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AGROFORESTRY FOR MITIGATING CLIMATE CHANGE IMPACTS

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ABSTRACT

Climate change resulting in shift of temperature and weather pattern over a longer period of time. These changes might have occurred naturally, for instance through variations in the solar cycle. However, human activities like burning of fossil fuels, deforestation, emission of greenhouse gases, pollution and ever-increasing population are the primary cause of climate change. Nearly, 30% of the world's greenhouse gas (GHG) emissions are the cause of agriculture, which is also the main driver of 80% of tropical deforestation. Agroforestry is a land use management systems and technology where woody perennial plants (tree, shrubs, herbs etc.) are deliberately introduced in the same land management practices, along with the agricultural crops and/or livestock, in a spatial temporal sequence (ICRAF, 1982). It is a robust and resilient sustainable farming technique that could successfully address the climatic catastrophe. Planting of the appropriate plant in the appropriate cropping system can aid in the alleviation of harmful effects of climate change. Permanent tree covers along with varied ecological niches in agroforestry system can act as buffer in climate unpredictability.

Mitigation of climate change mainly takes the form of carbon sequestration, e.g. biomass, either above or below ground. Adaptation to climate change is very much a function of soil organic matter content and diversified, multispecies cropping technologies and agroforestry performs well on the above criteria and thus is a preferred approach to develop synergies between adaptation and mitigation.Agroforestry enhance the uptake of CO_2 or reduce its emission and has the potential to remove a significant amount of CO_2 from the atmosphere, if the trees are harvested, accompanied by replanting of same and/or other area, and sequestered carbon is locked through non-destructive use of such wood. Agroforestry systems are promising land use system to increase aboveground and belowground C stock to mitigate greenhouse gas emissions.
***Keywords*:** Green House gas, Deforestation, Climate, Agroforestry

Introduction

Climate change resulting in shift of average weather parameters-such as temperature, wind and rain experienced in a region over a longer period of time. These changes might have occurred naturally, for instance through variations in the solar cycle. However, human activities like burning of fossil fuels, deforestation, emission of greenhouse gases, pollution and ever-increasing population are the primary cause of climate change. Burning fossil fuels generates greenhouse gas emissions that act like a blanket wrapped around the Earth, trapping the sun's heat and raising temperatures. Nearly, 30% of the world's greenhouse gas (GHG) emissions are the cause of agriculture, which is also the main driver of 80% of tropical deforestation. In the atmosphere, gases such as water vapour, carbon dioxide, ozone, and methane act like the glass roof of a greenhouse by trapping heat and warming the planet. These gases are called greenhouse gases. The natural levels of these gases are being supplemented by emissions resulting from human activities, such as the burning of fossil fuels, farming activities and land-use changes. As a result, the Earth's surface and lower atmosphere are warming. Even small rises in temperature are accompanied by many other changes. Rising levels of greenhouse gases are already changing the climate. According to the IPCC report, (2014) changes in climate are unequivocal and anthropogenic greenhouse gases are the major drivers of this change. The emission of greenhouse gases has become a matter of great concern because of the future projection of the global warming and related effects on biological life. Examples of greenhouse gas emissions that are causing climate change include carbon dioxide and methane. These come from using gasoline for driving a car or coal for heating a building, for example. Clearing land and forests can also release carbon dioxide. Landfills for garbage are a major source of methane emissions. Energy, industry, transport, buildings, agriculture and land use are among the main emitters. And emissions continue to rise. As a result, the Earth is now about 1.1°C warmer than it was in the late 1800s. The last decade (2011-2020) was the warmest on record. The consequences of climate change now include, among others, intense droughts, water scarcity, severe fires, rising sea levels, flooding, melting polar ice, catastrophic storms and declining biodiversity. Human activities accelerating the de-glaciation process.

Climate change: Impact and Causes

Deforestation: It is the removal of a forest or stand of trees from land that is then converted to non-forest use. Deforestation can involve conversion of forest land to farms, ranches, or urban use. Cutting down forests to create farms or pastures, or for other reasons, causes emissions, since trees, when they are cut, release the carbon they have been storing. Each year approximately 12 million hectares of forest are destroyed. Since forests absorb carbon dioxide, destroying them also limits nature's ability to keep emissions out of the atmosphere. Deforestation, together with agriculture and other land use changes, is responsible for roughly a quarter of global greenhouse gas emissions.

Pollution: Pollution is the introduction of contaminants into the natural environment that cause adverse change. Pollution can take the form of any substance or energy. It mainly from manufacturing and industry produce emissions, mostly from burning fossil fuels to produce energy for making things like cement, iron, steel, electronics, plastics, clothes, and other goods. Mining and other industrial processes also release gases, as does the construction industry. Machines used in the manufacturing process often run on coal, oil, or gas; and some materials, like plastics, are made from chemicals sourced from fossil fuels. The manufacturing industry is one of the largest contributors to greenhouse gas emissions worldwide.

Increasing population: The world's population is more than three times larger than it was in the mid-twentieth century. Actual global human population growth amounts to around 83 million annually, or 1.1% per year. The global population has grown from 1 billion in 1800 to 7.9 billion in 2020.When the population are increasing day by day but land area is not increasing accordingly. Human need food and shelter for their livelihood.

Globally, residential and commercial buildings consume over half of all electricity. As they continue to draw on coal, oil, and natural gas for heating and cooling, they emit significant quantities of greenhouse gas emissions. Growing energy demand for heating and cooling, with rising air-conditioner ownership, as well as increased electricity consumption for lighting, appliances, and connected devices, has contributed to a rise in energy-related carbon-dioxide emissions from buildings in recent years.

Threatened biodiversity: Climate change is likely to become the dominant direct driver of biodiversity loss by the end of the century. Projected changes in climate, combined with land use change and the spread of exotic or alien species, are likely to limit the capability of some species to migrate and therefore will accelerate species loss.

Drought: Climate change increases the odds of worsening drought in many parts of the United States and the world. Regions such as the U.S. Southwest, where droughts are expected to get more frequent, intense, and longer lasting, are at particular risk.Warmer temperatures enhance evaporation, which reduces surface water and dries out soils and vegetation. This makes periods with low precipitation drier than they would be in cooler conditions.Climate change is also altering the timing of water availability.Warmer winter temperatures are causing less precipitation to fall as snow in the Northern Hemisphere, including in key regions like the Sierra Nevada of California.Decreased snowpack can be a problem, even if the total annual precipitation remains the same.

Flood: Floods are made more likely by the more extreme weather patterns caused by long-term global climate change. Change in land cover-such as removal of vegetation and climate change increase flood risk.

Land degradation: The deterioration or loss of the productive capacity of the soils for present and future is a global challenge that affects everyone through food insecurity, higher food prices, climate change, environmental hazards, and the loss of biodiversity and ecosystem services. Land degradation is happening at an alarming pace, contributing to a dramatic decline in the productivity of croplands and rangelands worldwide.

Land degradation is one of the world's most pressing environmental problems and it will worsen without rapid remedial action. Globally, about 25 percent of the total land area has been degraded. When land is degraded, soil carbon and nitrous oxide is released into the atmosphere, making land degradation one of the most important contributors to climate change. Scientists recently warned that 24 billion tons of fertile soil was being lost per year, largely due to unsustainable agriculture practices. If this trend continues, 95 percent of the Earth's land areas could become degraded by 2050.

