climate change, it is essential and appropriate to have the correct knowledge about the status of regional agroforestry, creating opportunities for further promotion to fulfil climate promises, and ensuring successful acceptance of agroforestry practices are all crucial and appurtenant in light of climate change (Dhakal and Rai, 2020).

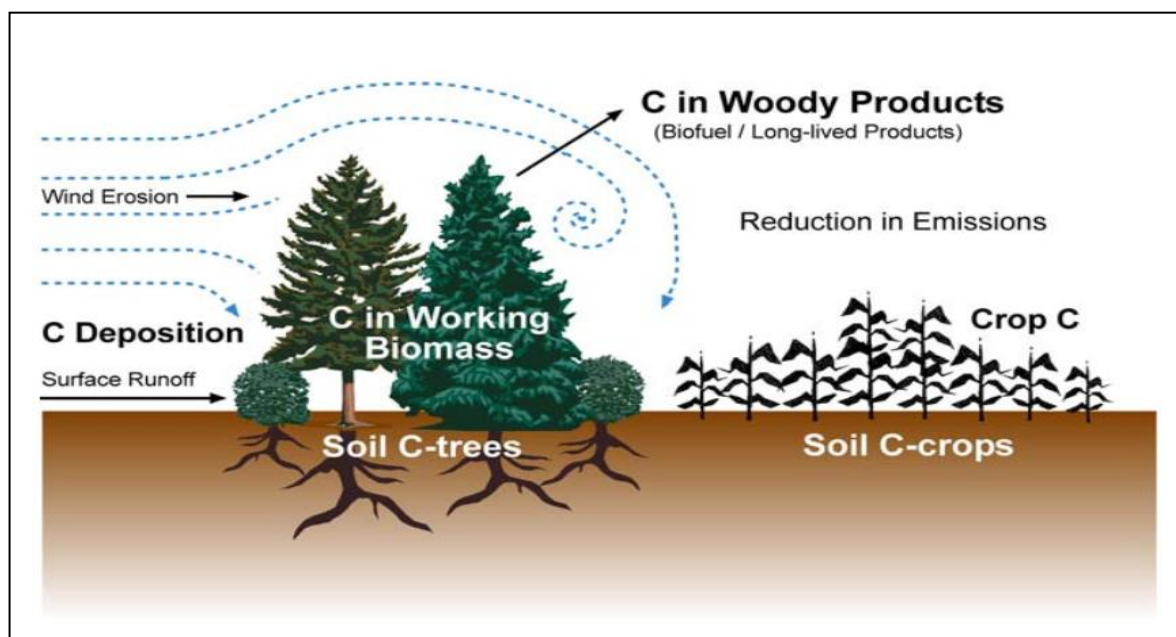
Agroforestry is a traditional land use system that helps to solve many current and future environmental problems. Trees on arable land have the potential to act as carbon sinks, aiding in climate change adaptation and mitigation by sequestering carbon. It is an integrated approach to solving land-use problems by allowing farmers to produce food, fibre, fodder, and fuel from the same unit of land at the same time. It also serves as a response option for climate change adaptation and mitigation, in addition to addressing many of the challenges that farmers face. Agroforestry can provide numerous benefits, including aiding in climate change mitigation and assisting farmers in adapting to extreme and variable weather (IPCC, 2019). Agroforestry contributes to ecosystem services such as water and sediment flow regulation, carbon and nutrient cycling in soils, and also provides biodiversity habitat. This increases soil fertility, reduces soil erosion, and controls pests and floods. Farmers benefit from agroforestry by increasing farm productivity and reducing external inputs such as conventional fertilizers and pest management chemicals, resulting in increased income.

**Table 1: Global agroforestry cover overview**

% of Tree Cover Present in the Agricultural Lands	Global Agricultural Land with Trees (in km <sup>2</sup> )	% of All Agricultural Land with Trees
>10	10,120,000	46
>20	5,960,000	27
>50	1,670,000	7.5

(Zomer *et al.*, 2016)

The most frequent greenhouse gas produced is carbon dioxide, and agroforestry has a significant impact on lowering greenhouse gas emissions relative to atmospheric CO<sub>2</sub> through carbon sequestration. The process known as carbon sequestration involves the long-term storage of atmospheric CO<sub>2</sub> as well as carbon capture (Newaj *et al.*, 2012). In order to slow down global climate change, this strategy can minimise the amount of carbon dioxide in the atmosphere. Agroforestry can significantly contribute to climate change adaptation because it enhances microclimate, guards against soil erosion, boosts soil fertility, lowers carbon emissions, and increases carbon sequestration.



