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Agroforestry as a strategy for climate change adaptation and mitigation

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ABSTRACT: Agroforestry is addressing the issues of designing ecologically sound and economically appealing strategies for climate change adaptation and mitigation. Being an intensive, integrated, intentional and interactive, it helps in creating favorable conditions in terms of microclimate modification, biodiversity conservation, soil health improvement and shelter (windbreaks and shelterbelts). Agroforestry practices are a potential tool to alter the harsh environment to provide better conditions for crop, forage and livestock productions. The induced conditions could be critical in providing extra resiliency to shifting temperature and moisture regimes. Further, the carbon sequestration with varied benefits creates opportunities in trading carbon and reducing farmers' vulnerability. This paper discusses different adaptation and mitigation options provided by multifunctional agroforestry systems against climate change.

Key words: Carbon sequestration, climate resiliency, global warming, microclimate

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1. INTRODUCTION

The series of Intergovernmental panel on climate change (IPCC) reports on climate change and greenhouse gases (GHG) have reconfirmed that the global concentration of carbon dioxide (CO_2), methane (CH_4) and nitrous oxide (N_2O) has increased significantly as a result of anthropogenic activities like fossil burning, deforestation, non-sustainable agricultural practices and land degradation since 19th century. These increased atmospheric GHGs have been attributed as one of the most severe driving force behind the ghost of climate change. Global climate change is increasingly recognized as the greatest global threat facing humanity in present era. In a recent report of the United Nations Scientific Experts Group on Climate Change and Sustainable Development concluded that the human race has never faced such a greater challenge ever before. The concentration of CO_2 was around 397.23 ppm in July 2013 (www. CO_2Now.org). The methane and nitrous oxide concentration were 1.7 and 0.34 ppm, respectively (IPCC, 2007). The recent inventory on GHG emissions from India in 2007 estimated 1727.71 million tons of CO_2 equivalent of which CO_2 emissions were 1221.76 million tons, CH_4 emissions were 20.56 million tons and N_2O emissions were 0.24 million tons. The GHG emissions from energy, industry, agriculture and waste sectors constituted 58%, 22%, 17% and 3% of net CO_2 equivalent emissions, respectively. Increasing extreme events such as high intensity rainfall, heat waves, frost and drought events are worst effects of global warming on agriculture. In addition to this, climate change is an additional threat that might affect a country's ability to food security, alleviate poverty and malnutrition, and livelihood of small and marginal farmers.

In recent years, with the growing recognition of the possibility of global climate change, an increasing emphasis on world food security in general and its regional impacts in particular have come to forefront of the scientifc community in the country like India. The growing population and diversified food requirements of the country calls for enhancing food production substantially in the years to come inspite of several limitations such as land degradation, declining factor productivity and soil health and growing concerns of climate change. In such situation of extreme events, climate change is causing irreversible and drastic changes in food grain production and cropping pattern in terms of physiological and phenological changes in crops and reducing production. In an effort to reconcile current food deficit against future environmental debt, most food deficit regions face the challenge to identify appropriate technological and policy approaches that are affordable, and best meet food security objectives and provide opportunities for smallholder farmers to adapt to climate change (Ajayi *et al.* 2008). Hence, there is urgent need to address these negative impacts of climate change in order to sustain livelihood of people. Nobel Prize Laureate, Wangari Maathai quotes, 'Trees have an important role to play, not only in climate change mitigation, but also in reducing vulnerability to climate-related risks'. Under this background, agroforestry is receiving long overdue attention as an alternative land-use practice that is resource efficient and environmentally friendly (Jose and Gordon, 2008). Therefore, agroforestry has provided such a great opportunity to address all these problems by adapting and mitigating climate change. Agroforestry systems are providing better option of climate change mitigation than ocean, and other terrestrial options, because of its potential capacity of land use management and secondary environmental benefits such as food security and secured land tenure, increasing farm income, restoring and maintaining above ground and below ground biodiversity, maintaining watershed hydrology and soil conservation (Kursten and Burschel, 1993).The potential capacity of agroforestry to adapt harsh climatic event is greater than agriculture because it is playing important role in ecosystems services and prevents land degradation, which makes them to cope up in all type of climatic vagaries. Agroforestry systems are a key type of agriculture that allow for a high level of progressive adaptation from simply increasing structural and temporal diversity of the production system to selling ecosystem services for increased economic diversification (Lin, 2011). Based on present scenario this is an attempt to address the different adapting and mitigating strategies of agroforestry in the context of carbon sequestration and livelihood improvement.