Hunger: Extreme weather is a driver of world hunger. As global temperatures and sea levels rise, the result is more heat waves, droughts, floods, cyclones and wildfires. Those conditions make it difficult for farmers to grow food and for the hungry to get it. India ranks 107th out of the 121 countries with sufficient data to calculate 2022 GHI scores. With a score of 29.1, India has a level of hunger that is serious.

Malnutrition: Climate change can influence nutrition through the infectious disease pathway. Malnutrition can worsen infectious diseases, which in turn are influenced by water security and can increase the risk of malnutrition, by reducing nutrient absorption. Child malnutrition will increase by 20% due to climate change and other determinants by 2050.

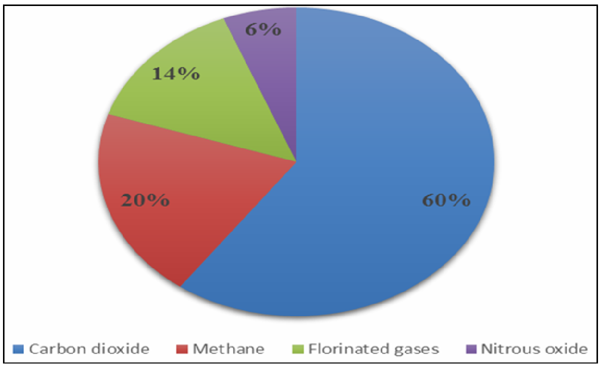


Fig. 1: Relative Contribution of Major Greenhouse to Global warming (Sources: WRI, 2021; FAO, 2020)

Concept of CSA by FAO: Trees are key component

Climate-smart agriculture is an approach for transforming and reorienting agricultural production systems and food value chains so that they support sustainable development and can ensure food security under climate change. As noted in the overview to this module, climate-smart agriculture has three main objectives: sustainably increase agricultural productivity and incomes; adapt and build resilience to climate change and reduce and/or remove greenhouse gas emissions, where possible. Climate-smart agriculture is not a set of practices that can be universally applied, but rather an approach that involves different elements that are embedded in specific contexts and tailored to meet local needs. Climate-smart agriculture builds on sustainable agriculture approaches, using principles of ecosystem and sustainable land and water management and landscape analysis, and assessments of the use of resources and energy in agricultural production systems and food systems. Climate-smart agriculture relates to actions in fields, pastures, forests, and oceans and freshwater ecosystems. It involves the assessment and application of technologies and practices, the creation of a supportive policy and institutional framework and the formulation of investment strategies. Climate-smart agricultural systems include different elements such as:

- The management of land, crops, livestock, aquaculture and capture fisheries to balance near-term food security and livelihoods needs with priorities for adaptation and mitigation;
- Ecosystem and landscape management to conserve ecosystem services that are important for food security, agricultural development, adaptation and mitigation;
- Services for farmers and land managers that can enable them to better manage the risks and impacts of climate change and undertake mitigation actions; and
- Changes in the wider food system including demand-side measures and value chain interventions that enhance the benefits of climate-smart agriculture.

Agroforestry is a best example of Climate-smart agriculture.

Agro-forestry:

Agro-forestry begins with placing the right plant, in the right place, for the right purpose.

Toria as intercrop in Jackfruit

Fodder as intercrop in Manjum

Why Agroforestry?

- 9.1 Billion People in 2050 will require 70 per cent increase in global food production *(U.N. Food & Agric. Org)*

THE REAL QUESTIONIS: *Can we find a way to make food and energy production sustainable? THE ANSWER INCLUDES:* ***AGROFORESTRY***

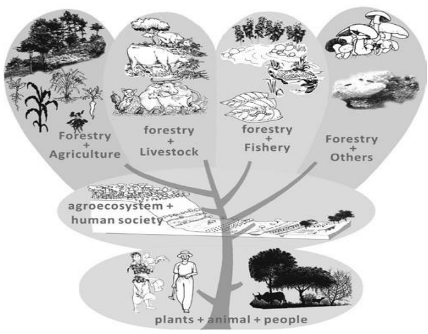


Fig. 2: Agroforestry is an integrated dynamic system

In this figure various integrations are shown with different agroforestry practice which finally leads to a successful plant + animal + people integration.

What is Agroforestry?

Agroforestryis a land use systems and technology where woody perennial plants (tree, shrubs, herbs etc.) are deliberately introduced in the same land management practices, along with the agricultural crops and/or livestock, in a spatial temporal sequence(ICRAF).

Forest and tree cover area in India and Assam:

The total forest and tree cover in India is 80.9 million hectares, which is 24.62% of the geographical area of the country. As compared to the assessment of 2019, there is an increase of 2,261 sq km in the total forest and tree cover of the country in last two years. Total forest and tree cover in the state of Assam is 29,237 sq km which is 37.27% of the geographical area.

(Source: India State of Forest Report 2021, Forest Survey of India)

Area under agroforestry in India:

Though agroforestry is being practised in large parts of the country in one or another and has been adopted by the farmers in different agro-climatic zones, periodic estimation and monitoring of the area under it is still a challenging task due to lack of uniform methodology adopted by the different agencies (Kumar, 2014). The current approximate area under agroforestry is estimated to be 25.32 million hectares, or 8.2% of the total geographical area of the country according to (Dhyani2014). Based on data from CAFRI, Jhansi and Bhuvan LISS III, the area under agroforestry is 13.75 m ha (Rizvi*et al.,* 2014). However, Forest Survey of India (FSI; 2013) estimated the same as 11.54 m ha, which is 3.39% of the geographical area of the country. Maharashtra, Gujarat and Rajasthan rank high in state-wise area under agroforestry.

Dhyani, 2014

Agroforestry Practices:

Alley Cropping: Growing of an annual or perennial crop between the rows of high value trees.

Benefits:

- Crop Protection & Production,
- Economic Diversification,
- Nutrient Utilization,
- Soil Erosion Control,

Silvipasture: It is the practice of integrating trees, forage and the grazing of domesticated animals on the same piece of land same piece of land.

Benefits:

- Annual Grazing Income,
- Long-Term Timber Income,
- Lower Animal Stress,
- Reduced Wildfire Risk,
- Wildlife Benefits,
- Visually Pleasing,
- Carbon Sequestration,

Forest farming: It is the cultivation of high-value specialty crops under the protection of a forest canopy that has been modified to provide the correct shade level. Crops like ginseng, shiitakemushrooms, and decorative ferns are sold for medicinal, culinary, and ornamental uses.

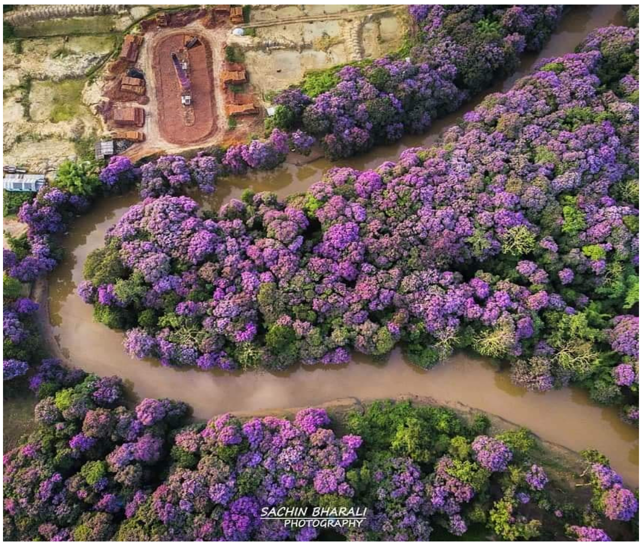
Benefits:

