Chapter 29
Mitigation and Adaptation Strategies to Climate Change Through Agroforestry Practices in the Tropics

S. L. Swamy and V. P. Tewari

Abstract The rapidly increasing concentrations of greenhouse gases (GHGs) in the atmosphere are mainly responsible for global warming and consequences of climate change. Agriculture is the mainstay of livelihood and food security to millions of people living in tropical countries; climate change is posing a serious threat on food production, nutritional security, and livelihoods of poor farming communities of developing countries. This has prompted a renewed interest in mitigation and adaptation strategies to minimize negative impacts of climate change on agroecosystems through introducing promising tree-based alternate land-use systems. Agroforestry systems (AFS) indeed offer viable opportunity to mitigating the atmospheric accumulation of CO_2 and other greenhouse gases and potential for transforming into resilient farming systems and help the farmers in adapting to climate change in tropics. The potential of AFS to accumulate carbon (C) was estimated to be 12–228 Mg ha^{-1}, with an average of 95 Mg ha^{-1}. Agroforestry practices also offer climate change adaptation by means of buffering agricultural crops against water deficiencies through ameliorating microclimate, maintaining long-term soil health, and minimizing the incidence of insect and pests under climate change scenarios. The degree of mitigation and adaptation varies according to the structural and functional complexities of systems. In addition, agroforestry systems will provide many tangible benefits to farming communities in the form of food, fuel wood, fodder, timber, medicine, fiber, etc. and be able to address the diverse issues of livelihoods, unemployment, and poverty. Agroforestry systems in developing countries shall ensure the farmers in gaining additional economic benefits of C sequestration by C trading with developed countries under CDM projects. It will help the farmers to improve their farm economy besides securing environmental benefits to global communities. The chapter discusses the potential role of agroforestry systems for mitigation and adaptation to climate change and buffering climate extremities in diverse socioeconomic and environmental setups in tropics.

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1 Introduction

One of the major issues of global concern today is increasing levels of greenhouse gases (GHGs) and their consequences on climate change. Anthropogenic activities, viz., inappropriate land-use practices, excessive fossil fuel combustion, and rapid industrial expansion, are mainly responsible for accumulation of greenhouse gases into the atmosphere causing global warming (Albrecht and Kandji 2003). The major greenhouse gases accountable for this phenomenon are carbon dioxide, methane, NOx, and chlorofluorocarbons. CO_2 is the most culprit gas, which alone majorly contributes to global warming. The emissions of CO_2 increased dramatically from 280 ppm in preindustrial era to 399 ppm in 2015 and are predicted to be almost double to preindustrial level by 2050 (IPCC 2014). The concentrations of methane and NO_X were also significantly enhanced up to the tune of 1890 ppb and 326 ppb (IPCC 2014). Due to increase in levels of greenhouse gases, the earth's temperature is already increased by 1–1.5 °C in the last 100 years and further predicted to rise by 2.5–3.0 °C by 2050, if the same rates of emissions are continued (IPCC 2014). The extreme weather events are occurring due to abrupt change in intensity and patterns of rainfall and temperature, which is attributed to rapid climate change. There are overwhelming evidences of negative impacts of climate variability on structure and functioning of many terrestrial ecosystems (Verchot et al. 2007; Nath and Behra 2011; Sheshta et al. 2014; Jat et al. 2016). Agriculture, a human developed enterprise, is highly dependent on specific climate conditions. Climate change is likely to influence crop and livestock production, hydrological balances, input supplies, and other components of agriculture system. The magnitude of impact varies across the agroecological regions of the world.