**Fig. 1: Carbon capture by trees (Newaj *et al.*, 2012)**

**Table II: Extent of agroforestry systems in different parts of Asia**

Regions of the world	Agricultural area with trees (in Million km <sup>2</sup> )	% of all agricultural area with trees
South-East Asia	1.34	82
Northern and Central Asia	0.65	27
East Asia	0.41	23
South Asia	0.38	21
Western Asia and North Africa	0.1	9
<b>Total (Global)</b>	<b>10.12</b>	<b>46</b>

(Zomer *et al.*, 2009)

**Climate change mitigation, adaptation, and carbon sequestration through agroforestry:** Changes in temperature and land pressure are the two factors that have a negative impact on farming systems in developing nations and both contribute to food shortages. Despite the general success of the advanced agricultural methods, the yield decline brought on by soil deterioration exacerbates the food shortage. At the local level, the unfavorable effects of agricultural output and intensification on the biodiversity and soil system have an impact on the climate, food security, and on-farm income (Kirby and Potvin 2007). Incorporation of trees in land-use system ascertained to achieve dual purpose viz, intensification of cultivation in a sustainable manner and diversification to enhance crop management (Garnett *et al.*, 2016). In most parts of Africa, food and agriculture organization (FAO, 2016) reported that plantation of trees along with forest protection can be effective measure to mitigate climate effect in the world.

**Table III: Carbon sequestration potential of different agroforestry systems**

Agroforestry systems	Carbon accumulation
Taungya Agroforestry system	174 MgC ha <sup>-1</sup>
Mixed multistorey system	162 MgC ha <sup>-1</sup>
Falcata- coffee multistorey system	92 MgC ha <sup>-1</sup>

(Yirefu Tefera *et al.*, 2019)

Deforestation and forest degradation result in higher carbon emissions, although these emissions can be controlled by managing land and forests sustainably. One of the key methods for lowering atmospheric greenhouse gas concentrations is the enhancement of carbon stocks through agroforestry. By using physical or biological processes, carbon can be removed from the atmosphere and stored in carbon sinks. Comparing agroforestry systems to monocultures, the incorporation of trees or shrubs can enhance the amount of carbon sequestered (Kirby and Potvin 2007). According to Griscom *et al.*, 2017 carbon sequestration primarily involves the uptake of atmospheric CO<sub>2</sub> during photosynthesis and the transfer of fixed carbon into vegetation, detritus, and soil pools for “secure” (i.e. long-term) storage. The largest and most permanent form of carbon may be sequestered by increasing rotation age of trees and/or shrubs and by manufacturing durable products from them for enhancing carbon sinks (Murthy *et al.*, 2013). Table IV shows that there is a clear evidence of carbon sequestration differences in various land use systems.

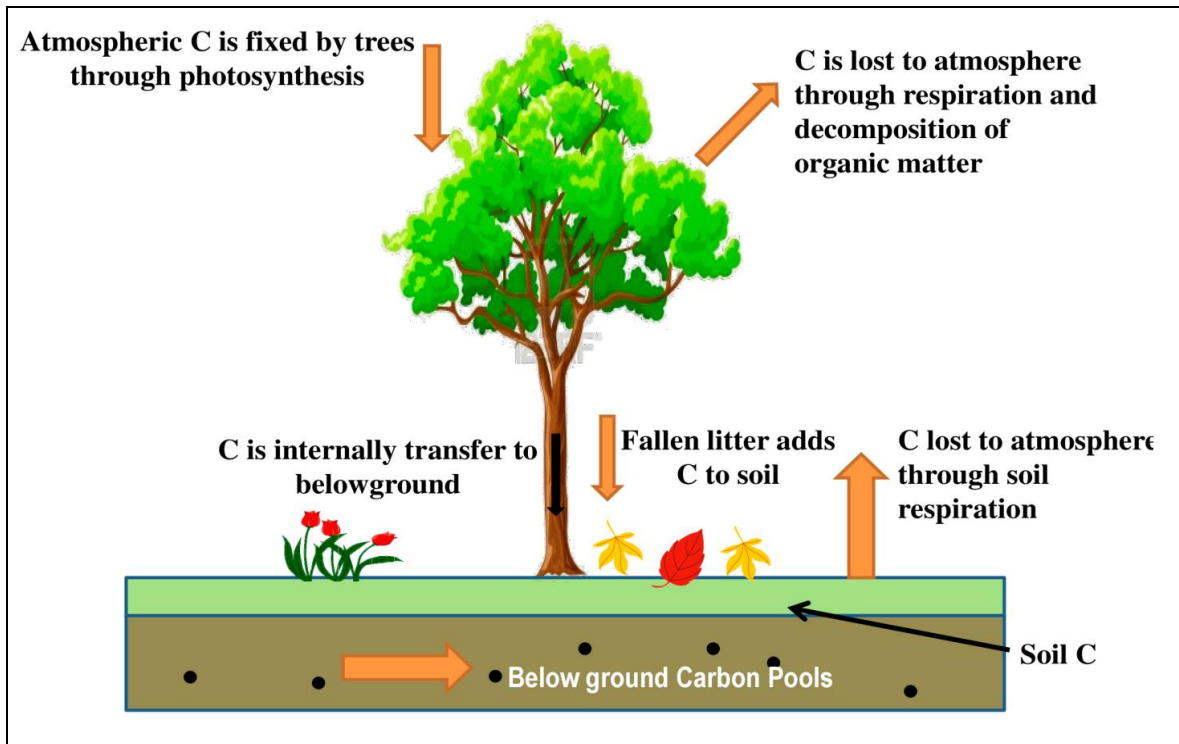
**Table IV: Carbon sequestration differences in different land use systems**