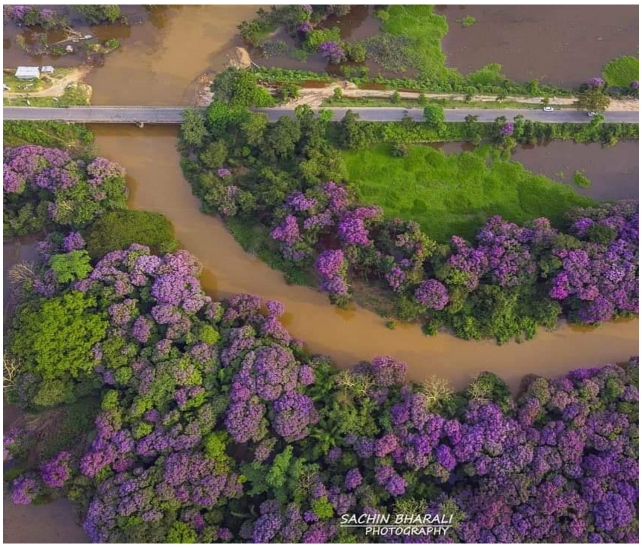
- Provide shorter-term income,
- Long-Term Timber Income,
- Lower Animal Stress,
- Reduced Wildfire Risk,

Riparian Forest Buffers: A riparian forest buffer is an area adjacent to a stream, lake, or wetland that contains a combination of trees, shrubs, and/or other perennial plants and is managed differently from the surrounding landscape, primarily to provide conservation benefits.

Benefits:

- Stabilizing eroding banks,
- Providing shade, shelter, and food for fish and other aquatic organisms,
- Protecting cropland and downstream communities from flood damage,





Wind breaks: A windbreak (shelterbelt) is a planting usually made up of one or more rows of trees or shrubs planted in such a manner as to provide shelter from the wind and to protect soil from erosion. They are commonly planted in hedgerows around the edges of fields on farms.

Benefits:

- Reduce soil loss,
- Increase crop yield,
- Protect livestock,

Multi storied Farming: Multistoried cropping are multi-layer cropping and multi-tire cropping. It is one kind of intercropping. Growing plants of different height in the same field at the same time is termed as multistoried cropping. It is mostly practiced in orchards and plantation crops for maximum use of solar energy.

Bora *et al.,* 2019

Agroforestry systems: Different agro forestry systems are

i) **Agri-silviculture:** Agri-silviculture is a production technique which combines the growing of agricultural crops with simultaneously raised and protected forest crops. A similar practice involving forest villagers and tribesmen is known as the "taungya system" in Asia.

ii) **Silvipastoral system:** (Tree+ pasture/animal) The production of woody plants combined with pasture is referred to as *Silvipastoral system*. The trees and shrubs used primarily to produce fodder for livestock. This *system* is needed in dry area to meet the fodder demand throughout the year.

iii) **Agrisilvipastoral system:** (Tree Crops + Grain crops + animals) This is the system in which the forest tree crops for fodder like Anjan, Subabhul, Babhul, Tamrind, Hadga and Khejedi etc. are taken withinter crops of grasses like Stylo, Burssem, Haemeto are taken for fodder purpose as well as the food grain crop like Wheat, Rice, Jowar etc. are taken in between the strips of forest tree species. The forest tree species are planted at 10 to 12 m distance and in the lines the grasses and food grains are cultivated as intercrop.

iv) **Horti-silviculture system:** This system is defined as growing of trees and fruit trees or ornamental trees or vegetables/flower together in same lands at the same time. This system is common in home gardens.

v) **Agri-horticulture system:** It is a land management system in which agricultural crops are grown on space between two rows of fruit tree species. Integration of fruit crops in croplands is referred to as *agrihorticultural* land use *system* of Agroforestry.

vi) **Agrihortisilviculture system:** In this system, in addition to arable crops, MPTS (Multi-Purpose Tree Species) like Subabul, are grown along with fruit trees like ber and aonla. The MPTS, besides providing green fodder and fuel wood annually, also protect the fruit trees from hot winds in the summer and cold winds in the winter and improve the soil by virtue of their nitrogen-fixing abilities. It is possible to grow 100to 400 fruit trees per hectare along with arable and also with MPTS like Subabul (200 to 400 perha) which are planted in between the fruit trees.

vii) **Multipurpose forest tree production** (**MPTS** other specialized agroforestry systems): *Multipurposetrees* are *trees* that are deliberately grown and managed for more than one *output*. They may supply food in the form of fruit, nuts, or leaves that can be used as a vegetable; while at the same time supplying firewood, add nitrogen to the soil, or supply some other combination of multiple outputs. "*Multipurpose* tree" is a term common to agroforestry, particularly when speaking of tropical agroforestry where the tree owner is a subsistence farmer.

viii) **Apiculture with trees:** In this system various honey (nector) producing trees frequently visited by honeybees are planted on the boundary of the agricultural fields.

ix) **Aqua silviculture or Aquaforestry:** It is a management strategy that combines and harmonizes fish production and mangrove development. In this system various trees and shrubs preferred by fish are planted on the boundary and around fish ponds.

x) **Agrisilviaquaculture:** In paddy field, fish can easily be reared by planting trees on field bunds or boundary. A land management system followed in high rainfall areas which involve rearing of fish in fields and planting of trees on bunds or boundary.

Bora *et al.,* 2019

Agroforestry Models In North-Eastern States of India:

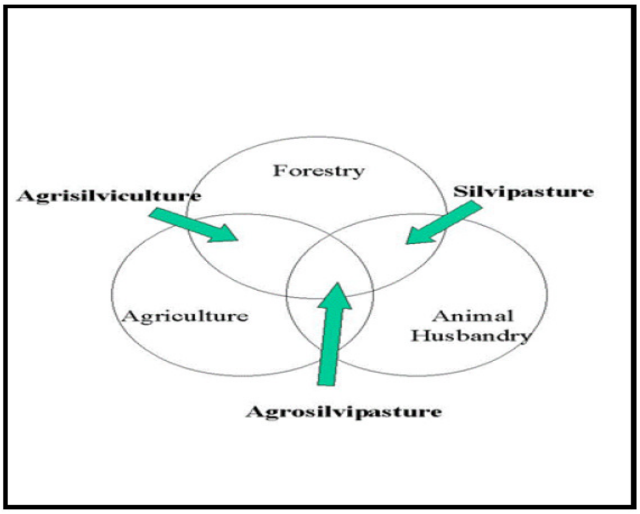
About 80% of the people of north-east India lives in the rural areas and almost all of them are directly or indirectly concerned with agriculture. Farmers, in this region, are generally small holders and an attempt with agroforestry practices can result an increase in their earnings without endangering the fragile ecosystem. So far as geographical location and socio-cultural behaviour of the people are concerned, the following systems has edge over other systems of agroforestry in NE region of India-

- Agri-Silviculture: (crops + trees)
- Agri-Horticulture: (crops + fruit trees)
- Silvi-Pasture: (trees + fodder crops)
- Horti- Pasture: (fruit trees + fodder crops)
- Agri-Horti-Silviculture: (crops + fruit trees + trees)
- Homestead Agroforestry : (may be the mixtures of crops, vegetables, fruit trees, fodder crops and trees)

Thus, agroforestry in north- east India holds a great potential to make a positive and significant contribution to agricultural output, besides raising fuel-wood, timber, fodder, milk and meat production in one way and conserving the soil and water in other.