2. ADAPTATION AND MITIGATION IN CONTEXT OF AGROFORESTRY

Most of scientific community considers that agroforestry has huge potential to adapt and mitigate climate change (Nair *et al.* 2012; Yadava *et al.* 2010 and Batish *et al.,* 2008). Many times we talk about adaptation and mitigation strategies of agroforestry in context with global warming, but there is need to explain these key words. The most important point about climate change is its realization and understanding at local levels before taking appropriate mitigation and adaptation initiatives (Prasad *et al,* 2011). Agroforestry provides an unique opportunity to reconcile the objectives of mitigation and adaptation to climate change. Schoreneberger *et al.* (2012) have highlighted the adaptation and mitigation measures of climate change through agroforestry (Table 1).

3. ADAPTATION STRATEGIES

As per IPCC lexicon adaptation are adjustments in ecological, social or economic systems in response to actual or expected climatic stimuli and their effects or impacts. It refers to changes in processes, practices, and structures to moderate potential damages or to

Table 1. Measures of climate change adaptation and mitigation through agroforestry

Climate change activity	Major functions	Agroforestry role
Mitigation		
Activities that reduces GHGs in the atmosphere or enhance the storage of GHGs stored in ecosystems	Sequester carbon	Accumulate C in woody biomass and in soil
	Reduce GHG emission	Reduce fossil fuel consumption by minimizing use of equipments in areas with trees
		Reduce farmstead heating and cooling
		Reduce CO_2 emission by C sink
		Reduce N_2O emissions by greater nutrient uptake through trees and lowering N fertilizer consumption in tree systems
		Enhance forage quality, thereby reducing CH_4
Adaptation		
Action to reduce or eliminate the negative effects of climate change or take advantage of the positive effects	Reduce threats and enhance resilience	Amelioration of microclimate, reduce impact of extreme weather events on crop production and maintain quality & quantity of forage to reduce livestock stress.
		Provide greater habitat diversity to support organisms (e.g. native pollinators & useful insects), structural and functional diversity to maintain and protect natural resources and create diversified production opportunities to reduce risk under fluctuating climate
	Allow species to mitigate to more favorable conditions	Provide habitat corridors for species migration

benefit from opportunities associated with climate change. Adaptations are actions taken to help communities and ecosystems moderate, cope with, or take advantage of actual or expected changes in climate conditions. As adaptation emerges as a science, the role of agroforestry in reducing the vulnerability of agricultural systems (and the rural communities that depend on them for their livelihood) to climate change or climate variability needs to be addressed (UNFCCC, 2013). The adaptive measures of agroforestry are microclimate amelioration through increasing moisture, reducing temperature for better growth of crops in high atmospheric temperature; shading effect that cut downs the evapotranspiration from crops and nurturing high biodiversity; minimizing pest and disease occurrence, and buffering agricultural crops against water deficiencies. Adaptation is central aspect to many proposed strategies for climate change and agroforestry systems provides opportunity to cope with all type of ill impacts like high temperature, limiting moisture, wind velocities, hails, frost and drought. This becomes possible due to the fact that agroforestry integrates woody perennials which have great potential to bear harsh climatic effects and make overall system sustainable with its coping mechanism. Some of the adaptive strategies of agroforestry systems are explained in brief as under.

3.1 Microclimate amelioration

Agroforestry is ecologically dynamic, complex and sustainable system which provides opportunity to mimic natural forest in farm land with high complementary economical and environmental benefits. Tree systems are having ability to improve microclimatic environment by lowering temperature, evapotranspiration, moisture reduction, and acting as a filter for providing buffer against direct sunlight. Microclimatic amelioration is considered as one of the important role of trees in agroforestry systems to provide sustainability. In dryland and low rainfall areas, water availability to crops is paramount and seems to be the dividing factor between absolute crop failure and reasonable food production (Garrity *et al.,* 2006). As a method of adapting agriculture to climate change, agroforestry systems have been shown to increase on-farm production resilience to climate variability by buffering crops from the effects of temperature and precipitation variation as well as strong winds associated with storms (Lin, 2011). From the meteorological point of view agroforestry systems are providing two key facts *viz.,* shade tree concept (radiation) and mechanic concept. For the first concept, shade will create microclimates with lower seasonal means in ambient temperature and solar radiation as well as smaller fluctuations. The effect of solar radiation during the day and night times increases the surface temperature considerably and affect the crop during critical periods such as flowering and seed maturing. The shade tree reduces evaporative demands from soil evaporation and crop transpiration. Shade trees are a potential adaptive strategy for farmer's vulnerability to reduce water scarcity and microclimate alteration (Lin *et al.,* 2008). Some of the studies by Lin (2007 and 2010) on coffee based agroforestry systems mentioned that crops grown under heavy shade (60-80%) were kept 2-3°C cooler during the hottest times of the day than crops under light shading (10-30%) and lost 41% less water through soil evaporation and 32% less water through plant transpiration.

