

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

Abstract:

Impact of climate change on agriculture is the major difficulty which the world is facing, especially developing countries like India will be affecting more due to increased population, water scarcity, decrease in 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. Agroforestry, which is intensive, integrated, intentional, and interactive, it is addressing the issue of ecologically sound and economically appealing strategies of adaptation and mitigation of climate change through carbon sequestration, biodiversity conservation, microclimate amelioration, reduction in green house gas emission.

Key words: Agroforestry, Climate change, farm productivity

Introduction

The climate change is the rule of nature. Climate change is a continuous process. Changing climate has made life possible on earth. Present climatic conditions are congenial for the existence of life on earth but rapid change in the composition of the atmosphere due to increasing greed of human beings unfavourable changes in climate has been noticed. 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, ultimately affecting the food and livelihood security of farmers 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. Changes in temperature and precipitation will alter the distribution of agro-ecological zones and intensify the drought stress in semiarid tropics and sub tropics. Increased frequency of extreme events such as droughts and floods results in losses in agriculture.

Agricultural systems affected by unsustainable management of land and resource degradation which are most vulnerable to climate change. Agricultural practices lead to the reduction in carbon stocks mainly due to removal of aboveground biomass as harvest with subsequent burning and decomposition, loss of soil carbon as CO₂ and loss of soil Carbon by erosion. As much as 25% of the

net annual CO₂ emissions worldwide are caused by tropical deforestation (Schlamadinger and Bernhard,2005). The concentration of CO₂ in the atmosphere is currently 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 CO₂ which is the drive for climate change on a global scale. Conversely, agriculture & plantation could also be a solution for climate change by adoption of mitigation and adaptation strategies (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 farming system, agroforestry is an approach to sustainable land use that integrates agriculture and forestry (Jose and Shibu,2009). By enabling farmers to produce food, fibre, fodder, and fuel simultaneously from the same land, it is an integrated strategy to resolve land-use issues. There are interactions between the many components of an agroforestry system on both ecological and economic level (Bishaw *et al.*, 2003). Agroforestry can generate multiple livelihood and environmental benefits, as it can help to mitigate climate change and help farmers to adapt to extreme and variable weather (IPCC, 2019). It also reduces soil degradation, maintains soil fertility, diversifies the source of income, enhances the efficiency of soil nutrients, carbon sequestration, enhancing water quality, protecting soil and conserving biodiversity (Tamale *et al.*, 1995).The capacity of some agroforestry techniques to capture atmospheric CO₂ and store it in plant biomass and soil has drawn more attention to their net carbon sequestration effect (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.

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

- Agri-silviculture (trees + crops)
- Boundary plantation (trees on boundary + crops)
- Block plantation (block of trees + block of crops)
- Energy plantation (trees + crops during initial years)
- Alley cropping (hedges + crops)
- Agri-horticulture (fruit trees + crops)
- Agri-silvi-horticulture (trees + fruit trees+crops)
- Agri-silvipasture (trees+crops + pasture or animals)
- Silvi-olericulture (trees + vegetables)

- Horti-pasture (fruit trees + pasture or animals)
- Horti-olericulture (fruit trees + vegetables)
- Silvi-pasture (trees+pasture/animals)
- Forage forestry (forage trees + pasture)
- Shelter-belts (trees + crops)
- Wind-breaks (trees + crops)
- Live fence (shrubs and under- trees on boundary)
- Silvi or horti-sericulture (trees or fruit trees + sericulture)
- Horti-apiculture (fruit trees + honeybee)
- Aqua-forestry (trees + fishes)
- Homestead (multiple combinations of trees, fruit trees, vegetable etc.)

Agroforestry for Adaptation and Mitigation

Impact of climate change on agriculture will be one of the major deciding factors influencing the future food security of mankind on the earth. Understanding the weather changes over a period of time and adjusting the management practices towards achieving better harvest are challenges to the growth of agricultural sector as a whole. The climate sensitivity of agriculture is uncertain, as there is regional variation in rainfall, temperature, crops and cropping systems, soils and management practices. The crop losses may increase if the predicted climate change increases the climate variability. With low levels of technology, wide range of pests, diseases and weeds, land degradation, unequal land distribution and rapid population growth, agriculture will affect livelihood.