Carbon sequestration potential of different land use system	Potential carbon sequestration by 2040 (Mt C yr <sup>-1</sup> )
Agroforestry	500-600
Grazing management	300-400
Forest management	150-200
Crop land management	70-120

(Yohannes and Tamene 2016)

Environmental and socioeconomic factors influence the effectiveness of agroforestry systems in storing carbon. For example, in the humid tropics, agroforestry systems sequester more than 70 Mg/ha in the top 20 cm of 427 soil C stock data pairs grouped into four main agroforestry systems—alley cropping, windbreaks, silvopastures, and home gardens—and evaluated changes in agroforestry and adjacent control cropland or pasture. Soil carbon stocks in AF (1m depth) were 126 Mg C ha<sup>-1</sup>, which is 19% higher than in cropland or pasture. Soil carbon stocks in Agroforestry systems were lower than aboveground carbon stocks, with the exception of alley cropping soil carbon stocks. Home gardens stored the most carbon, both above and below ground, particularly in the subsoil (20-100cm). Agroforestry could store  $5.3 \times 10^9$  Mg additional carbon in soil on 944 Mha globally, with most in tropics and subtropics (Peichl., 2006).

Agroforestry is a greenhouse gas mitigation mechanism that sequesters carbon (C) in both aboveground (stem, branch, and foliage) and belowground biomass (roots and soil) and can be sold as a carbon credit. Particularly for climate change adaptation and mitigation, the large volume of aboveground biomass and deep root systems of trees in agroforestry systems have received increased attention (Palm *et al.*, 2004). The total amount sequestered in each compartment varies greatly depending on a number of factors such as ecoregion, system type, site quality, and previous land use Fig. 1. Aboveground parts and soil, on average, are estimated to hold roughly one-third and two-thirds of the total carbon stored in tree-based land use systems, respectively (Haile *et al.*, 2008).



**Fig. 2.** The process of carbon sequestration through trees, ( Haile *et al.*2008)

The input of dead organic matter from plants, soil characteristics including structures and aggregations, and climate all affect how much carbon is scooped up by the soil. There is evidence that carbon storage in deep soil layers is greater than that in treeless pastures, irrespective of the fact, agroforestry systems are a favoured approach for aboveground biomass carbon sequestration (Mbow *et al.*, 2014). In some of the largest agroforestry systems in the world, the aboveground carbon sequestration ranges from 0.29 to 15.21 Mg ha<sup>-1</sup> yr<sup>-1</sup> and 30-300 Mg ha<sup>-1</sup> yr<sup>-1</sup> up to 1 m depth in soil.

