Agro-forestry – a crop diversification strategy for adaption and mitigation ofclimate change

Authors contribution

This work was carried out in collaboration with all the authors. Conceptualization and literature search, ATG, SKS, SHD,VGV and writing-reviewing and editing, ATG,SKS, SHD, KGY and NCN. All authors have read and agreed to the published version of the manuscript.

Abstract:

The biggest challenge the world is currently experiencing is the impact of climate change on agriculture. Developing nations like India will be particularly affected because of their growing populations, water shortages, declining soil fertility, and loss of biodiversity. Agroforestry system is a major component in sustainable agricultural production under climate change situation as inclusion of agroforestry system ensures the production of food, fuel, fodder, timber, manures and fibre even under adverse climatic situations.The issue of ecologically sound and commercially viable strategies for adaptation and mitigation of climate change is being addressed by agroforestry, which is intensive, integrated, intentional, and interactive. This is done through carbon sequestration, biodiversity conservation, microclimate improvement, and a decrease in greenhouse gas emissions.Modern, effective agroforestry techniques enable farm activity diversification and improved stewardship of the environment. There are three ways that agroforestry helps to mitigate climate change. Sequestering carbon in biomass and soils, lowering greenhouse gas emissions, and reducing energy consumption on farms to minimize emissions are all ways to reduce emissions. This review highlights successful adoption of agroforestry as an crop diversification option for mitigating climate change effects.

Key words: Agroforestry, Climate change, Farm productivity, Environment, Mitigation, GHG, Carbon sequestration, Livelihood, Carbon sink

Introduction

The climate change is the rule of nature. Climate change is a continuous process. Changing climate has made life possible on earth. The planet's current climatic circumstances are favourable for life to exist, but due to a rapid change in the atmosphere's chemical composition brought on by humans' growing avarice, unfavourable changes in temperature have been observed. The most imminent climate change in recent times is the increase in the atmospheric temperature due to rise in levels of greenhouse gases which have severe ill effects on Agriculture, eventually hurting farmer's security of supply and means of subsistence and others. In developing countries, climate change will not only cause yield decline in crops but also has an influence on the crop growing period, crop growth, soil erosion, fertility and pest incidence. The distribution of agro-ecological zones will change due to changes in temperature and precipitation, and drought stress in semiarid tropical and subtropical regions will increase.Agriculture experiences losses as a result of an increase in the frequency of extreme occurrences like floods and droughts.

The agricultural systems most at risk from climate change are those impacted by unsustainable land management and resource degradation. Agricultural operations reduce carbon stocks primarily as a result of the removal of above-ground biomass during harvest, which is then burned and decomposed, as well as the loss of soil carbon as CO_2 and soil carbon due to erosion. Tropical deforestation accounts for up to 25% of global net yearly CO_2 emissions.(Schlamadinger and Bernhard,2005). Concentration of current CO_2 in the atmosphere is 388 ppm and is expected to rise to 470–570 ppm by 2050 (IPCC Climate,2007). Trees play significant roles in lowering vulnerability, boosting farming systems resilience and protecting households from threats related to the climate (Meragiaw and Misganaw, 2017). Forestry has assumed a prominent position as one of the solutions to reduce CO_2which is the drive for climate change on a global scale. On the other hand, by implementing measures for adaptation and mitigation, agriculture and plantations could potentially be a solution for combating climate change (Meragiaw and Misganaw, 2017). This is made possible by well managed agroforestry techniques (Nair and Ramachandran, 1993). In developing nations where trees on farmland play a crucial role in the systems of farming, agroforestry is a strategy to sustainable land usage that integrates agriculture and forestry (Jose and Shibu,2009). Allowing farmers to simultaneously produce food, fiber, fodder, and fuel from the same land, it is an integrated strategy to resolve land-use issues. In an agroforestry system, there are interactions between the various parts on an ecological and financial level. (Bishaw*et al*., 2003). Agroforestry can improve farmers' livelihoods and the environment by reducing climate change and assisting them in coping with intense and unpredictable weather (IPCC, 2019). It also reduces soil degradation, maintains soil fertility, diversifies sources of income, improves soil nutrient use, sequesters carbon, improves water quality, safeguards soil, and preserves biodiversity. (Tamale *et al*., 1995).The capacity of some agroforestry techniques increased awareness of their net carbon sequestration effect by capturing atmospheric CO_2 and storing it in plant biomass and soil. (Nair,2012).Agroforestry helps to stabilize the weather and climate of the regions which affects the growth of the crops and also hampers the life of the species by regulating various climate and weather patterns across the region. By this background this review paper study call attention on agroforestry systems adoption as an best option for mitigating climate change.