Agroforestry has huge potential to adapt and mitigate climate change. Many of the time we talk about adaptation and mitigation strategies of agroforestry in context with global warming. Agroforestry provides a unique opportunity to reconcile the objectives of mitigation and adaptation to climate change. Schoreneberger *et al.*, 2012 highlighted the adaptation and mitigation measures and are presented in Table 1.

Table 1. Climate change adaptation and mitigation through agroforestry

| Climate change activity | Major Climate Change Functions | Role of Agroforestry |
|---|--|---|
| Mitigation | | |
| Activities that reduces GHGs in the atmosphere or | Sequester carbon Accumulate C in woody biomass and in soil | Sequester carbon Accumulate C in woody biomass and in |

| | | |
|--|--|--|
| enhance the storage of GHGs stored in ecosystems | | soil |
| | Reduce GHG emission | <p>Reduce fossil fuel consumption:</p> <ul style="list-style-type: none"> ● Reduce equipment runs in areas with trees. ● Reduce farmstead heating and cooling. ● Reduce CO₂ emission by C sink. <p>Reduce N₂O emissions:</p> <ul style="list-style-type: none"> ● By greater nutrient uptake through trees. ● By reducing N fertilizer consumption in tree systems. ● Enhance forage quality, thereby reducing CH₄. |
| Adaptation | | |
| Action to reduce or eliminate the negative effects of climate change or take advantage of the positive effects | Reduce threats and enhance resilience | <p>Amelioration of microclimate to reduce impact of extreme weather events on crop production to maintain quality & quantity of forage to reduce livestock stress.</p> <p>Provide greater habitat diversity to support organisms (e.g. native pollinators & useful insects).</p> <p>Provide greater structural and functional diversity to maintain and protect natural resources.</p> <p>Create diversified production opportunities to reduce risk under fluctuating climate.</p> |
| | Allow species to mitigate to more favorable conditions | Provide habitat corridors for species migration. |

The IPCC lexicon defined adaptation refers to adjustments in ecological, social, or economic systems in response to actual or expected climatic stimuli and their effects or impacts. In order to mitigate possible harm or take advantage of opportunities brought on by climate change, systems, methods, and structures must be changed. The function of agroforestry in lowering the susceptibility of agricultural systems (and

the rural communities that depend on them for their livelihood) to climate change or climate variability must be addressed as adaptation develops as a science (UNFCCC, 2013).

The adaptive measures of agroforestry are:-

- Microclimate amelioration through increasing moisture and lowering temperature
- The effect of shade reduces evapotranspiration from crop and land surface
- High biodiversity which minimizes the pest and disease occurrence
- Buffering agricultural crops against water deficiencies

Therefore, agroforestry mainly consists of woody perennials which have a significant ability to withstand adverse climatic influences and make the overall system sustainable through its coping mechanism.

Agroforestry is an ecologically dynamic, intricate, and sustainable system that offers the chance to "copy" a natural forest on farmland with significant additional advantages for the economy and ecology. Tree systems are capable of enhancing micro climatic conditions in such situations by reducing temperature, evapotranspiration, moisture reduction, acting as a filter, and acting as a buffer against direct sunshine. One of the crucial functions of trees in agroforestry systems to offer sustainability is micro climatic amelioration. Agroforestry systems have been found to boost on-farm production resilience to climatic variability as a way to adapt agriculture to climate change by protecting crops from the effects of temperature and precipitation variation as well as from the strong winds associated with storms (Lin, 2011).

Agroforestry systems provide two important facts from a meteorological perspective: the shade tree concept (radiation) and the mechanistic concept. For the first idea, shade will produce micro climates with smaller seasonal means for the ambient temperature and solar radiation. The shade tree reduces evaporative demands from soil evaporation and crop 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 reduce wind velocity, increasing moisture and decreasing temperature and also providing shelter against direct sunlight. Therefore it is considered as good adaptive strategies of climate change. 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. These help farmers to protect their crops from extreme climatic events by altering the field's weather.

Agroforestry is a system of complex and integrated approach which provides opportunity to intermingle trees, crops, pastures and animals and providing shelter for soil flora & fauna, birds, insects and wildlife. The most effective methods for preserving agro-biodiversity are traditional agroforestry

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.