2 Impact of Climate Change on Agriculture

Agriculture is the mainstay of livelihood and food security to millions of people living in tropical countries (Adams et al. 1998; Nath and Behra 2011). Agriculture sector is extremely climate sensitive and explicitly vulnerable to climate change. The climatic variations causing frequent floods, droughts, windstorms, and outbreaks of pests and diseases increase the incidences of crop failures in many regions. The economic, social, and nutritional securities are emerging as serious challenges to humankind. More than 800 million people in the world are chronically malnourished, and 1100 million live in absolute poverty (Verchot et al. 2007). The population of developing countries, particularly in South Asia and sub-Saharan Africa, continue to grow at high rates, while the food production is gradually declining. The food production needs to be doubled within the next 20–30 years (Verchot et al. 2007). The shortfall in cereal production in the developing world is expected to widen the gap between demand and supply. The lack of new varieties and increased fertilizer use to further increase yields degrade the ecosystem and will undermine future efforts to boost agricultural productivity. Several studies have shown decrease in the growing season as temperature increases and depleted the yields of crops (Lal 2008). Higher temperatures increase evapotranspiration and decrease winter precipitation which may bring about more droughts. Changes in precipitation patterns and amount and changes in temperature will affect crop growth through changes in soil water content, runoff and erosion, workability, nutrient cycles, salinization, biodiversity, and soil organic matter (Rao et al. 2007; Jose 2009; Sushant 2013; Mbow et al. 2014). The cyclonic storms, storm surge, and coastal inundation also lead to catastrophe. High temperature leads to increase in respiration rates, short periods of seed formation, and consequently lower biomass production. Such reductions were only partially offset by a positive response to increased CO_2 concentrations as CO_2 fertilization effect. Increase in precipitation shall benefit arid and semiarid regions by increasing soil moisture, while aggravating the problem in regions with excess water. There are other stressors also which antagonistically influence along with climate change process (Luedeling et al. 2014).

Climate change coupled with unsustainable agricultural practices like excessive use of fertilizers, pesticides, and herbicides to enhance food production has further aggravated the environmental problems. Productive agricultural systems are gradually turning into unproductive systems affecting the livelihood and economy of small and marginal farmers. Some effective measures are initiated by communities but are not enough as the primary drivers of climate change are not going to halt. Therefore, the emphasis is given on mitigation and adaptation of agricultural systems to reduce the vulnerability and risks associated with climate change (Nair et al. 2009; Nath and Behera 2011). Climate change has emerged as a global issue where efforts for mitigation and adaptation to changing conditions have been strongly recommended by the Intergovernmental Panel on Climate Change (IPCC 2014). Mitigation refers to lessening of the impact of climate change which can be achieved either by reducing the source of emissions of greenhouse gases at source level or by capturing them from the atmosphere and locking them in the diverse ecosystems and expanding the sinks. In recent years, the mitigation measures in the agriculture and forestry sectors together simulated a lot of interest as a potential source for additional income and also as a means of adaptation strategy to climate change. Within the United Nations Framework Convention on Climate Change (UNFCCC) negotiation process, the development of mitigation and adaptation activities attracted new dimensions for negotiating the problems (IPCC 2014). The potential synergies between adaptation and mitigation measures need to be carefully exploited in addressing the current situation.

The understanding of the link between adaptation and mitigation measures is quite useful for planners and policy makers. There is a growing interest in developing resilient agricultural systems to withstand against climate change. Increasing system resilience is directly related to increasing the adaptive capacity of farmers, which is intricately linked to social and economic status. Sustainable agricultural development is essential not only to ensure the food supply but also alleviate poverty through economic growth by creating additional employment opportunities in nonagricultural rural sectors (Antle et al. 2007). It is possible that climate change may force the pace of rural-urban migration (urbanization) over the next few decades. Innovative technologies and policies are required to strengthen the capacity of communities to cope effectively with both climatic variability and changes. Agricultural lands are believed to be a major potential sink and could absorb large quantities of C if trees are reintroduced to these systems and judiciously managed together with crops and/or animals (Nair and Nair 2014). Thus, the importance of agroforestry as a land-use management is receiving wider recognition not only in terms of agricultural sustainability but also in issues related to climate change (Pandey 2002). Agroforestry systems could potentially sequester significant amount of C per year. Agroforestry, a tree-based agriculture land-use system, is recognized as cost-effective and beneficial technologies proved as viable intervention. It not only offers opportunity for mitigation and adaptation to climate change but also secures a large number of tangible benefits, viz., food, fuel wood, fodder, fiber, timber, medicine, etc., and intangible services like biodiversity conservation, slope stability, runoff control, soil and water conservation, etc. (Jose 2009; Nair et al. 2009; Mbow et al. 2014).