The existence, distribution, and adoption of various agroforestry models are dependent on the viability and restrictions of agroforestry systems, which are detailed in Table V (de Souza *et al.*, 2012). These agroforestry practices have potential positive implications for temperature change mitigation (Albrecht and Kandji, 2003) and play a key role in overall climate change mitigation (Raj *et al.*, 2020). The practice of integrating land-use systems, like agro-silvopastoral systems, plays a vital role in combining high carbon stocks and high sequestration potential of carbon. Furthermore, agroforestry systems can significantly reduce the high energy demand caused by overexploitation of natural forests. Tree component in Agroforestry will even be seen as CO<sub>2</sub> neutrals, since they need CO<sub>2</sub> from the beginning of their life cycle and till the time of harvesting, the identical amount is released often felling. Wood products from forests still act as significant

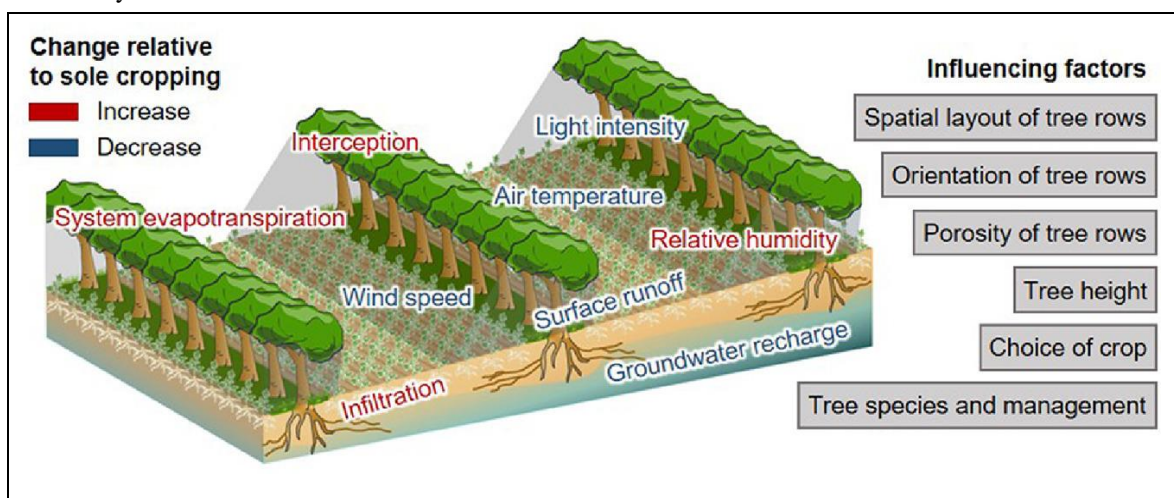
carbon stores in society and extend the carbon sink until the day the merchandise decays or is burned (Wang *et al.*, 2015). This also means that increased use of wood will help to lessen the discharge of CO<sub>2</sub> at felling. The IPCC Report (Watson *et al.*, 2000) estimates the area currently under agroforestry worldwide as 400 million hectares with an estimated carbon gain of 0.72 Mg C ha<sup>-1</sup> yr<sup>-1</sup> with potential for sequestering 45 Tg C yr<sup>-1</sup> by 2040 (1 Tg = 1012 g or 1 million tons). Recent studies under various Agroforestry systems in diverse ecological conditions (Nair *et al.*, 2010) revealed that tree-based agricultural systems, compared to treeless systems, stored more carbon in deeper layers of soil near the tree than away from it and higher soil organic carbon content was associated with higher species richness and high density of trees.

**Table V: Feasibilities and Limitations of Some Agroforestry Practices**

Objectives	Feasibility	Limitations
Increased soil fertility and availability of water	Using nitrogen fixing trees, conservation agriculture	Tree crop interactions and competitions for nutrients.
Low input of chemical fertilizer	Conserving agriculture practices including woody perennial tree species, incorporating valuable shade trees for minimizing evaporation losses, long fallows, windbreaks, and erosion control.	Tree density and selection of suitable species in different agroclimatic zones.
Timber and fuelwood productions, several NTFPs including quality fruit production and maintenance of ecosystem health	The practices of thinning and coppicing in woodlots and fruit orchards for high market value (e.g., shea butter), incorporating shade trees (e.g., in Cocoa farms), promotion of agrobiodiversity, forest corridor	Long term viability, land tenure, tree age and productivity in parklands, space competition between cash crops and food crops
Animal husbandry	Management practices for fodder trees and natural grassland, etc.	Pressure on desirable fodder trees, land availability for animals, etc.

Source: de Souza *et al.* (2012).

**Agroforestry systems play a critical role in moderating the microclimate:** Locally, agroforestry systems with the suitable shade offer promising option to moderate heat stress. By altering the radiation flux, air temperature, wind speed, and saturation deficit of understorey crops, trees on farms can improve microclimates, which will have a positive impact on the rate and duration of photosynthesis and consequent plant development, transpiration, and soil water usage (Monteith *et al.*, 1991). Examples include using shade trees to shield heat-sensitive plants like coffee, cacao, ginger, and cardamom from high temperatures, wind breaks and shelter belts to reduce wind speed and prevent crops from being physically damaged, mulches to cool the soil, and various crop tree mixes to minimise erosion and maximize efficiency of resource use sustainably.