Gogoi, 2015

Interrelationship of different components in agroforestry:



Objectives of Agroforestry

- To utilize the available farm resource properly
- To maximize per unit production of food, fodder, fuel
- To optimizing-biological and physiological resources
- To maintain the ecological balance
- To check soil erosion, conserves oil moisture and increase the soil fertility

Tree species to be chosen for Agroforestry:

a) They should be amenable to early wide spacemen.

b) They should tolerate relatively high incidence of pruning, i.e., their photosynthetic efficiency should not decrease with heavy pruning.

c) They should belight branching in their habit.

d) They should betolerant to side shades.

e) Their phenology, particularly with reference to leaf lushing and leaf fall, should be advantageous to the growth of the annual crop in conjunction with which they are being raised.

f) The rate of litter fall and litter decomposition should have positive effects on the soil.

g) Their root system sand root growth characteristics should ideally result exploration of soil layers that are different to those being tapped by agricultural crops.

Gill and Roy, 2012

Agroforestry Model for Assam:

(1) Agaru (*Aquilariamalaccensis*Lam.)

Agroforestry Model: Agri-Silviculture, Horti-Silviculture, Aqua-Silviculture

Common Name: Eagle wood tree, Agar tree
Trade name: Agar tree
Assamese name: Agaru, Sanchi
Family: Thymelaeaceae

Suitable Intercrop

Any crop can be grown when agar tree is planted in boundary. In block plantation of Agaru, vegetables/pulses/fruits or medicinal and aromatic crops like Patchouli, Sugandh mantri, Kalmegh, Gathion, Pineapple, etc. can be cultivated during first 3-5 years of plantation. Ginger/turmeric may also be planted during initial 2 to 3 years. In later stages shade tolerant medicinal plant like Sarpagandha, Pipali and Kalmegh can be grown successfully depending on tree population and land situation. In homestead Agaru can also be grown along with areca nut, coconut, banana, etc.

Agaru in *Baree*

(2) Baghnala (*Litseaglutinosa*(Lour) C.B.Rob.)

Agroforestry Model: Agri-Silviculture, Horti-Silviculture

Common Name: Indian Laurel
Trade Name: Maidalakri
Assamese Name: Baghnala
Family: Lauraceae

Suitable Intercrop

Mixed planting of bean, groundnut and other legumes can also be done in first two years. It is recommended for forest planting in mixed system/agroforestry system.

(3) Bhaluka banh (*Bambusabalcooa* Roxb.)
Agroforestry Model: Agri-Silviculture, Horti-Silviculture
Common Name: Balcooa Bamboo
Assamese name: Bhaluka banh
Family: Poaceae

Suitable intercrop

Intercrops such as pineapple, banana, ginger and turmeric can be grown up to 4th year; however, due to profuse canopy of bamboo inter crops cannot be grown thereafter.

Pineapple and turmeric as intercrop in Jati

Pineapple and banana as intercrop in Bhaluka

Bamboo being C4 plant contributes a lot for carbon sequestration and thereby cleanses the environment. Above ground C stock of Balcooa bamboo has been estimated as 84.06 Mg/ha in 10 years plantation.

(4) Coconut (*Cocos nucifera*L.)

Agroforestry Model: Agri-Horticulture, Horti-Horticulture, Aqua- Horticulture
Common Name: Coconut
Assamese name: Narikal
Family: Palmaceae

Suitable intercrop

Crops like fodder (maize, sorghum. Oat, hybrid napier, etc.), rice nursery, pineapple, turmeric, ginger, banana (chenichampa & kachkal), assam lemon and vegetables like pumpkin, french bean, okra, brinjal, cowpea, colocasia, etc. Companion crops like black pepper, betel vine and Dioscorea.

Fodder as intercrop in Coconut

Turmeric as intercrop in Coconut

The species has immense potentialities for cleaning environment by fixing carbon. Above ground C stock of 35 year old coconut orchard is 10.165 Mg/ha.

(5) Gomari (*Gmelina arborea* Roxb.)

Agroforestry Model: Agri-Silviculture, Horti-Silviculture
Common Name: Gmelina
Trade name: Gamhar
Assamese name: Gomari
Family: Verbanaceae

Suitable intercrop

Field crops can be grown as intercrop up to 3rd year of plantation. Thereafter some shade tolerant crops like Pineapple, Turmeric, Ginger, vegetables and fodder etc. can be cultivated as intercrop. Black pepper, Betle vine and Dioscorea may be grown as companion crops.

Toria as intercrop in Gomari

Above ground C stock of 16 year old Gomari tree is 471.59 Mg/ha

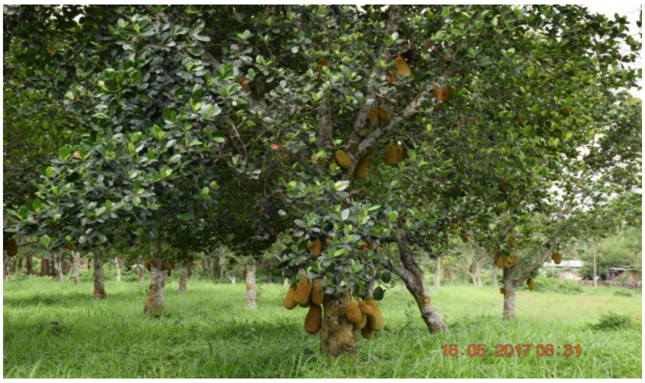
(6) Jackfruit (*Artocarpus heterophyllus* Lam.)

Agroforestry Model: Agri-Horticulture, Horti-Silviculture, Hori-Horticulture
Common Name: Jackfruit, Jak, Jack tree
Assamese name: Kothal
Family: Moraceae

Suitable intercrop

Field crops like sesamum in kharif and niger/toria in rabi season, vegetables, spices, pineapple and fodder crops can be grown as intercrop up to 8th year of plantation. Fodder crop like hybrid napier can be grown thereafter. In homestead jackfruit can be grown along with other fruit crops like mango, coconut, areca nut, pineapple, etc.

Toria as intercrop in Jackfruit



Jackfruit block plantation

It is found that 14 years old jackfruit plantation results in above ground C stock of 44.06 Mg/ha.

(7) Mahaneem (*Azadirachta indica*A. Juss.)

Agroforestry Model: Agri-Silviculture, Horti-Silviculture
Common Name: Neem
Trade name: Neem
Assamese name: Mahaneem
Family: Meliaceae

Suitable intercrop

All the field crops including oilseeds and pulses, vegetables, spices, pineapple and forage crop can be grown.

Mahaneem at boundary

(8) Sisu (*Dalbergiasissoo*Roxb. ex DC.)

Agroforestry Model: Agri-Silviculture, Horti-Silviculture
Common Name: Indian Rosewood
Trade name: Shisham, Sissoo, Sisu
Assamese name: Sisu
Family: Fabaceae

Suitable intercrop

Sisu is suitable for plantation in the boundary of crop field. Intercropping of different field and horticultural crops in the plantation at a wider spacing of 4 m x 4 m can be done.

Sisu at pond dyke

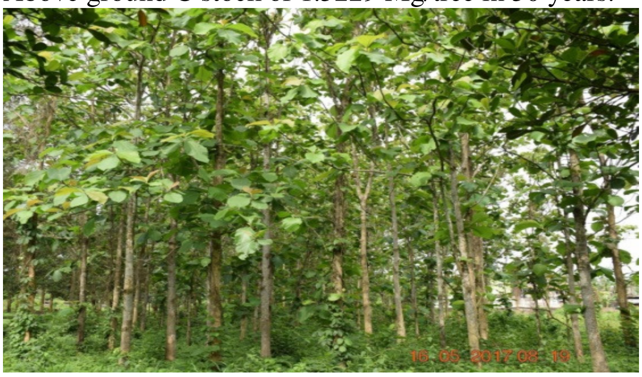
(9) Teak (*Tectona grandis* L.f.)