The effect of extremely high temperature on some crops may be reduced through modifying the microclimate e.g. by adding shade and shelter as in agroforestry systems (Cannell *et al.,* 1996). In arid Western Rajasthan presence of shelterbelts on farmers' field reportedly has reduced daily air temperature on downwind side in comparison to reference up wind air temperature with maximum reduction beneath the tree canopy. The maximum and minimum reduction in air temperature was caused by double-row (8.0 ^{0}C) and single-row (3.5 0C) shelterbelts of *D. sissoo*, respectively (Prasad *et al.* 2013). An example of microclimate modifcation is that of growing coffee under shade, which increases the resilience of coffee growing under climate change by lowering maximum temperature and improving moisture retention (Lin *et al.*, 2008).The challenge for scientists, policy makers, and land managers working on developing productive adaptation strategies is to strengthen current farming practices and farming systems to make them less vulnerable to climate variability (Verchot *et al.,* 2007). Addressing issues of climate change adaptation in the scenario of microclimate improvement is important factor which reduces yield loss and drudgery of small farmers by agroforestry interventions in agriculture. The mechanic concept of agroforestry explained in shelterbelts and windbreaks.

3.2 Shelterbelt and windbreaks

Shelterbelts and windbreaks are important components of agroforestry systems in rainfed, dry, temperate and desert areas. Windbreaks are located around the field mostly on bunds but shelterbelts are integrated with cropping systems in the field. Brandle *et al.* 2004 stated that windbreaks or shelterbelts are barriers used to reduce wind speed. Historically, they have been used to protect homes, crops and livestock, control wind erosion and blowing snow, provide habitat for wildlife, and enhance the agricultural productivity. Cleugh (1998) addressed the mechanisms by which a porous windbreak modifies airflow, microclimates and hence crop yields. These are providing crop assurance to farmers against extreme climatic events by modifying weather condition of the field. Windbreaks and shelterbelts reduce wind velocity, increase moisture and decrease temperature and also provide shelter against direct sunlight. Therefore, it is considered as good adaptive strategies of climate change (Montagnini and Nair 2004; Dixon *et al.* 1993). Cleugh (1998) described that windbreaks are believed to reduce evaporative water losses from surfaces downwind, and thus conserve soil moisture, based on the notion that increased shelter from wind reduces evaporation.

In Rajasthan, windbreaks of *Prosopis cineraria* have played an important role in the changing scenario of agricultural field by depositing sands, reducing hot wind, lowering temperature and improving soil moisture status. A study by Prasad *et al.* (2013) has demonstrated how morphological characteristics of different shelterbelts *(Acacia tortilis, Eucalyptus camaldulensis, Dalbergia sissoo, Tecomella undulata)* affect wind regimes, air temperature and soil properties in arid Western Rajasthan. Their findings revealed that all the shelterbelts had caused maximum reduction (21.5 to 36.0%) in wind speed on downwind side at distance of 2 H (H is average height of shelterbelt). The reduction was more pronounced between 2H and 10H, and slowly nullified up to 20 H. On an average, more reduction in speed of upwind was caused by double-row shelterbelts, however, single-row belts provided more sheltered area on lee side. Besides reducing speed of wind, presence of shelterbelts also enhanced soil organic carbon and reduced daily air temperature in sheltered area. The enrichment of soil and moderation of microenvironment on downwind side was more pronounced up to distance of 5H. The height, foliage density and length of shelterbelt were found to be decisive for tunnelling effects at the ends of shelterbelts (Prasad *et al* 2009). Fairly tall (~10m) and dense (double-row) shelterbelts having length and height (L/H) ratio of 10 to13 were most suitable and efficient in providing protection against wind hazards in arid Western Rajasthan. Conserving fertile soil, protecting water quality, enhancing air movement and biological connectivity in the landscape, reducing energy bills, capturing carbon, recreation opportunities, aesthetic, bird-watching and cultural identity of a community are few examples of shelterbelts' multi-functionality. One might call it the backbone of desert farmer resilience and sustainability.