The following are the agroforestry systems which can be practiced as adaption and mitigation strategy for climate change in different parts of country.

- Agroforestry (trees and crops)
- Boundary plantation (trees and crops along the boundary)
- Block plantations (blocks of crops and trees)
- Energy plantations (early years of crops and trees)
- Alley cropping (crops and hedges)
- Agri-horticulture (crops and fruit trees)
- Agri-silvi-horticulture (fruit trees, crops, and trees)
- Agri-silvipasture (trees + crops + pasture or livestock)
- Silvi-olericulture (vegetables and trees)
- Horti-pasture (fruit trees and grazing land or livestock)
- Horticulture (fruit and vegetable trees)
- Silvi-pasture (trees plus pasture + creatures)
- Forage forestry (pastures and forage trees)
- Shelterbelts made of trees and crops
- Windbreaks made of trees and crops
- Live fence (bushes and tree roots on the boundary)
- Silviculture, also known as horti-sericulture (culture of trees or fruit trees)
- Aqua-forestry (trees + fish)
- Horti-apiculture (fruit trees + honeybees)
- Homestead (a variety of tree, fruit, and vegetable combinations)

Agroforestry for Adaptation and Mitigation

One of the key determining elements affecting the future food security of humanity on earth will be the impact of climate change on agriculture. The agricultural industry as a whole faces issues in understanding how the weather changes over time and modifying management strategies to produce better harvests. Given the geographical variety in rainfall, temperature, crops and cropping methods, soils, and management techniques, it is unclear how sensitive agriculture is to climate change. Crop losses could rise if the expected climate change results in a rise in climate variability. Agriculture will have an impact on livelihood due to low technological levels, a broad variety of pests, illnesses, and weeds, land degradation, unequal land distribution, and rapid population growth. The ability of agroforestry to adapt to and lessen climate change is enormous. Agroforestry adaptation and mitigation measures are frequently discussed in relation to global warming. Agroforestry offers a singular chance to balance the goals of climate change adaptation and reduction.Schoreneberger*et al.*,2012 Table 1 lists the adaptation and mitigation actions in further detail.

Table 1.Climate change adaptation and mitigation through agroforestry

Affected by climate change	**Functions of Climate Change**	**Agroforestry's function**
Mitigation		
Activities that lower atmospheric GHG levels or improve the storage of GHGs in ecosystems	carbon sequestering Build up C in soil and woody biomass	carbon sequestering Build up C in soil and woody biomass
	lowering GHG emissions	**Reduce use of fossil fuels.:** ● Reduce the number of equipment runs in treed areas. ● Reduce the heating and cooling of the farmstead. ● Lower CO_2 emissions by using a C sink. **Reduce N_2O emissions:** ● By increasing nitrogen uptake through plants ● Decreasing the need for N fertilizer in tree systems. ● Improve fodder quality to cut down on CH_4.
Adaptation		
Taking steps to mitigate or reverse the harmful effects of climate change or to benefit from its beneficial effects	Streamline threats and strengthen resistance	Improvement of microclimate to lessen the effects of harsh weather on crops cattle stress by maintaining the quality and quantity of feed. Increase the variety of habitats available for supporting organisms (e.g. native pollinators & useful insects). To preserve and safeguard natural resources, more structural and functional diversity is required. To lower risk in an environment that is changing, create diverse production opportunities.

	Permit species to adapt to better environments.	Create migration routes for animals through habitat.