3 Climate Change Mitigation Through Agroforestry Practices

Agroforestry is an age-old practice which integrates trees, shrubs, and animals with annual crop production to ensure steady supply of food and/or income throughout the year; arrest degradation and maintain soil fertility; diversify income sources; enhance the efficient use of soil nutrients, water, and radiation; and provide regular employment (Rao et al. 2007). Agroforestry can both sequester carbon and produce a range of economic, environmental, and socioeconomic benefits (Jose 2009). The perennial trees/shrubs are capable of absorbing large amounts of atmospheric CO_2 through photosynthesis and store C in long-lived and short-lived biomass components in addition to enriching the soil productivity. For example, trees in agroforestry farms improve soil fertility through maintenance of soil organic matter and physical properties, increased N, extraction of nutrients from deep soil horizons, and promotion of more closed nutrient cycling (Montagnini and Nair 2004). Combined yields of tree, crop, and livestock products from well-planned and well-managed agroforestry systems tend to be higher than those from sole systems due to increased and efficient use of scarce resources. Agroforestry systems therefore can enhance resilience by diversifying the production base and ensure the risks involved in mono-cropping due to climate change. Promising agroforestry systems capable of ameliorating microclimate, arresting soil degradation and restoring soil fertility, and diversifying income-generating opportunities were evolved in tropics in the last few decades (Table 29.1).

Table 29.1 Some prominent agroforestry systems and practices in tropics

Agroforestry system	Practices	Combination	Components
Agri-silvicultural system	Shifting cultivation/ improved fallow	Trees grown in noncrop period	Fast-growing trees, agricultural crop
	Taungya	Intercropping in initial stages of establishment of trees	Plantation of tree species and agricultural crops
	Hedgerow intercropping	Perennial trees such as woody hedges and crops in alleys	Woody trees with coppicing ability and crops
	Tree gardens	Multiple species, dense mixed	Fruit trees shade tolerant
	Multipurpose trees on farm lands	Trees scattered on field/ boundaries	Multipurpose trees and crops
	Plantation crops	Shade trees with plantation crops	Coffee, coconut, fruit trees, and shade-loving crops
	Shelterbelts, wind breaks, live fences	Trees/shrubs in single or multi-rows	Multipurpose trees on boundaries plus crops
	Homegardens	Multi-strata systems around homes	Multipurpose fruit, timber trees with crops
	Farm woodlots	Firewood and MPTs	Trees and crops in separate settings
Agri-silvipasture system	Homegardens with animals	Multi-strata system around home with fodder trees	Coppicing fodder trees, fruit trees, plantation crops, and crops
	Multipurpose woody hedgerows	Multipurpose trees such as woody hedges with crops	Leaves forage for animal rearing with crops
	Aqua-forestry	Trees on the bunds of ponds	Multipurpose trees forage
Silvopastural system	Trees on rangelands	Scattered fodder trees in combination with grasses and legumes	Scattered trees on rangelands, grasses, and legumes
	Protein/fodder banks	Fodder trees in association with forage crops	Fast-growing leguminous trees fodder crop
	Plantation crops with pasture	Plantation crops along with grasses	Plantation crops like rubber, coconut, coffee, cashewnut etc. with forage grasses
	Riparian buffers	Combination with trees and natural grasses along the stream banks	Multipurpose trees in association with natural grasses and legumes

Source: Rao et al. (2007)

The tropical agroforestry systems are distinguished by their distinctive spatial and temporal dimensions and structural and functional complexities. Agri-silviculture system integrates annual food crops along with trees simultaneously or sequentially and mainly includes improved fallows, taungyas, alley cropping, plantation crops, shelterbelts, woodlots, homegardens, etc. practiced in various ecological and socioeconomic situations (Rao et al. 2007). The systems are designed for simultaneous production of food along with wood products, etc. On the other hand, agri-silvopasture is a more complex system aimed at concurrent production of food, fodder, wood, and animal, which includes homegardens with animal, multipurpose woody hedge rows, aqua forestry, etc. (Nair et al. 2010). Silvopasture system incorporates fodder trees, grasses, and legumes for the concurrent production of timber and forage for animal rearing. It includes rangelands with scattered trees, protein/fodder banks, riparian buffers, etc. All these systems by and large provide multiple benefits to the societies and secure local as well as global interests.