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 carbon dioxide concentration. Mitigation is nothing but preventing emission and allowing sinks of GHGs through carbon sequestration process. In simple language, adaptation can be carried out at local level but mitigation is at globally. 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' option. Introduction of the resistant plant variety, mixed cropping, reforestation and agroforestry practices are major remedial measure to mitigate climate change which helps to uplift socioeconomic status of people. Therefore, agroforestry can upsurge resilience against environmental change, to enhance carbon sequestration and also to generate income, which will result in improved livelihood of small and subsistence farmers (Buchman, 2008).

Potential of agroforestry systems in Carbon sequestration:

Carbon sequestration is the term used to describe the process of removing more carbon from the atmosphere and depositing it in various "reservoirs". In practical terms, carbon sequestration occurs mostly through the expansion of tree plantation. Numerous researchers have documented the carbon sequestration via agroforestry, including Kaushalet *al.* (2014), Prasad *et al.* (2012), Swami and Puri (2005), Chauhanet *al.* (2010), and RamnewajandDyani.(2008). Agroforestry, the practice of introducing trees in farming has played a significant role in enhancing land productivity and improving livelihoods in both developed and developing countries. It also has the ability to enhance the resilience of the system for coping with the adverse impacts of climate change. Although carbon sequestration through afforestation and reforestation of degraded natural forests has long been considered useful in climate change mitigation, agroforestry offers some distinct advantages. This system can function as sink of carbon (Montagnini and Nair, 2004). Effects of agroforestry practices on the soil carbon pool indicated a rate of increase by 2-3 Mg C/ha/yr (Jose, 2009). The effectiveness of agroforestry systems in storing carbon depends on both environmental and socioeconomic factors and it has the potential to sequester 70 Mg/ha in the top 20 cm of the soil (Mutuoet *al.*, 2005). The carbon storage capacity in agroforestry varies across species and geography (Newajet *al.*, 2008). Further, the amount of carbon in any agroforestry system depends on the structure and function of different components within the systems put into practice.

Depending on the type of system, species mix, soil and climate various agroforestry systems store varying amounts of carbon. Thus, India's agroforestry sector has a total carbon storage capacity of roughly 2400 million tonnes. Author P. K. R. Nair.,2012 quoted that agroforestry is like “low hanging fruits” because of its mitigation potential of climate change and low sequestrating cost (SangramChavanet *al.*, 2014)

Table 2. Carbon sequestration potential (Mg C ha⁻¹yr⁻¹) of various agroforestry systems in India