A change in ecological, social, or economic systems in response to existing or anticipated climatic stimuli and their effects or impacts is referred to as adaptation in the IPCC's lexicon. Systems, procedures, and structures must be altered in order to prevent potential harm or seize possibilities brought on by climate change. As the science of adaptation matures, it is important to consider how agroforestry reduces the sensitivity of agricultural systems (and the rural communities that depend on them for their livelihood) to climate change or climate variability. (UNFCCC, 2013).

The agroforestry adaptive measures are:-

- Improved microclimate due to increased moisture and decreased temperature;
- Decreased evapotranspiration from crops and the land surface due to the effect of shade
- Low pest and disease incidence due to high biodiversity
- Protecting agricultural crops from water shortages

As a result, woody perennials, which have a significant ability to tolerate adverse climatic impacts and make the overall system sustainable through their coping mechanism, make up the majority of agroforestry.

In order to "copy" a natural forest on farmland, agroforestry is an ecologically dynamic, sophisticated, and sustainable system that offers a number of additional benefits for the economics and ecology. By lowering temperature, evapotranspiration, moisture reduction, functioning as a filter, and acting as a buffer against direct sunlight, tree systems can improve microclimatic conditions in such circumstances. Microclimatic improvement is one of the essential roles that trees play in agroforestry systems to provide sustainability. In order to adapt agriculture to climate change, agroforestry systems have been proven to increase on-farm production resilience to climatic variability by shielding crops from the effects of temperature and precipitation variation as well as from the strong winds associated with storms (Lin, 2011).

From a meteorological standpoint, agroforestry systems offer two crucial facts: the mechanical concept and the shade tree concept (radiation). In line with the first hypothesis, shadow creates microclimates with more erratic seasonal mean values for solar radiation and ambient temperature. The shade tree lowers the need for evaporative cooling due to crop and soil transpiration. By implementing agroforestry practices in agriculture, it is possible to reduce crop loss and the drudgery of small farmers by addressing issues of climate change adaptation. Maintaining windbreaks and shelterbelts lowers wind speed, raises moisture, lowers temperature, and offers protection from direct sunlight. As a result, it is regarded as one of the best climate change adaptation techniques. Based on the idea that increasing shelter from wind reduces evaporation, windbreaks are thought to reduce evaporative water losses from surfaces downwind and so save soil moisture.These help farmers to protect their crops from extreme climatic events by altering the field's weather.

Agroforestry is a system with a sophisticated and integrated approach that allows for the coexistence of trees, crops, pastures, and animals while also offering a haven for wildlife, birds, insects, and other soil-dwelling organisms. The most effective methods for preserving agro-biodiversity are traditionalagroforestry systems. By giving shelter and habitat to a diverse range of flora and wildlife, trees further increase diversity. Additionally, it aids in preserving the genetic diversity of trees and wild cultivars that are in need of urgent protection.

Strategies for Mitigation

According to the IPCC's terminology, mitigation refers to technical advancement and replacement that lower input and emissions per unit of life. Mitigation is nothing more than a corrective action to address a bad effect that has only partially materialized, such as an increase in carbon dioxide concentration. Mitigation consists only of limiting GHG emissions and enabling sinks through the carbon sequestration process. In plain English, adaptation can be done locally, whereas mitigation must be done internationally. A "win-win" solution, mitigation measures increase soil organic matter, improve soil health and quality, and eventually increase crop output in agroforestry systems while also enhancing soil adaptability. Major corrective measures include the use of resistant plant varieties, mixed farming, reforestation, and agroforestry techniques. (Buchman, 2008).