Agroforestry Model: Agri-Silviculture, Horti-Silviculture
Common Name: Indian Oak, Teak
Trade name: Teak
Assamese name: Chegun

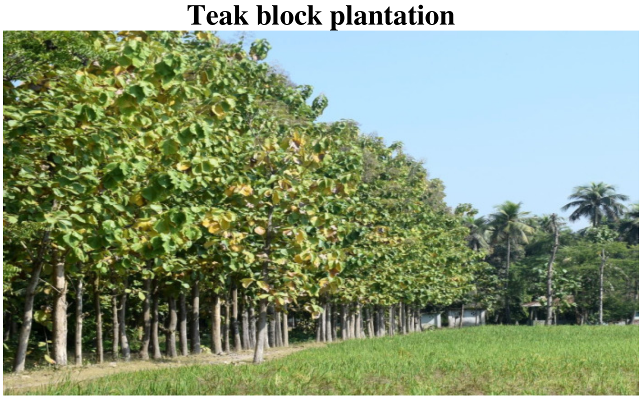
Suitable intercrop

In boundary plantation any field or horticultural crop may be grown as intercrop. The common intercrops are *Ahu* rice, chilli, maize, wheat, sesame and various vegetables. In between two rows of Teak tree crops like Subabul, Glyricidia, etc. can also be grown.

Above ground C stock of 1.5229 Mg/tree in 50 years.



Teak block plantation



Teak at boundary

(Source: AICRP on Agroforestry, HRS, AAU,Kahikuchi, Guwahati)

Useful Tree Species of North East India:

Based on the research findings and field observations, the following tree species have beenrecommendedforagro-forestry,under IndianconditionsincludingNorth-easternregion are:

Foddercum Fuel wood species:

1. Amara (*Albizia amara*)
2. Coroltree (*Erythrina sp.*)
3. Gliricidia (*Gliricidia sepium*)
4. Anjan (*Hardwickia binata*)
5. Subabul (*Leucaena leucocephala*)
6. Madrasthorn *(Pithecellobium dulce*)
7. Shevari (*Sesbania sesban*)

Fuel wood and Timber species:

1. Babul (*Acacia nilotica*)
2. Siris (*Albizia lebbeck*)
3. White Siris (*Albizia procera*)
4. Neem(*Azadiracta indica*)
5. Casuarina (*Casuarina equisetifolia*)
6. Shishum (*Dalbergia sissoo*)
7. Bamboo (*Dendrocalamus strictus*)
8. Pongamia (*Derris indica*)
9. Horsebean (*Parkinsonia aculeata*)
10. Portia (*Thespesia populnea*)

Soft wood and Pulp wood species:

1. Tree of Heaven (*Ailanthus excelsa*)
2. Dhup (*Ailanthus tryphysa*)
3. Silkcotton (*Bombax ceiba*)
4. White Albizia (*Paraserianthes falcataria*)
5. Poplar(*Populus deltoides*)

Fruitand Vegetable species:

1. Ramphal (*Annona reticulata*)
2. Custardapple (*Annonas quamosa*)
3. Jackfruit(*Artocarpus heterophylus*)
4. Amala (*Emblica officinalis*)
5. Drumstick (*Moringa oleifera*)
6. Ber (*Zizyphus mauritiana*)

Heavy rainfall and High watertable:

1. Bamboo (*Dendrocalamus strictus*)
2. Arjun(*Terminalia arjuna*)
3. Eucalyptus (*Eucalyptus grandis*)
4. Porita (*Thespesia populnea*)
5. Pongamia (*Derris indica*)
6. Sesbania (*Sesbania sesban*)
7. Whitesiris (*Albizia procera*)
8. Casuarina (*Casuarina equisetifolia*)
9. Silkcotton (*Bombax ceiba*)

Dry areas:

1. Babul (*Acacia nilotica*)
2. Amara (*Albizia amara*)
3. Custardapple (*Annonas quamosa*)
4. Neem (*Azadiracta indica*)
5. Dassod (*Cassia siamea*)
6. Horsebean (*Parkinsonia aculeata*)
7. Khejdi (*Prosopis cineraria*)
8. Ber (*Zizyphus mauritiana*)
9. Agaves pp.

Well managed irrigated areas:

1. Whitesiris (*Albizia procera*)
2. Casuarina (*Casuarina equisetifolia*)
3. Shishum(*Dalbergia sissoo*)
4. Gliricidia (*Gliricidia sepium*)
5. Anjan (*Hardoickia binata)*

(Source: N.G.Hegde, BAIF,1994)

Agroforestry: well-known buffering and resilience effects:

- Climate variability is well buffered by agroforestry because of permanent tree cover and varied ecological niches.
- Resilience or recovering after a disturbance (e.g. extreme weather events, or market failure) is well performed by agroforestry because of diversified temporal and spatial management options.

Sanchez (1995), Garrity*et al.* (2010)

Examples of criteria for the sustainability attributes of agroforestry:

- ❖ Permanent tree cover protects and improves the soil, while increasing soil carbon stocks
- ❖ Varied ecological niches allow for the presence of different crops, e.g. shade-tolerant and light-demanding
- ❖ Diversification of commodities allows for adjustment to market needs.
- ❖ Management flexibility is compatible with shifts in labour supply
- ❖ Non-harvested components play an important protective role

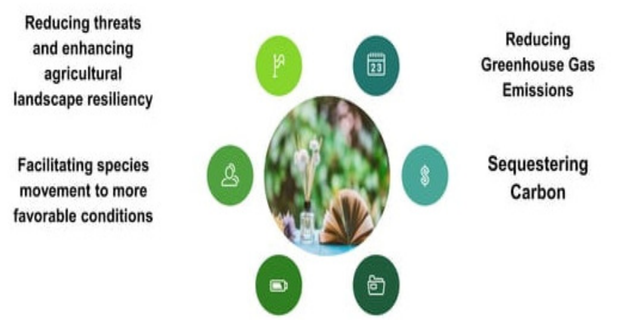
Agroforestry can boost synergy between adaptation to and mitigation of climate change:

- ➢ Mitigation of climate change mainly takes the form of carbon sequestration, e.g. biomass, either above or below ground
- ➢ Adaptation to climate change is very much a function of soil organic matter content and

diversified, multispecies cropping technologies

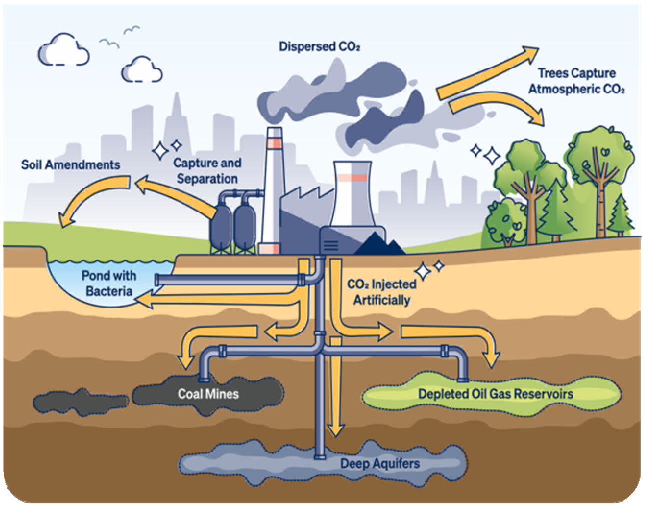
- Agroforestry performs well on the above criteria and thus is a preferred approach to develop synergies between adaptation and mitigation
- Agroforestry improved fallows provide an example of such synergy

Agroforestry- as climate change solution



Carbon sequestration:

According to the U.S. Geological Survey (USGS), carbon sequestration is the process of capturing and storing atmospheric carbon dioxide. It is one method of reducing the amount of carbon dioxide in the atmosphere with the goal of reducing global climate change.