| Location | Agroforestry System | Tree species | No. of trees per ha | Age (year) | Carbon sequestration potential (Mg C/ha/yr) | References |
|------------------------------------|---------------------|-------------------------|---------------------|------------|---|---|
| Uttarakhand | Agrisilviculture | <i>D. hamiltonii</i> | 1000 | 7 | 15.91 | Kaushalet <i>al.</i> , 2014 |
| Himachal Pradesh | Agrisilviculture | Fruit trees | 69 | - | 12.15 | Goswamiet <i>al.</i> , 2014 |
| Andrapradesh | Agrisilviculture | <i>L. leucocephala</i> | 4444 | 4 | 14.42 | Prasad <i>et al.</i> ,2012 |
| | | | 10000 | 4 | 15.51 | |
| Uttarakhand | Agrisilviculture | <i>P. deltoids</i> | 500 | 8 | 12.02 | Singh and Lodhiyal, 2009 |
| SBS Nagar, Punjab | Agrisilviculture | <i>P. deltoids</i> | 740 | 7 | 9.40 | Chauhanet <i>al.</i> , 2010 |
| Dehradun, Uttarkhand | Silviculture | <i>E. tereticornis</i> | 2500 | 3.5 | 4.40 | Dhyaniet <i>al.</i> , 1996 |
| | | | 2777 | 2.5 | 5.90 | |
| Haryana | Silvipasture | <i>A. nilotica</i> | 1250 | 7 | 2.81 | Kauret <i>al.</i> , 2002 |
| | | <i>E. sissoo</i> | 1250 | 7 | 5.37 | |
| | | <i>P. juliflora</i> | 1250 | 7 | 6.50 | |
| Chandigarh | Agrisilviculture | <i>L.leucocephala</i> | 10666 | 6 | 10.48 | Mittal and Singh, 1989 |
| Tripura | Silviculture | <i>T. grandis</i> | 444 | 20 | 3.32 | Negiet <i>al.</i> 1990 |
| | | <i>G.arborea</i> | 452 | 20 | 3.95 | |
| Tarai central devision, Uttarkhand | Silviculture | <i>T.grandis</i> | 570 | 10 | 3.74 | Negiet <i>al.</i> 1995 |
| | | | 500 | 20 | 2.25 | |
| | | | 494 | 30 | 2.87 | |
| Jhansi, Uttarpradesh | Agrisilviculture | <i>A. procera</i> | 312 | 7 | 3.70 | Ramnewajet <i>al.</i> 2008 Raiet <i>al.</i> 2002 |
| | | <i>A. pendula</i> | 1666 | 5.3 | 0.43 | |
| Hyderabad,Andrapradesh | Agrisilviculture | <i>L. leucocephala</i> | 11111 | 4 | 2.77 | Raoet <i>al.</i> 1991 |
| | | | 6666 | 4 | 1.90 | |
| Raipur, Chattisgarh | Agrisilviculture | <i>G. arborea</i> | 592 | 5 | 3.23 | Swami and Puri 2005 |
| Coimbatore, Tamilnadu | Agrisilviculture | <i>C. equisetifolia</i> | 833 | 4 | 1.57 | Vishwanathet <i>al.</i> 2001 |

| | | | | | | |
|--------|-------------|-----------------|-----|----|------|-----------------|
| Kerala | Home garden | Mixed tree spp. | 667 | 71 | 1.60 | Sahaet al. 2009 |
|--------|-------------|-----------------|-----|----|------|-----------------|

There is also clear evidence to suggest that the type of agroforestry system greatly influences the carbon source or sink role of the trees. For example, agri-silvicultural systems where trees and crops are grown together are net sinks while agro-silvipastoral systems are possibly sources of GHGs. According to IPCC-9 estimation agroforestry systems offer a technical mitigation potential of 1.1-2.2 PgC in terrestrial ecosystems over the next 50 years. By conversion of 630 Mha of unproductive croplands and grasslands to agroforestry a carbon sequestration potential of 977,000 MgC/yr by 2040 can be foreseen (Jose, 2009).

The carbon in the aboveground and belowground biomass in an agroforestry system is generally much higher than land use without trees (*i.e.* crop land without any trees). The potential to sequester carbon in aboveground components in agroforestry systems is estimated to be 2.1×10^9 MgCyear⁻¹ in tropical and 1.9×10^9 MgCyear⁻¹ in temperate biomes (Oelbermann *et al.*, 2004). Agroforestry systems can have indirect effects on carbon sequestration by decreasing the pressure on natural forests which are the largest sinks of terrestrial carbon.

Livelihood security through Agroforestry

Agroforestry can control runoff and soil erosion, thereby reducing losses of water, soil material, organic matter and nutrients. It can check development of soil toxicities, both soil acidification and salinization and trees can be employed in the reclamation of polluted soils, hence ensures farm yield and income (Murthy *et al.*, 2013). The diverse component of agroforestry provides multiple harvests at different times of the year and thus it reduces the risk of crop failure and ensures alternate income for the farmers (Pandey, 2007). Agroforestry increases the resilience of farming systems by buffering against various risks, both biophysically (hydraulic lift, soil fertility) and financially (diversification, income risk) (Verchot *et al.*, 2007). Other advantages include reducing seasonal labor peaks, earn income throughout the year and ensure benefits over the short, medium and long terms even under adverse situations (FAO, 2005). Agro forestry based IFS can create a healthy environment-interaction. These practices can enhance soil, water, air, animal and human resources of the farm (Murthy *et al.*, 2013). Agroforestry practices may use only 5% of the farming land area, yet account for over 50% of the biodiversity, improving the wildlife habitat and harboring birds and beneficial insects which feed on crop pests and insure good production (Makundi *et al.*, 2004).