4 Carbon Sequestration in Plants Under Agroforestry

Although most of the agroforestry systems are potential sinks, however some practices like shifting cultivation, pasture maintenance by burning, manuring, nitrogen fixation, N fertilization, frequent disturbances in soil, and animal production can act as source of GHGs. Carbon sequestration involves the net removal of CO_2 from the atmosphere and storage in long-lived pools of C. Such pools include the aboveground plant biomass; belowground biomass such as roots, soil microorganisms, and the relatively stable forms of organic and inorganic C in soils and deeper subsurface environments; and the durable products derived from biomass (Soto-Pinto et al. 2010). The significance of agroforestry with regard to C sequestration and other CO_2 mitigating effects is now widely recognized. According to an estimate, 630×10^6 ha are suitable for agroforestry in the world and have strong potential to sequester C across the world (Nair et al. 2009; Jose 2009). A major portion of this area lies in tropics and currently under some or other agroforestry practices, which could be further efficiently utilized for C sequestration by intensifying management practices. The C sequestration potentials of tropical agroforestry systems are highly variable (Albrecht and Kandji 2003). C storage in agri-silvicultural systems in humid tropics is relatively higher compared to silvipasture systems and range lands (Kaur et al. 2002). According to a study, shifting from traditional fallow to traditional maize caused a total living biomass carbon loss of 94%, and shifting from traditional fallow to improved fallow, taungya, or coffee prototypes maintains carbon in living biomass (average 50 Mg C ha^{-1}) (Soto-Pinto et al. 2010; Nair and Nair 2014), whereas changing from pasture toward silvopastoral systems increased carbon in living biomass by 20 times. Similarly, the multi-strata complex systems in homegardens have an advantage of higher number of components and could sequester more C as compared to less complex agri-silvicultural system (Nair et al. 2010). The agroforestry systems have more C than simple row crops and fallow

Table 29.2 C storage potential in agroforestry systems

Continents	Eco-region	System	Mg C ha^{-1}
Africa	Humid tropical high	Agrosilvicultural	29–53
South America	Humid tropical low dry lands	Agrosilvicultural	39–102
			39–195
Southeast Asia	Humid tropical dry low lands	Agrosilvicultural	12–128
			68–81
Australia	Humid tropical low	Silvopastoral	28–51
North America	Humid tropical high	Silvopastoral	133–154
	Humid tropical low dry lands	Silvopastoral	104–198
		Silvopastoral	90–175
Northern Asia	Humid tropical low	Silvopastoral	15–18

Source: Albrecht and Kandji (2003)

lands. The potential of AFS to accumulate carbon (C) is estimated to be 12–228 Mg ha^{-1}, with an average of 95 Mg ha^{-1} (Albrecht and Kandji 2003; Soto-Pinto et al. 2010). Agroforestry systems in the arid, semiarid, and degraded sites have a lower CSP than those in fertile humid sites; and the temperate agroforestry systems have relatively lower vegetation CSP than the tropical ones. A comparative account of C sequestration under different agroforestry practices is presented in Table 29.2.

One of the major issues of keeping the soil resource productive and in place could be accomplished by means of maintaining the levels of soil organic carbon. Agroforestry systems help in improving the status of organic C in the soil. Scientifically acceptable evidence to support the positive influence of trees in enhancing soil organic C is overwhelming (Chavan et al. 1995; Swamy and Puri 2005; Swamy and Mishra 2014). It is an established fact that soil factors (type, water content, pH, aeration, microflora, and so on), climatic conditions (temperature, rainfall), and litter fall (quantity) determine the soil resources. In this context, it is envisaged that the increased litter input and addition of root residues under agroforestry practices shall improve C storage in soil. According to a study conducted in humid tropics, agroforestry systems have the potential to sequester more than 70 Mg ha^{-1} in the top 20 cm of the soil (Soto-Pinto et al. 2010). Earlier studies showed that a significant increase in C was observed in the topsoil even after short duration of 5-year plantation. Soil organic C accretions through employing improved fallow were estimated to be between 1.69 and 12.46 Mg ha^{-1} (Soto-Pinto et al. 2010). Many studies indicated that the most marked differences in soil organic C are in the upper soil layer in plantations (Chavan et al. 1995; Fang et al. 2007; Gupta et al. 2009; Chauhan et al. 2012). However, the deeper layer seems to be more stable and responds to long-term sequestration. The higher amount of leaf litter and root residues in surface soil layer could be attributed to higher C pool as opined by many researchers (Swamy and Mishra 2014). The amount of C sequestered largely depends on the agroforestry system put in place, the structure and function of which are, to a great extent, determined by environmental and socioeconomic factors. Other factors influencing carbon storage in agroforestry systems include tree species, structure and function of different components, and system management (Nair and Nair 2014).