Status of Carbon stock in India:

- Total carbon stock in country's forest is estimated to be 7**,204 million tonnes** and there an increase of **79.4 million tonnes** in the carbon stock of country as compared to the last assessment of 2019. The annual increase in the carbon stock is **39.7 million tonnes**.

(Source: India State of Forest Report 2021, Forest Survey of India)

Table 1 : Comparison of different pillars of 3 m length designed for the same load of 20 kN

Materials	Primary energy input for production (kWh)	Resulting CO_2 emissions (kg)
Wood	60	15
Steel	561	126
Concrete	221	54
Brick	108	26

Burschel and Kursten (1992)

Study made by Burschel and Kursten (1992) revealed that CO_2 emissions was relatively less when fossil fuels are replaced by bio fuels generated in a sustainable manner from more or less closed carbon circle. According to the results, wood is a viable option for reduction of CO_2 emissions and can be substitution for building materials *viz.* brick, concrete, steel, etc. They performed an experiment for calculation of CO_2 emissions from 3 m length pillars with similar loads (20 kN) were constructed based on the energy consumed for their production. Energy required for production of steel pillar was nine times higher than that of wood. Energy use is typically linked to CO_2 emissions and other harmful environmental effects (maybe coal mining, SO_2-emissions, cooling water consumption etc.). This means selection of a material having reduced energy input can simultaneously lessen environmental issues that arise during entire production process.

Table 2 : GHG Mitigation potential of different lands use

Land Use	SOC Store (t/ha)	Mitigation Potential (up to 30 cm soil depth) (%)
Barren land	20.0	1.00
Pasture	40.0	2.00
Agriculture	66.0	3.30
Plantations	80.5	4.02
Agro-forestry	83.6	4.18
Forest	120.0	6.00

SOC= Soil Organic Carbon

Jha *et al.*, 2003

Jha *et al.* (2003) estimated the Soil Organic Carbon and Mitigation Potential upto soil depth of 30 cm in different land use system, including barren land, pasture, agriculture, plantations, agro-forestry and forest. It was found that agro-forestry system recorded highest Soil Organic Carbon and Mitigation Potential, except that of forest cover. Hence, they suggested that agro-forestry system is more preferable than other systems, as it is the integration of trees, livestock, crops, etc., as against forest, which consist of only trees.

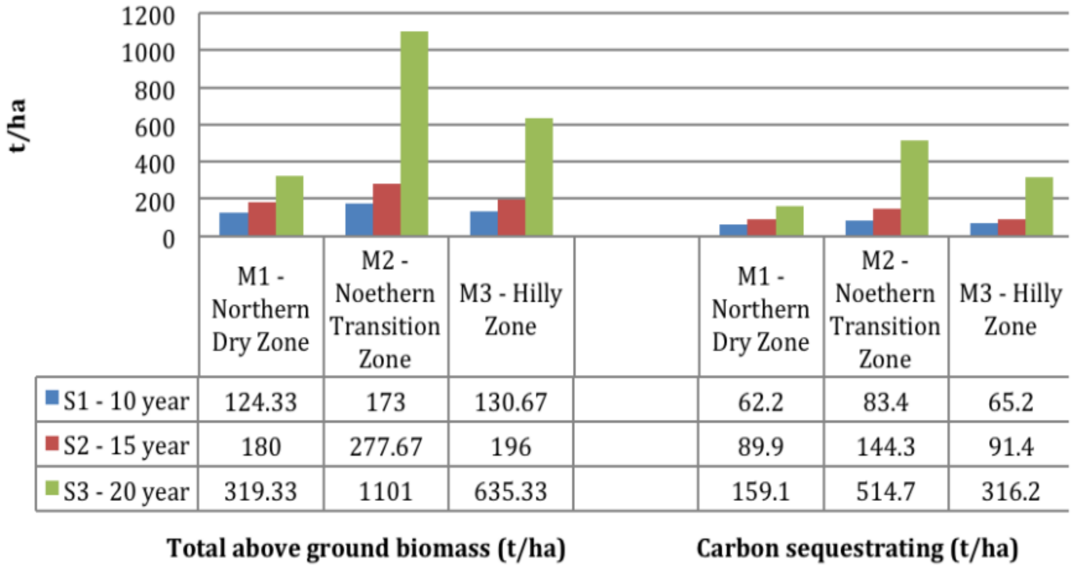
1. Technical Details

Study Area: 3 different agro-climatic zones of Karnataka i.e. Northern Dry Zone, Northern Transition Zone and Hilly Zone

Study tree: Teak plantations

Age: 3 age gradations i.e.10, 15 and 20 years

Statistical Analysis: Fisher's method. The mean values of main plots, sub-plots were subjected to M-STAT- C program on a computer.



	M1 - Northern Dry Zone	M2 - Noethern Transition Zone	M3 - Hilly Zone		M1 - Northern Dry Zone	M2 - Noethern Transition Zone	M3 - Hilly Zone
S1 - 10 year	124.33	173	130.67		62.2	83.4	65.2
S2 - 15 year	180	277.67	196		89.9	144.3	91.4
S3 - 20 year	319.33	1101	635.33		159.1	514.7	316.2

Fig. 2 : Total above ground biomass (t/ha) and carbon sequestration (t/ha) in teak plantations as influenced by agro climatic zones and age gradations

Reddy *et al.,* 2014

Reddy *et al.* (2014) studied the teak plantations in three age gradations of 10, 15 and 20 years in varying agro-climatic zones of Southern India (Northern Dry Zone, Northern Transition Zone and Hilly Zone) for estimation of total above ground biomass (t/ha) and Carbon Sequestration Potential (t/ha). It was found that Northern Transition Zone recorded higher carbon sequestration and total above ground biomass among the agro-climatic zones, which might be due to availability of moderate mean annual rainfall, improved soil fertility and lesser temperature fluctuations. However, soils of hilly zone are acidic and substantially less fertilealthough having much higher yearly rainfall. Southern Dry Zone and Northern Dry Zone's soils are alkaline and subjected to greater temperature swings, which reduces the amount of carbon sequestered despite establishment of teak plantations with protective irrigation. Hence, favourable climatic and soil condition in Northern Transition zone, as against the other zones might have led to higher carbon sequestration and above ground biomass during the three age-gradation period.

2. Technical Details

Study Area: Central part of the state of Kerala, India. The study location was in the Madakkathara subdivision. Three villages (Pandiparambu, Chirakkakode and Vellanikkara)

Land use types: Agroforestry, Paddy field, rubber plantations, coconut and homegardens.

Homegardens: Common perennial crops i.e.Arecanut, Banana, Cacao, Cashew, Cinnamon, Clova, Coconut, Gauva, Jackfruit, Mango, Nutmeg, Orange, Papaya, Tamarind, Rubber.