Government initiatives to encourage agroforestry

The Greening India mission under the National Climate Change Action Plan targets 1.5 Mha of degraded agricultural and fallow lands to be brought under agroforestry; about 0.8 Mha under improved

agroforestry practices on existing lands and 0.7 Mha of additional lands under agroforestry (Puri&Nair, 2004). Much of the opportunity to store carbon through afforestation in India will occur through agroforestry on agricultural lands due to the fact that majority of arable land in India is being cultivated (Ravindranath, 2007).

The total potential for agroforestry has been estimated at 25.36 Mha with almost half of it under tree borne oil seeds, silvi-pasture and others by 2025 (NRCAF, 2007). The National Forest Policy defined by the Government of India in 1988 aims to increase forest and tree cover throughout the country, thereby enhancing forest ecosystem services to local communities (mainly carbon sequestration).

Afforestation and reforestation are currently carried out under various programmes, namely the Farm Forestry Programme launched in the late 1970s; a Social Forestry Programme initiated in the early 1980s; a Joint Forest Management Programme started in 1990; afforestation carried out under National Afforestation and Eco-development Board programmes since 1992; and private farmer and industryinitiated plantation forestry schemes.

The Farm Forestry Programme was launched to create awareness about the benefits of tree planting. Under this initiative, more trees were planted in commercialized and agrarian regions. Developmental policy such as Mahatma Gandhi National Rural Employment Guarantee Act, 2005 contributed to the reduction of greenhouse gas emissions through plantation development and afforestation. In addition, an aggressive afforestation and sustainable forest management programme resulted in annual reforestation of 1.78 M ha during 1985-1997, and is currently 1.1 M ha annually. Due to this, the carbon stocks in Indian forests have increased to 9 -10 gigatons of carbon (GtC) during the years 1986 to 2005.

Conclusion:

Climate change is the most important global environmental challenge which is being faced by all living organisms including humans, natural ecosystems and agriculture. In this situation, agroforestry emerge as a robust farming practice addressing food security problem by providing food for people, mitigate adverse effects of climate change by enhancing environmental quality, sustain economic viability and enhance quality of life. Therefore, agroforestry systems plays an significant role to combat negative impact of climate change by increasing tree-crop diversification that leads to more carbon storage (carbonsequestration) capacity than cultivation of sole agricultural cropsalone. The management of agricultural lands is therefore important toenhance carbon sinks and in turn reduce emissions. Land use management measures such as conservation of existing tree cover, promotion of agroforestry,*etc.*, will not only have positive impacts on biodiversity but also promote the use of biomass fuels by

replacing the fossil fuels, thereby contributing to net reduction in CO₂ emissions and hence serves as best strategy for adaptation and mitigation to climate change.

REFERENCES:

- BISHAW., BADEGE AND ABDU ABDELKADIR., 2003, Agroforestry and community forestry for rehabilitation of degraded watersheds on the Ethiopian highlands. International Symposium on Contemporary Development Issues in Ethiopia.
- BUCHMAN, N., 2008, Agroforestry for carbon sequestration to improve small farmers livelihoods, From the NorthSouth Centre Research for development. *J. of Plant Development Sci.*, **6** (4) : 577-581.
- CHAUHAN, S. K., SHARMA, S. C., CHAUHAN, R., GUPTA, N. AND SRIVASTAVA, R., 2010, Accounting poplar and wheat productivity for carbon sequestration in agrisilviculture system. *Indian Forester.*, **136**(9): 1174-1182.
- DHYANI, S. K., PURI, D. N. AND NARAIN, P., 1996, Biomass production and rooting behaviour of *Eucalyptus tereticornis* Sm. on deep soils and riverbed bouldery lands of Doon Valley, India. *Indian Forester.*, **122**(2):128–136.
- FAO., 2005, Realizing the economic benefits of agroforestry: experiences, lessons and challenges. *State of the World's Forests.*, Pp : 85-99.
- GOSWAMI, S., VERMA, K. S. AND KAUSHAL, R., 2013, Biomass and carbon sequestration in different agroforestry systems of a Western Himalayan watershed. *Biol. Agric. Hortic.*, Pp : 196-204.
- IPCC., 2007, The physical science basis. Contribution of working group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change. Pp :996.
- IPCC., 2019, Special Report on Climate Change, Desertification, Land Degradation, Sustainable Land Management, Food Security and Greenhouse gas fluxes in Terrestrial Ecosystems. Intergovernmental Panel on Climate Change. Pp : 812.
- JOSE AND SHIBU., 2009, Agroforestry for ecosystem services and environmental benefits: an overview. Agroforestry systems. *Climate change mitigation.*, **76**(1): 1-10.
- KAUR, B., GUPTA, S. R. AND SINGH, G., 2002, Carbon storage and nitrogen cycling in silvi-pastoral systems on a sodic soil in northwestern India. *Agrofor. Syst.*, **54**: 21-29.
- KAUSHAL, R., TEWARI, S. K., BANIK, R. L. AND CHATURVEDI, S., 2014, Growth, Biomass Production and Soil properties under different bamboo Species. In: ISTS-IUFRO Conference on Sustainable Resource Management for Climate Change mitigation and social security at Chandigarh, India.