Although most of agroforestry systems are potential sinks, some practices like shifting cultivation, pasture maintenance by burning, manuring, nitrogen fixation, N fertilization, frequent disturbance in soil, and animal production can act as sources of GHGs. Silvopastoral systems, improved fallow, taungya, and coffee systems (especially polyculture-shade coffee and organic coffee) also have the potential to sequester carbon by maintaining polyculture and optimum number of trees (Soto-Pinto et al. 2010). Agroforestry systems could also contribute to carbon sequestration and reduce emissions when burning, and frequent tillage is avoided. A study conducted in Zimbabwe, Africa, showed that in improved fallow-maize rotation system, N_2O emissions were found to be almost ten times to those of continuous unfertilized maize, but these levels were still extremely low when compared to the increase in the amount of carbon stored (Jat et al. 2016). Therefore, there is a need to optimize the tree-crop-animal component combinations and adopt an integrated management to help in minimizing the sources and enhance the sink potential for better adaptation and mitigation of climate change through agroforestry.

5 Adaptation to Climate Change Through Agroforestry Interventions

Adaptation is believed to enhance the resilience of ecosystems against increasing climate variability. It is now increasingly accepted as a viable strategy to reduce the vulnerabilities of climate change. Adaptation refers to adjustments in ecological, social, or economic systems in response to actual or expected climatic change and their negative impacts (Antle et al. 2007). It mainly includes processes, practices, and structures to moderate potential damages or to benefit from opportunities associated with climate change. Adaptation to climate change has the potential to substantially reduce many of the adverse impacts on agriculture and enhance beneficial impacts though neither without cost nor without leaving residual damage.

Agroforestry practices offer the most viable opportunities to climate change adaptation and promote the maintenance of agricultural production by making resilient agricultural system (Nair and Nair 2014; Swamy and Mishra 2014; Sheshta et al. 2014; Jat et al. 2016). The perennial tree component of agroforestry system efficiently utilizes the scarce resources available in climate change scenarios and minimizes the risks involved in mono-cropping. In low-rainfall years, water availability may further decline, cause frequent droughts, and decrease food production. Agroforestry systems help in buffering agricultural crops against water deficiencies through ameliorating microclimate by influencing radiation flux, air temperature, wind speed, saturation deficit of understorey crops all of which will have a significant impact on modifying the rate and duration of photosynthesis and subsequent plant growth, transpiration, and soil water (Rao et al. 2007; Lin 2007). The shading of trees further reduces heat stress and controls wind storms, thus saving crop failure in extremely hot dry season. Some examples where the beneficial aspects of microclimatic changes are extensively used are shade trees to protect heat-sensitive crops like coffee, cacao, ginger, and cardamom from high temperatures, wind breaks and shelterbelts to slow down wind speed to reduce evaporation and physical damage to crops, mulches to reduce soil temperature, and various crop tree mixes to reduce erosion and maximize resource use efficiency (Lin 2010). However, the magnitude of microclimatic modification depends on spatial and temporal arrangement of trees and architecture and phenology. In the semiarid and arid regions, farmers are exploiting the benefits of agroforestry practices providing buffering effect against climate change (Jose 2009). Mulching practices in hedge row intercropping systems in semiarid regions are proved to be a best practice for conservation of soil moisture, enhancing soil fertility, and minimizing the yield losses. The addition of mulch can lower soil temperatures, reduce evaporation, and improve soil fauna activity and soil structure resulting in better infiltration, reduced runoff, and improved water-use efficiency. On sloping land, the tree rows act as a physical barrier to soil and water movement, resulting in significant reductions in erosion losses.