Agroforestry systems potential for carbon sequestration

The process of taking more carbon out of the atmosphere and storing it in various "reservoirs" is known as carbon sequestration. Practically speaking, the growth of tree plantations is the primary method of carbon sequestration. Numerous studies have confirmed how agroforestry sequesters carbon, including Kaushal*et al.* (2014), Prasad *et al.* (2012), Swami and Puri (2005), Chauhan*et al.* (2010), and RamnewajandDyani.(2008). In both industrialized and developing nations, agroforestry, the process of integrating trees into farming, has significantly increased land productivity and improved lifestyles. Additionally, it has the capacity to increase the system's resilience to detrimental effects of climate change. Agroforestry has certain particular benefits over traditional methods of carbon sequestration, which have traditionally included replanting and afforestation of damaged natural forests. This system can serve as a carbon sink. (Montagnini and Nair, 2004).Agroforestry practices' effects on the soil carbon pool showed an increase of 2-3 Mg C/ha/yr (Jose, 2009). Agroforestry systems have the ability to store 70 Mg/ha of carbon in the top 20 cm of the soil, depending on socioeconomic and environmental conditions (Mutuo*et al*., 2005). Different species and geographical regions have different agroforestry carbon storage capacities (Newaj*et al*., 2008). Additionally, the design and operation of many system components determines how much carbon is present in any given agroforestry system. Different agroforestry systems store different quantities of carbon, depending on the system type, species mix, soil, and climate. As a result, India's agroforestry sector has a capability to store almost 2400 million tonnes of carbon. Author P. K. R. Nair.,2012cited as saying that agroforestry is similar to "low hanging fruits" because it has the potential to mitigate climate change and doesn't cost much to sequester carbon. (SangramChavan*et al.*, 2014)

Table 2.Potential for sequestering carbon in India's diverse agroforestry systems (Mg C ha-1yr-1)

Location	Agroforestry System	Tree species	No. of trees per ha	Age (year)	Carbon sequestration potential (Mg C/ha/yr)	References
UttaraKhand	Agriculture-forestry system	*D. hamiltonii*	1000	7	15.91	Kaushal*et al.*, 2014
Himachalpradesh	Agriculture-forestry system	Fruit trees	69	-	12.15	Goswami*et al.*, 2014
Andrapradesh	Agriculture-forestry system	*L. leucocephala*	4444	4	14.42	Prasad *et al.*,2012
			10000	4	15.51	
UttaraKhand	Agriculture-forestry system	*P. deltoids*	500	8	12.02	Singh and Lodhiyal, 2009
SBS Nagar of Punjab	Agriculture-forestry system	*P. deltoids*	740	7	9.40	Chauhan*et al.*, 2010
Dehradun of Uttarkhand	System of Silviculture	*E.tereticornis*	2500	3.5	4.40	Dhyani*et al.*, 1996
			2777	2.5	5.90	
Haryana	System of Silvipasture	*A. nilotica*	1250	7	2.81	Kaur*et al.*, 2002
		E. sissoo	1250	7	5.37	
		P. juliflora	1250	7	6.50	
Chandigharh	Agriculture-forestry system	*L.leucocephala*	10666	6	10.48	Mittal and Singh, 1989
Tri-pura	Silviculture	*T. grandis*	444	20	3.32	Negi*et al.* 1990
		G.arborea	452	20	3.95	
central devisionTarai, UttarKhand	System of Silviculture	*T.grandis*	570	10	3.74	Negi*et al.* 1995
			500	20	2.25	
			494	30	2.87	
Jhansi, Uttarpradesh	Agriculture-forestry system	*A. procera*	312	7	3.70	Ramnewaj*et al.* 2008
		A. pendula	1666	5.3	0.43	Rai*et al.* 2002
Hyderabad,Andrapradesh	Agriculture-	*L. leucocephala*	11111	4	2.77	Rao*et al.* 1991

	forestry system		6666	4	1.90	
Raipur of Chattisgarh	Agriculture-forestry system	*G. arborea*	592	5	3.23	Swami and Puri 2005
Coimbatore of Tamilnadu	Agriculture-forestry system	*C. equisetifolia*	833	4	1.57	Vishwanath*et al.* 2001
Kerala state	garden at home	Mixed tree species	667	71	1.60	Saha*et al.* 2009

Additionally, there is strong evidence to support the idea that the type of agroforestry system considerably affects the role of the trees as a source or sink of carbon. For instance, agro-silvicultural systems that grow crops and trees together are net sinks of greenhouse gases, whereas agro-silvipastoral systems may be sources. Agroforestry systems offer a technological mitigation potential of 1.1-2.2 Pg C in terrestrial ecosystems over the ensuing 50 years, according to IPCC-9 estimates. Agroforestry has the potential to sequester 977,000 Mg C/yr of carbon by 2040 by replacing 630 M ha of unproductive crop fields and grasslands(Jose,2009).