3.3 Biodiversity conservation

Agroforestry is a system of complex and integrated approach, which provides opportunity to intermingle trees, crops, pastures and animals in a managed aspect and provides shelter for soil flora & fauna, birds, insects and wildlife. Traditional agroforestry systems are best examples of agro-biodiversity conservations. The presence of trees further enhances diversity by providing shelter and habitat to a various diversified flora and fauna. It also helps in conserving genetic diversity of wild cultivars or landraces and trees, which are in danger of loss and require priority conservation (Pandey, 2007). Batish *et al* (2008) and Jose (2009) reported that agroforestry helps in biodiversity conservation through (i) provision of secondary habitats for species, (ii) reduction in the rate of conversion of natural habitats, (iii) creation of a corridor and permeable matrix between habitat remnants, which may support the integrity of these remnants and the conservation of area sensitive to foral and faunal species (iv) preservation of germplasm of sensitive species and conserve biological diversity by providing other ecosystem services such as erosion control, microclimate improvement and water recharge. Agroforestry systems acting as a forest mimics in true sense in home gardens of tropical climate which consisting from 27 in Sri Lanka to 602 in West

Java (Kumar and Nair, 2004) and this diversification and intensification of systems providing ability to small and marginal farmers to reduce vulnerability of climate change and sustain production with up-scaling the livelihood. The characteristics of agroforestry systems for biodiversity conservation adapted from Harvey *et al.* (2007) are presented in Table 2. Jose (2009) suggested in one of review that agroforestry systems are dynamic nature and adopting most of indigenous tree species supporting insects, butterflies, birds & bats and playing key role in conservation of biodiversity.

4. MITIGATION STRATEGIES

Mitigation refers to technological change and substitution that reduce input and emissions per unit of life (IPCC lexicon). Mitigation is nothing but remedial measure to cure the adverse impact which has occurred in limited extent like increased CO_2 concentration. Mitigation through agroforestry is storing atmospheric carbon dioxide in trees known as carbon sequestration process. Carbon sequestration through land use, land-use change and forestry (LULUCF) as a measure for mitigating climate change is an important issue of recent negotiations and these activities form an interrelation with Clean Development Mechanism (CDM). In simple language, adaptation can be carried out at local level but mitigation is at globally. Carbon sequestration by trees and soil is considered as one of the important mitigation measure of climate change. The primary aim of the mitigation is to reduce the concentration of greenhouse gases and to increase the soil carbon storage. Mitigation measure increases soil organic matter in the soil and ultimately improves soil health and quality so that it enhances crop yield in agroforestry systems and also enhance the adaptive capacity of soils, so is a 'win–win–win' option (Smith and Olesen, 2010). Therefore, the mitigation options affect the C and/ or N cycle of the agroecosystem in some way.

4.1 Carbon sequestration

The United Nations Framework Convention on Climate Change (UNFCCC) defines carbon sequestration as the process of removing C from the atmosphere and depositing it in a reservoir. It entails the transfer of atmospheric CO_2, and its secure storage in long-lived pools (UNFCCC, 2007). Carbon sequestered by trees and stored in above ground biomass and soil contributes to reducing greenhouse gas concentrations in the atmosphere. Estimates of the carbon sequestration potential of agroforestry systems vary greatly, from under 100 Mt CO_2 per year by 2030 to over 2000 Mt CO_2 yr^{-1} over a 30 year period. Regardless of the exact amount, agroforestry systems tend to sequester much greater quantities of carbon than agricultural systems without