In another study conducted under coffee-based agroforestry systems, 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 (Lin 2007). Windbreaks planted in citrus groves have been shown to reduce wind speeds by 80–95%, reducing wind damage up to two times the distance of windbreak height (Rao et al. 2007). Shelterbelts in coastal areas have the potential to reduce the flood damage in extreme weather events during cyclonic storms, control wind and water erosion, and restrict the movement of salt-laden winds. Shelterbelts/windbreaks effectively change microclimates and decouple the climates of sheltered areas from those that are unsheltered. Thus, it is expected shelterbelts would be effective and function under a wide range of climate change conditions.

A crop modeling study in eastern Nebraska found that sheltered maize production continued to perform better than unsheltered crops under a wide range of projected climatic conditions. The scenarios considered included temperature increases up to 5 °C, precipitation levels up to 70–130% of normal, and wind speed changes of plus or minus 30%. A study conducted in poplar-based agri-silviculture showed that there was a decrease in leaf temperature and transpiration rates in soybean and wheat grown under poplar clones (Swamy and Mishra 2014). Climate change processes result in soil degradation in tropics. Higher temperatures and drier conditions lead to lower organic matter accumulation in the soil resulting in poor soil structure, reduction in infiltration of rain water, and increase in runoff and erosion. Agroforestry practices have the potential for restoring soil health by ameliorating the physical, chemical, and biological properties of soil. The continuous enrichment of organic matter and efficient nutrient cycling under agroforestry system help in maintaining long-term soil productivity (Kandji et al. 2006; Nair et al. 2009).

Pests, diseases, and weed incidences may likely to increase in tropical agroecosystems with changing climate (Jat et al. 2016). The huge losses in crop production may be encountered due to increased epidemics in warmer climate. Agroforestry offers a range of tools to reduce the disease losses and achieve sustainable production (Pumarino et al. 2015). Agroforestry systems enhance the diversity and complexity and could minimize the incidence of pests and diseases by slowing the spread of water and aerosol-dispersed pathogens. Trees and shrubs often provide better shelter and mating sites than do short-lived annual plants. Studies indicated that hedges provide very favorable environments for parasitic Hymenoptera and Diptera. The humid conditions in an agroforestry system may be favorable for the development of disease in insect pests (Pumarino et al. 2015). Coupled with the absence of direct sun, the effectiveness of entomopathogenic fungi may be increased by humidity. Enhancing plant biodiversity and mixing tree and herbaceous species in agricultural landscapes can produce positive interactions that can contribute toward controlling pest and disease outbreaks. Studies also demonstrated that introduction of flowering perennials or short-lived plants in an agroforestry system will contribute toward biological control of pests. Monoculture crops are likely to be more prone to attack of pest compared to polycultures (Sieshi et al. 2007).

The degree of structural and functional complexities of agroforestry determines the risks of insect pests. Many epiphytic, endophytic, and microbial associations with perennial trees contribute to natural biocontrol of plant diseases. Besides agroforestry system often creates conducive environment by modification of microclimate to harbor a range of parasite and predator population, which will act as natural enemies in reducing the incidence of infestation of pests and diseases (Jose 2009). Greater colonization and abundance of natural enemies in a mixed culture of plants have been demonstrated in many previous experiments. Polycultures, especially those containing flowering trees and shrubs, can provide more pollen and nectar sources attractive to and sustaining predators than monoculture. Agroforestry also provides shelter and nesting habits for many insectivorous birds and bats. Most of the birds play a useful role in agriculture by decreasing the number of insect and other pests. Insectivorous and carnivorous species are useful to agriculture since they keep a very potent check on populations of insect and rodent pests of crops (Jat et al. 2016). The exudates from tree components like stems, roots, and leaves also repel certain insects from crop lands managed under agroforestry systems. Still a lot of understanding is needed to comprehend the complex interaction in crops grown under different agroforestry practices. In simultaneous agroforestry systems, a number of factors governing tree-crop-environment interactions, such as diversity of plant species, host range of the pests, microclimate, spatial arrangement, and tree management modify pest infestations by affecting populations of both herbivores and natural enemies. Further, trees also influence pest infestations by acting as barriers to movement of insects, masking odours emitted by other components of the system and sheltering herbivores, and natural enemies (Rao et al. 2007; Sieshi et al. 2007). Trees also affect pest infestations by acting as the system and sheltering herbivores and natural enemies (Sileshi et al. 2007).