- LIN, B. B., 2011, Agroforestry adaptation and mitigation options for smallholder farmers vulnerable to climate change. CSIRO Climate Adaptation Flagship, PMB 1 Aspendale VIC (3195) Australia.
- MAKUNDI, W.R. AND SATHAYE, J.A., 2004, GHG mitigation potential and cost in tropical forestry- relative role for agroforestry. *Environment, Development and Sustainability* **6**: 235-260.
- MERAGIAW AND MISGANAW., 2017, Role of Agroforestry and Plantation on Climate Change Mitigation and Carbon Sequestration in Ethiopia. *J. of Tree Sci.*,**36**(1): 1-15.
- MITTAL, S. P. AND SINGH, P., 1989, Intercropping field crops between rows of *Leucaena leucocephala* under rainfed conditions in northern India. *AgroforSyst.*,**8**(2):165-172.
- MONTAGNINI, F. AND NAIR, P. K. R., 2004, Carbon sequestration: An underexploited environmental benefit of agroforestry systems. *Agrofor.Syst.*,**61**: 281- 295.
- MURTHY, I. K., GUPTA, M., TOMAR, S., MUNSI, M., TIWARI, R., HEGDE, G.T. AND RAVINDRANATH, N.H., 2013, Carbon Sequestration Potential of Agroforestry Systems in India. *J. Earth Sci. Climate Change.*,**4** (1): 2-7.
- MUTUO, P. K., CADISCH, G., ALBRECHT PALM, C. A. AND VERCHOT, L., 2005, Potential of agroforestry for carbon sequestration and mitigation of greenhouse gas emissions from soils in the tropics. *Nutr.Cycl.*,**71**: 43-54.
- NAIR AND RAMACHANDRAN, P. K., 1993, *An introduction to agroforestry*. Springer Science & Business Media.
- NAIR, P. K. R., 2012, *Advances in Agroforestry*. Agroforestry-The future of global land Use Climate change mitigation: a low-hanging fruit of agroforestry. Springer Nature Publisher, Dordrecht, Switzerland.,**9** : 31-67.
- NEGI, J. D. S., BAHUGUNA, V.K. AND SHARMA, D.C., 1990, Biomass production and distribution of nutrients in two years old teak (*Tectona grandis*) and gamar (*Gmelina arborea*) plantation in Tripura. *Indian Forester.*,**116** (9):681-686.
- NEGI, M. S., TANDON, V. N. AND RAWAT, H. S., 1995, Biomass and nutrient distribution in young teak (*Tectona grandis*) plantation in Tarai Region of Uttar Pradesh. *Indian Forester.*,**121**(6):455-463.
- NEWAJ, R. AND DHYANI, S. K., 2008, Agroforestry for carbon sequestration: Scope and present status. *Ind. J. of Agrofor.*,**10**: 1-9.
- NRCAF, National Research Centre for Agroforestry, 2007, *Vision-2025: NRCAF Perspective Plan* Jhansi, report, India.
- OELBERMANN, M., VORONEY, R.P. AND GORDON, A. M., 2004, Carbon sequestration in tropical and temperate agroforestry systems: a review with examples from Costa Rica and southern Canada *Agriculture Ecosystems and Environment* **104**: 359-377.