**Fig. 3: Modification of the microclimate and water balance through the integration of trees into cropping systems**

**The potential for agroforestry systems to reduce carbon emissions and store carbon:** The greatest impact of agroforestry on climate change is its ability to capture carbon from the atmosphere and reduce CO<sub>2</sub> emissions. In agricultural fields, the tree component of agroforestry systems can serve as a carbon sink. The three main ways to reduce atmospheric carbon are: sequestration through improved fallows and integration with trees; conservation of existing carbon pools through practises like avoiding deforestation and alternatives to slash and burn; and biofuel and bioenergy plantations to replace the use of fossil fuels (Montagnini and Nair, 2004). It is estimated that an increase of 1 ton of soil carbon of degraded cropland soils may increase crop yield by 20 to 40 kg ha<sup>-1</sup> for *Triticum aestivum*, 10 to 20 kg ha<sup>-1</sup> for *Zea mays* and 0.5 to 1 kg ha<sup>-1</sup> for *Vigna unguiculata*.

Rural landscape Agroforestry systems contribute to environmental sustainability and aids in climate change adaptation by storing carbon, cessation of land degradation, and fixing nitrogen, conserve Biodiversity. Agroforestry impinges on biodiversity by reducing exploitation of protected areas, increasing biodiversity in a human-dominated or working landscape, and increasing the species and within-species diversity of trees in farming systems (Garrity., 2004).

Thus, due to its ecological, economic, and social benefits, agroforestry is currently drawing more attention as a sustainable land-management choice throughout the world. As a result, the body of knowledge on agroforestry is growing at an accelerating rate, as seen by the rise in the quantity and calibre of scholarly publications on a variety of agroforestry-related topics. So, the severity of climate change impact will be reduced by climate change adaptation and mitigation. If we manage agroforestry properly, it can survive globally among other options for reducing climate change. Tree crops will accumulate carbon through roots, litter, and above-ground biomass, whereas annual crops will only do so through roots and the preservation of crop residue (Nair, 2009; Singh and Pandey, 2011; Jose, 2009). Agroforestry is all about using trees on farms and in landscapes for the benefit of rural communities and other land users (Dawson *et al.*, 2012).

**Carbon sequestration in Agroforestry through block and boundary plantations:** The carbon stock in the soil and above ground in the block and boundary plantation in the agroforestry systems may influence the soil fertility and build up carbon. These are several studies in India and abroad in carbon sequestration in tree biomass. Kumar,(2010) reported that the 9-year old block and boundary plantations for four different agroforestry systems (Populus deltoides block plantation + wheat, Eucalyptus hybrid boundary plantation + wheat, Populus deltoides boundary plantation + wheat and Populus deltoides block plantation + lemon grass), and it was found that total carbon sequestration in trees was 70.59, 21.38, 116.29 and 18.53 t ha<sup>-1</sup> in system Populus deltoides + wheat followed by 68.53, 20.63, 113.03 and 17.60 t ha<sup>-1</sup> in system Populus deltoides + Lemon grass, respectively.

**Adaptation-mitigation in agroforestry:** Particularly in the agriculture, forestry and other land use sector. In reality, there is no dissociation between crop production and other ecosystem services from land use. Agroforestry in general may increase farm profitability through improvement and diversification of output per unit area of tree/crop/livestock, through protection against damaging effects of wind or water flow, and through new products added to the financial diversity and flexibility of the farming enterprise. It can also substantially contribute to climate change mitigation (Louis *et al.*, Combining adaptation with mitigation has been recognized as a necessity in developing countries, 2017)

**Table VI: Examples of positive or negative implications of agroforestry practices for adaptation or mitigation to climate change**

Positive	Negative
Soil carbon sequestration, improved water holding capacities, use of manure, mixed Agroforestry for commercial products, income diversification with trees reduced nitrogen fertilizer, fire management	Dependence of 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
Integral protection of forest reserves, limited rights to Agroforestry trees, forest plantation excluding harvest	Use of forest fires pastoral and land management, tree exclusion in farming lands

The use of multipurpose trees and integrated approaches can enhance the profitability of agroforestry for example, trees can be sources of fodder, which in turn is converted into valuable plant nutrients. Trees on

farms can provide wild edible fruits and non-timber products that serve as alternative food during periods of deficit and primary sources of income for many rural communities. Hence, a growing scientific challenge relates to the methods and tools to assess useful trees in various human-ecological contexts. In most cases, benefits of agroforestry add up to a substantial improvement of the economic and resource sustainability of agriculture, while contributing to GHG sequestration.