Climate change also poses a serious threat to agricultural systems by increasing the incidence of invasive weeds. The germination and growth of most weed species are usually stimulated by exposure to light. Thus, some control of weeds may be affected if a closed canopy can be maintained during the fallow period in an alley cropping system (Nair et al. 2009). In agroforestry shading by trees suppresses the weed proliferation and growth. Trees also suppress weed growth through the litter layer which forms from natural leaf fall and pruning residues. The potential of agroforestry to control both ordinary weeds and parasitic weeds had been well demonstrated by earlier researchers. A study conducted on hedge row intercropping system proved that weed numbers were reduced drastically in mulched plots compared to un-mulched plots. However, only limited studies were made in this direction, and further studies are needed to better understand the complex mechanisms in reducing weed population under different agroforestry practices in tropics.

6 Livelihood Securities and Other Services of Agroforestry

The agroforestry systems play indispensable role in enhancing farm income from diversified components, namely, crop, tree, and animal, at different intervals (Nair et al. 2009). Besides crop commodities, trees provide a variety of wood and non-wood products under agroforestry practices. In addition to timber and firewood, the leaves, fruits, nuts, seeds, livestock, and livestock products also generate substantial amount of income to farmers. Agroforestry systems in developing countries shall ensure the farmers are gaining additional economic benefits of C sequestration by C trading with developed countries under CDM projects (Nair et al. 2009). It will help the farmers to improve their farm economy besides securing environmental benefits to global communities. Policy analysis has shown that at prices of $100 per Mg C, carbon sequestration in agroforestry systems would have the potential to raise per capita incomes of farmers by up to 15% (Antle et al. 2007). However, it depends on the willingness of the farmers to adopt these potential tree-based land-use practices.

7 Conclusions

The anthropogenic activities are alarmingly increasing the concentrations of CO_2 in the atmosphere leading to the climate change. Agriculture ecosystem especially tropical agriculture is most vulnerable to climate change posing a serious threat on food production, nutritional security, and livelihoods of poor farming communities in developing countries (Verchot et al. 2007; Nath and Behera 2011; Murthy et al. 2013; Luedeling et al. 2014). Developing mitigation and adaptation strategies to minimize negative impacts of climate change on ecosystems has prompted a renewed interest in establishing promising tree-based alternate land-use systems. Agroforestry technologies have tremendous potentials in supplying diverse products as well as sequestering significant amount of C in degraded agroecosystems (Chauhan et al. 2011). Agroforestry technologies indeed offer viable opportunity to mitigate the atmospheric accumulation of CO_2 and other greenhouse gases and potential for transforming into resilient farming systems and help the farmers in adapting to climate change in tropics (Jose 2009; Yadava 2010). The degree of mitigation and adaptation varies according to the structural and functional complexities of systems. Some agroforestry systems also act as sources of GHGs, which could be reduced by judicious integration of components and their management. Burning, frequent tillage, and excessive use of agrochemicals shall be avoided. The agroforestry practices further facilitate better adaptation to adverse climate changes by ameliorating the microclimate, reducing the incidences of pests and diseases, and controlling weed population and cover the risks associated in crop failure. The beneficial effects of mulching, sheltering, and shading could be further exploited under agroforestry to minimize the risks of climate change.

Agroforestry systems in developing countries shall ensure the farmers in gaining additional economic benefits of C sequestration by C trading with developed countries under CDM projects. It will help the farmers to improve their farm economy besides securing environmental benefits to global communities (Antle et al. 2007). However, it is largely depending on the willingness of the farmers to adopt these potential tree-based land-use practices and policies of states to promote climate-resilient farming systems. The development of sustainable agroforestry system technologies is vital to achieve resilience in agroecosystems by linking mitigation and adaptation strategies to secure food production, livelihoods, economy, and unemployment in climate change scenarios in tropics (Jat et al. 2016). The current understanding of the potential of agroforestry to contribute to mitigation and adaptation to climate change is rather limited, and still a lot of research is needed for better understanding the role of agroforestry in buffering climate extremities in diverse socioeconomic and environmental setups in tropics.

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