Table 2. Desirable characteristics of agroforestry for biodiversity conservation

Type of activity	Variable	Desirable characteristics
Design of agroforestry systems	Species composition	Diverse species composition, mixture of early, mid and late successional species, preferably native species
	Tree/shrub density	Higher tree/shrub density (and greater areas) leads to greater biodiversity
	Type of agroforestry system	Any system as long as it is floristically and structurally diverse
	Duration of agroforestry system	Long rotation is desirable to provide stability
Management of agroforestry systems	Management regime	Minimal management is preferable Management strategies should maximize habitat heterogeneity and availability of diverse resources for wildlife
	Soil management	Minimal
	Harvesting of products	Minimal harvesting or harvesting that emulates natural disturbance regimes
	Fire management	Fire regimes should follow natural regimes to the extent possible
	Management of snags and Coarse woody debris	Maintain snags and coarse woody debris as habitat for certain species
Spatial configuration	Location within broader landscape	Position the agroforestry practices strategically to enhance landscape connectivity, by functionally linking habitat fragments
	Types land	Degraded sites, where revegetation through agroforestry will have a beneficial impact on biodiversity

Source: Harvey *et al.* (2007)

Table 3. Potential carbon[1] storage for agroforestry systems in different eco-regions of the world

Region	Eco region	Agroforestry systems	Carbon storage (Mg C ha^{-1})
Africa	Humid tropical high	agrosilviculture	29-53
South America	Humid tropical low Dry lowlands	agrosilviculture	30-102 39-195
Southeast Asia	Humid tropical dry lowlands	agrosilviculture	22-228 68-81
Australia	Humid tropical low	silvopastoral	28-51
North America	Humid tropical high Humid tropical low dry lowlands	silvopastoral	133-154 104-198 90-175
Northern Asia	Humid tropical low	silvopastoral	15-18

[1]Carbon storage values were standardized to a 50 year rotation

(Sources: Dixon *et al.,* 1993; Krankiana & Dixon, 1994; Schroeder, 1993 & Wimjhum *et al.,* 1992)

trees (Neufeldt *et al.,* 2009). Different agroforestry systems sequestering varied amount of carbon based on type of system, species composition, soil and climate. The home gardens consisting higher biomass compared to other systems and arid zones agroforestry systems consisting more root biomass. The aboveground carbon stocks are 17 to 36 Mg C ha^{-1} in tropical homegardens of Kerala (Kumar and Nair, 2011) and 21 to 65.6 Mg C ha^{-1} in poplar based systems of North India (Rizvi *et al.,* 2011). Area under agroforestry is always tricky question to the scientists and policy makers in India, but NRCAF, Jhansi came up with rough estimates of 25.32 M ha or 8.2 % area under agroforestry systems (Dhyani *et al.,* 2013). In this way, the total potential of agroforestry in India to store carbon is about 2400 million tons. Some of the earliest studies of potential carbon storage in agroforestry systems and alternative land use systems in India had estimated a C sequestration of 68-228 Mg C ha^{-1} (Dixon *et al.,* 1994) and studies from Jha *et al.* (2001) showed that agroforestry could store nearly 83.6 Mg C ha^{-1}. Average carbon storage by agroforestry practices, of which fertilizer trees is an integral part has been estimated as 9, 21, 50, and 63 Mg C ha^{-1} in semi-arid, sub-humid, humid and temperate regions, respectively (Montagnini and Nair, 2004). Carbon sequestration potential of biofuels crops was 10.08 Mg C ha^{-1} in Jatropha and 34.85 Mg C ha^{-1} in *Pongamia* at 10 year of growth and such biofuel type of crops not only help to mitigate climate change through sequestration and storage of carbon in the biomass, but also helps to produce renewable energy by replacing fossil fuels, as its seed can be used for biofuel productions (Rao, 2013). Carbon sinks potential of different agroforestry systems of world are shown in Table 3. Due to this innumerable benefits and potential of agroforestry, Nair (2012) quoted that agroforestry is like “low hanging fruits” because of its mitigation potential of climate change and low sequestrating cost. Hence, agroforestry providing opportunity to get carbon credits under the Kyoto protocol agreements, so it’s considered as security bank for small holder farmers.

5. CONCLUSION

Climate change is a well known word to all due to its impact on environment and people. The increased levels of GHGs can be reduced by the intervention of trees in agriculture. Therefore, agroforestry has a critical role to play in the evergreen agriculture that not only underpins food security, but also provides ecosystems services that can made human life secure. There is a need to build a bridge between adaptation and mitigation measures for creating environmental secure options of carbon sequestration with multifunctional benefits from agroforestry. Scientists, policymakers, agriculture entrepreneurs and farmers need to realize the agroforestry importance in the context to adaptation and mitigation of climate change so the issues of adoption of agroforestry and drawing new sustainable policy can be successfully addressed.

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