Statistical Analysis: Split-plot design. Multiple linear model (GLM) and analysis of variance (ANOVA). Waller Ducan K-ratio test was used to compare the mean difference between land-management practices on SCOC in whole soil, macro-sized and silt and clay-sized fractions for all sites.

Table 3 : Total Soil organic carbon (Mg ha^{-1}) in various soil aggregate fractions in land-use systems

Soil Fraction (μm)	Agroforestry	Coconut	HGL	HGS	Rubber	Paddy
250-2000	58.52	21.28	34.66	37.96	45.42	17.84
53-250	61.74	33.46	37.66	40.04	39.62	16.39
<53	56.3	36.96	35.86	41.32	34.12	21.36
Total	176.56	91.7	108.18	119.32	119.16	55.59

HGL=Large Homegarden (>0.4 ha),
HGS=Small Homegarden (<0.4 ha) Saha *et al.,* 2010

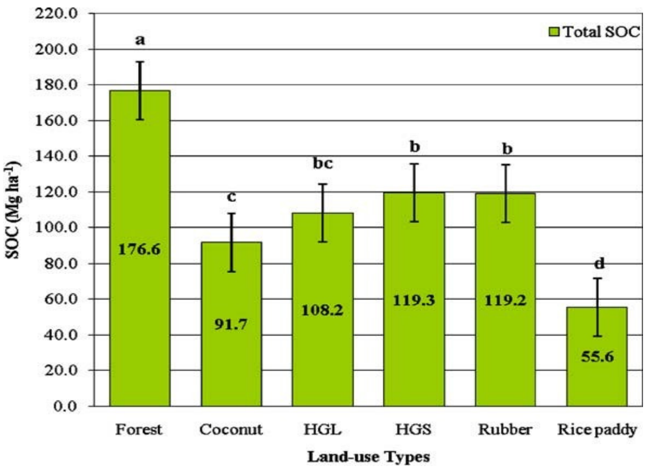


Fig. 3 : Total Soil organic carbon (SOC) content in the whole soil up to 1 m depth in six different land-use systems

Saha *et al.* (2009) tested the potentiality of total Soil Organic Carbon in various soil aggregate fractions in land-use systems, including agroforestry, coconut, Large Homegarden (>0.4 ha),Small Homegarden (<0.4 ha), Rubber and Paddy. Homegardens include Common perennial crops like Arecanut, Banana, Cacao, Cashew, Cinnamon, Clova, Coconut, Gauva, Jackfruit, Mango, Nutmeg, Orange, Papaya, Tamarind. Three aggregate size classes (250-2000 μm, 53-250 μm, and <53 μm) were manually fractionated from the soil samples. It was found that Soil Organic Carbon (SOC). This indicates that changes in land-use types over time are first reflected in the macro-sized class, followed by the micro-sized, and then the silt-and-clay sized fractions. Soil organic carbon contents in the macro-sized class (250-2000 m) showed more difference among land-use systems, followed by those of the micro-sized (53-250 m), and silt-and-clay-sized (>53 m) classes. The SOC concentration was highest in agroforestry and lowest in the rice paddy. It makes sense that tree-dominated ecosystems, such as forests with significant amounts of litterfall and root activity, would have higher SOC than monoculture agricultural systems, such rice paddy. Addition of trees to treeless systems might result in boost of below-ground C stock during number of instances.

3. Technical Details

Study Area: Kachchh, Gujarat in the arid north-western part of India at the research farm of Central Arid Zone Research Institute, Regional Research Station, Khukma-Bhuj.

Land use systems: Two with trees namely *Acacia tortilis*, (Umbrella thorn) *Azadirachta indica* (Neem), two *with* grass species namely *Cenchrus ciliaris* (foxtail buffalo grass), and *Cenchrus setigerus* (Birdwood grass) and four silvipastoral systems with combination of one tree and one grass.

Year of plantation: 1998

Year of harvesting trees: 2008

Statistical Analysis: Analysis of variance was used to compare carbon from different land-use systems for both biomass and soils at various depths

Table : 4 Carbon stocks (above and below ground) in selected land use systems in Kachchh, India

Land use systems	Carbon stock (above ground) (Mg C ha^{-1})	Carbon stock (below ground) (Mg C ha^{-1})	Total Plant carbon stock (Mg C ha^{-1})
Acacia	5.03	0.98	6.02
Neem	2.92	0.71	3.64
Cenchrusciliaris	2.44	1.82	4.26
Cenchrussetigerus	1.04	0.71	1.74
Acacia+ *C. ciliaris*	5.08	1.75	6.82
Acacia+ *C. setigerus*	4.91	1.24	6.15
Neem+ *C. ciliaris*	3.53	1.39	4.91
Neem+ *C. setigerus*	3.65	1.22	4.87

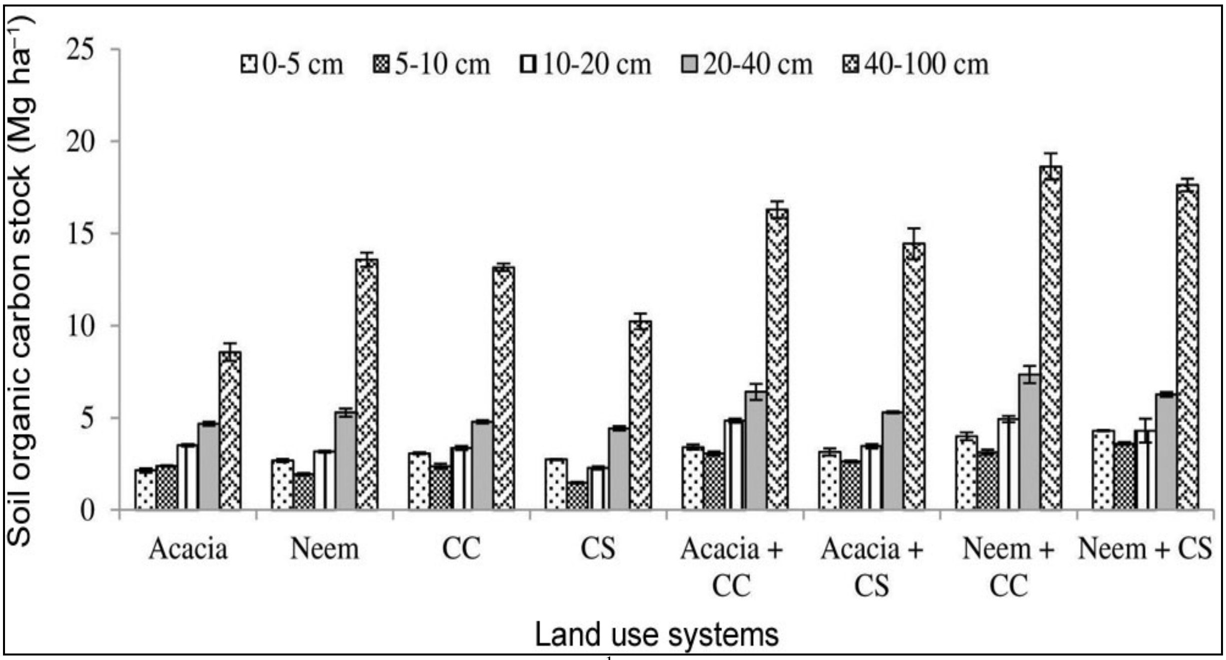


Fig. 4 : Soil organic carbon stock (Mg C ha^{-1}) in various land-use systems at different soil depths in Kachchh, India