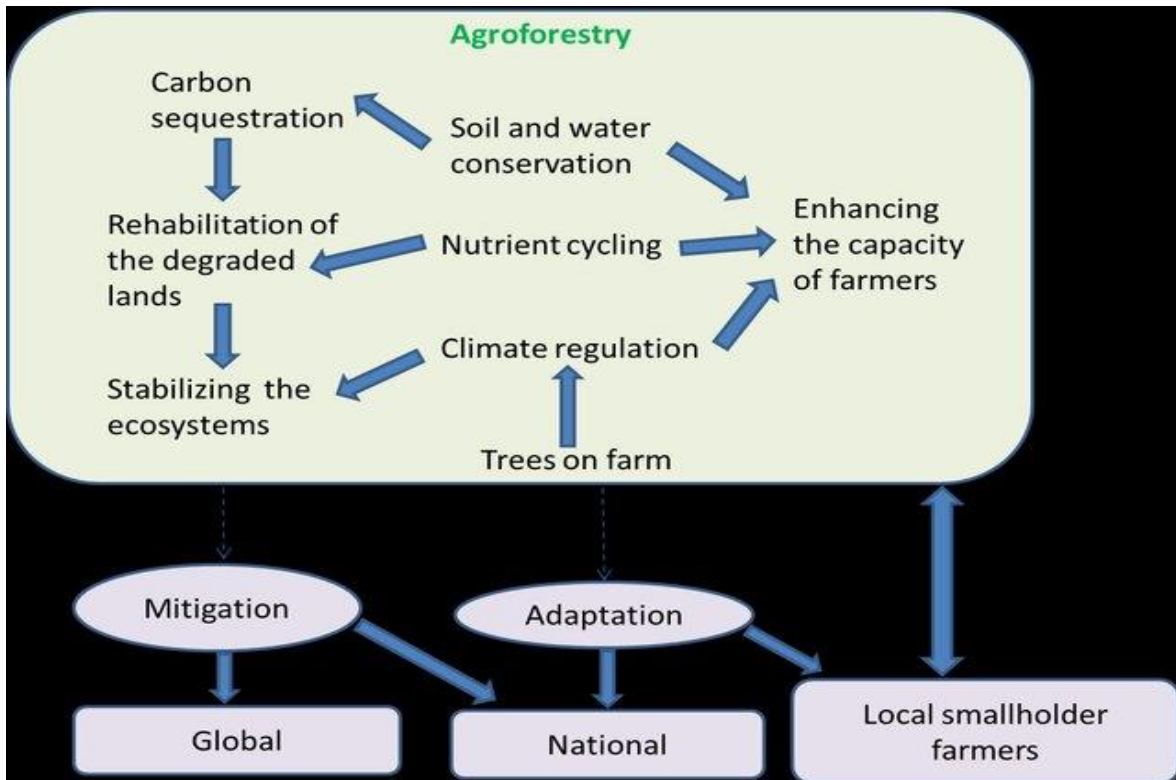


Fig. 4: Profitability of Agroforestry systems (Louis *et al.* 2017)

Agroforestry may nevertheless involve practices that raise GHG emissions, such as shifting cultivation, pasture maintenance by burning, nitrogen fertilization and animal production. In order to optimize agroforestry for adaptation and mitigation to climate change, there is a need for more integrated management to increase benefits and reduce negative impacts on climate (VI).

#### CONCLUSION

Agroforestry practices can reduce greenhouse gas emissions significantly by increasing carbon storage in biomass both above and below ground, as well as in soil organic carbon. Home gardens, boundary planting, fruit orchards, riverine, hedgerows, woodlots, and firewood lots are significant agroforestry activities that store CO<sub>2</sub>. Agroforestry systems have the capacity to mitigate and confront climate change and its effects on our natural environment, our societies, and our food production systems. Agroforestry systems store more carbon than pastures and fields and offer viable and sustainable solutions on current environmental issues. Agroforestry systems can assist increase carbon sequestration and compensate for continuous biodiversity loss. By developing agroforestry systems, a large proportion of carbon emissions brought on by human activity could be reduced to a greater extent.

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