- PANDEY, D. N., 2007, Multifunctional agroforestry systems in India. *Current Science*, **92**: 455-463.
- PRASAD, J. V. N. S., SRINIVAS, K., RAO, C. S., RAMESH, C., VENKATRAVAMMA, K. AND VENKATESWARLU, B., 2012, Biomass productivity and carbon stocks of farm forestry and agroforestry systems of *leucaena* and *eucalyptus* in Andhra Pradesh, India. *Current Sci.*, **103**(5): 536-540.
- PURI, S. AND NAIR, P. K. R., 2004, Agroforestry research for development in India: 25 years of experiences of a national program. *Agroforestry Systems*, **61**: 437-452.
- RAI, A. K., SOLANKI, K. R. AND RAI, P., 2002, Performance of *Anogeissus pendula* genotypes under Agri-silvi-culture system. *Indian J. of Agroforestry.*, **4**(1): 71-77.
- RAMNEWAJ AND DHYANI, S. K., 2008, Agroforestry for carbon sequestration: Scope and present status. *Indian J. Agroforestry.*, **10**: 1-9.
- RAO, M. R., ONG, C. K., PATHAK, P. AND SHARMA, M. M. 1991, Productivity of annual cropping and agroforestry systems on a shallow Alfisol in semi-arid India. *Agrofor.Syst.*, **15**: 51-63.
- RAVINDRANATH, N. H., 2007, Mitigations and adaptation synergy in forest sector. *Mitigation and Adaptation Strategies for Global Change.*, **12**: 843-853.
- SAHA, S., NAIR, P. K. R., NAIR, V. D. AND KUMAR, B. M., 2009, Soil carbon stocks in relation to plant diversity of home gardens in Kerala, India. *Agrofor.Syst.*, **76**: 53-65.
- SANGRAM CHAVAN., RAM NEWAJ., KEERTHIKA, A., ASHA RAM., ANKUR, J. AND ANIL KUMAR., 2014, Agroforestry for Adaptation and Mitigation of Climate Change. *Pop.Kheti.*, **2**(3): 214-219.
- SCHLAMADINGER AND BERNHARD., 2005, *Carbon forestry*. Proceedings of workshop on carbon sequestration and sustainable livelihood, Centre for International Forestry Research, Chapter : **03**, P p : 26-41.
- SCHOENEBERGER, M., BENDRUB, G., GOOIJER, H., SOOLANAYAKANAHAL, R., TOM SAUER., BRANDLE, J., ZHAN, X. AND DEN CUER., 2012, Branching out: agroforestry as a climate change mitigation and adaptation for agriculture. *J. of Soil and Water Conserv.*, **67**(5): 128-136.
- SINGH, P. AND LODHIYAL, L. S., 2009, Biomass and carbon allocation in 8-year-old poplar (*Populus deltoides* Marsh) plantation in Tarai agroforestry systems of central Himalaya, India. *New York Sci. J.*, **2**: 49-53.
- SWAMY, S. L. AND PURI, S., 2005, Biomass production and C-sequestration of *Gmelina arborea* in plantation and agroforestry system in India. *Agrofor.Syst.*, **64**(3): 181-195

- TAMALE, E., JONES, N. AND RIDDIHOUGH, I. P., 1995, Technologies related to participatory forestry in tropical and sub-tropical countries. *World bank Technical papers*, Paper number-299.
- UNFCCC., 2013, United Nations Framework Convention on Climate Change, The United Nations Climate Change Conference, COP19 or CMP9 was held in Warsaw, Poland.
- VERCHOT, L. V., NOORDWIJK, M. V., KANDJI, S., TOMICH, T. AND ONG, C., 2007, Climate change: linking adaptation and mitigation through agroforestry. *Mitigation and Adaptation Strategies for Global Change*, **12**: 901-918.
- VISWANATH, S., PEDDAPPAIAH, R. S., SUBRAMONIAM, V., MANIVACHAKAM, P. AND GEORGE, M., 2004, Management of *Casuarinaequisetifolia* in wide-row intercropping systems for enhanced productivity. *Indian J. Agroforestry*, **6**(2):19-25.

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