When compared to land use without trees (i.e. crop land devoid of any trees), the carbon in the above-ground and below-ground biomass in an agroforestry system is typically significantly higher. According to estimates, agroforestry systems have the ability to sequester 2.1 Mg C per year in tropical biomes and 1.9 Mg C per year in temperate biomes (Oelbermann*et al.,* 2004). By alleviating strain on natural forests, which are the greatest sinks of terrestrial carbon, agroforestry systems can indirectly affect carbon sequestration.

Livelihood security through Agroforestry

Agroforestry can reduce losses of water, soil material, organic matter, and nutrients by controlling runoff and soil erosion. Trees can be used in the reclamation of polluted soils to stop the development of soil toxicities, soil acidity, and soil salinization, ensuring farm yield and income (Murthy*et al.,* 2013). Agroforestry's diversified component offers numerous harvests at various times of the year, lowering the risk of crop failure and ensuring farmers have alternate sources of income (Pandey, 2007). Agroforestry strengthens farming systems' resilience by mitigating risks on both a biophysical and financial level (diversification, revenue risk), as well as hazards related to hydraulic lift and soil fertility (Verchot*et al.,* 2007). Other benefits include lowering seasonal labor peaks, earning money all year long, and ensuring rewards over the short, medium, and long durations even in difficult circumstances (FAO, 2005). Agroforestry-based IFS can promote a positive engagement with the environment. These procedures can improve the farm's land, water, air, animal, and human resources (Murthy*et al.,* 2013). Only 5% of farming land may be used for agroforestry activities, but they account for over 50% of biodiversity, enhancing the habitat for wildlife and supporting birds and beneficial insects that eat crop pests and ensure good crop output (Makundi*et al.,* 2004).

Government initiatives to encourage agroforestry

The National Climate Change Action Plan's Greening India mission is to convert 1.5 million hectares (ha) of fallow and degraded agricultural land into agroforestry; an additional 0.7 million hectares of land are to be converted into agroforestry (Puri&Nair, 2004). Given that the vast majority of India's arable land is under cultivation, agroforestry on agricultural areas will provide the country with the majority of the chance to store carbon through afforestation (Ravindranath, 2007).

By 2025, over half of the entire area that might be used for agroforestry will be planted with tree-borne oil seeds, silvi-pasture, and other crops, according to estimates of NRCAF, 2007.The National Forest Policy, established by the Government of India in 1988, intends to expand the amount of trees and forests across the nation, improving the ecosystem services provided by forests to local communities (mostly carbon sequestration).

The Farm Forestry Programme was established in the late 1970s, followed by the Social Forestry Programme in the early 1980s, the Joint Forest Management Programme in 1990, the National Afforestation and Eco-development Board programs since 1992, and private farmer and industry initiated plantation forestry schemes. Afforestation and reforestation are currently carried out under a variety of programs.

The Farm Forestry Program was established to raise awareness of the advantages of planting trees. More trees were planted in rural and commercialized areas as a result of this project. Through the expansion of plantations and afforestation, development policies like the Mahatma Gandhi National Rural Employment Guarantee Act, 2005, helped to lower greenhouse gas emissions. Additionally, a vigorous program of afforestation and sustainable forest management led to yearly reforestation of 1.78 million ha between 1985 and 1997, and it currently occurs on 1.1 million ha annually. As a result, from 1986 to 2005, the carbon stocks in Indian forests rose to 9–10 gigatons of carbon (GtC).

Conclusion

The most significant worldwide environmental challenge that all living things, including humans, natural ecosystems, and agriculture, are currently dealing with is climate change. This makes agroforestry an effective farming method for solving the issue of food security, reducing the negative consequences of climate change by improving the environment, preserving economic viability, and improving quality of life. As a result, agroforestry systems significantly reduce the adverse effects of climate change by boosting tree-crop variety, which increases the capacity for carbon storage (also known as carbon sequestration) over the cultivation of just one type of agricultural crop. Therefore, it's crucial to manage agricultural lands to improve carbon sinks and subsequently lower emissions. Measures to manage land use, such as preserving current tree cover and promoting agroforestry.

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