Mangalassery *et al.,* 2014

A study conducted by Mangalasseryet *al.* (2014) in arid North-western India to analyze the Carbon sequestration in biomass and soil, which consisted of two pasture systems (*Cenchrusciliaris* and *Cenchrussetegerus*), two tree systems (*Acacia tortilis* and *Azadirachtaindica*) and four silvipastoral system (combination of one tree and one grass).It was found that in comparison to the tree system and the pasture system, the silvipastoral system sequestered 36.3% to 60.0% greater total soil organic carbon stock than tree system and 27.1–70.8% more than the pasture system. The silvipastoral system produced higher levels of soil organic carbon and net carbon sequestration. As a result, silvipastoral systems with both trees and grasses can help sequestration of atmospheric carbon more effectively than those with only trees or pasture. Further, the total biomass was recorded maximum in silvipastoral system consisting of *Acacia tortilis*+ *Cenchrusciliaris*, succeeded by Neem + *C. ciliaris*. The total plant carbon stock was sequestered highest in *Acacia tortilis*+ *Cenchrusciliaris*. The study showed that, when compared to sole tree or sole pasture systems, a silvipastoral system could potentially offset the negative impact of climate change by contributing to sequester more carbon in the soil and biomass. The addition of grass components to tree systems increased the overall ecosystem biomass and, consequently, the overall biomass carbon pool.

Table 5 : Soil Carbon sequestration potential (Mg C ha^{-1}) of agroforestry systems

Agroforestry system	Location	Soil C (Mg C ha^{-1})	Reference
Mixed stands, Eucalyptus + Casuarina, Casuarina + Leucaena and Eucalyptus + Leucaena	Puerto Rico	61.9, 56.6 and 61.7	Parrotta (1999)
Silvipasture (*Pseudotsuga menziesii* + *Trifolium subterraneum*)	W Oregon, USA	95.89	Sharrow *et al.,*2004
Agrisilviculture (*Gamelina arborea* + eight field crops)	Chhattisgarh, Central India	27.4	Swamy *et al.,* 2005
Tree-based intercropping: hybrid poplar + *Hordeum vulgare*	Ontario, Canada	78.5	Peichl *et al.,*2005
Silvipastoral system: *Acacia mangium* + *Arachispintoi*	Pocora, Atlantic coast, Costa Rica	173	Amezquita *et al.,* 2005
Silvipastoral system: *Brachiaria brizantha* + *Cordia alliodora* + *Guazuma ulmifolia*	Esparza, Pacific coast, Coat Rica	132	Amezquita *et al.,* 2005
Alley cropping: hybrid poplar + Wheat, soyabeans (*Glycine max.*) and maize rotation	S. Canada	1.25	Lal (2005)
Shaded coffee, *Coffea canephora* var. robusta + *Albizia adianthifolia*	SW Togo	97.27	Dossa *et al.,* 2008
Live fence (*Acaianilotica, A. senegal, Bauhinia rufescens, Lawsonia inermis,* and *Ziziphus maurritiana*)	Segou, Mali	24	Takimoto *et al.,* 2008
Fodder bank (*Gliricidia sepium, Pterocarpus lucens*, and *P. erinaceus)*	Segou, Mali	33.4	Takimoto *et al.,* 2008
Tree-based pastures; slash pine (*Pinus elliottii*) + bahiagrass (*Paspalum notatum*)	Florida, USA	6.9 to 24.2	Haille *et al.,* 2008
Gliricidia sepium + maize (*Zea mays*)	Zomba, Malawi	123	Makumba *et al.,* 20007

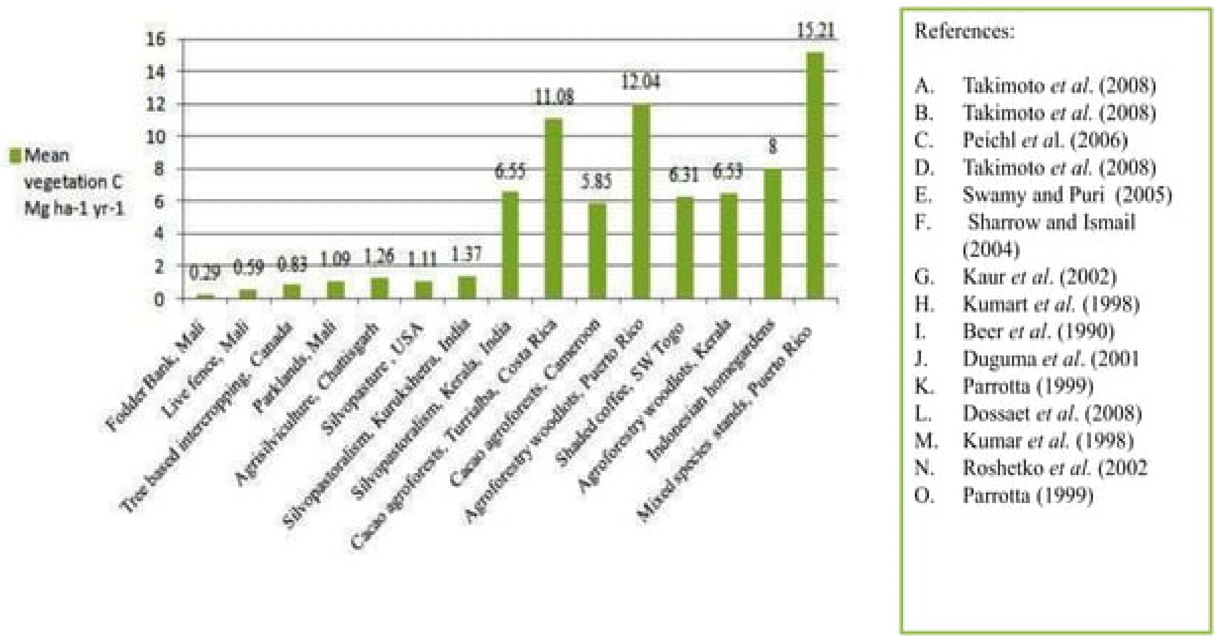


Fig. 5 : Mean vegetation carbon sequestration potential (Mg C ha^{-1} yr^{-1}) of agroforestry systems

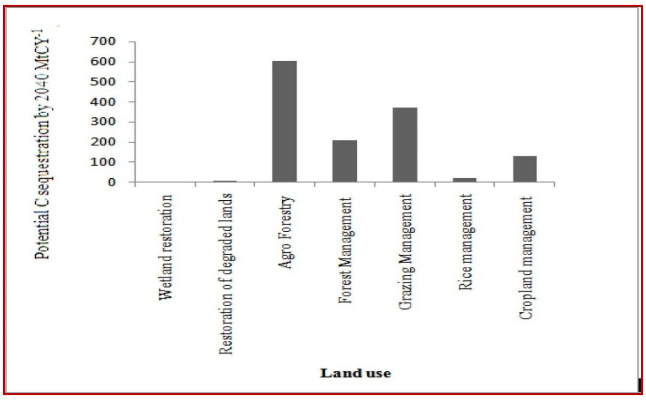


Fig. 6 : Carbon sequestration potential of different land use and management options

(Source: IPCC, 2000)

According to IPCC, 2000, the Carbon Sequestration potential was estimated in different land use and management options, *viz.* Wetland restoration, Restoration of degraded lands, Agro Forestry, Forest Management, Grazing Management, Rice Management and Cropland management. It was found that the potential Carbon Sequestration by 2040 $MtCY^{-1}$ was obtained maximum in Agroforestry system in comparison to other land use systems.

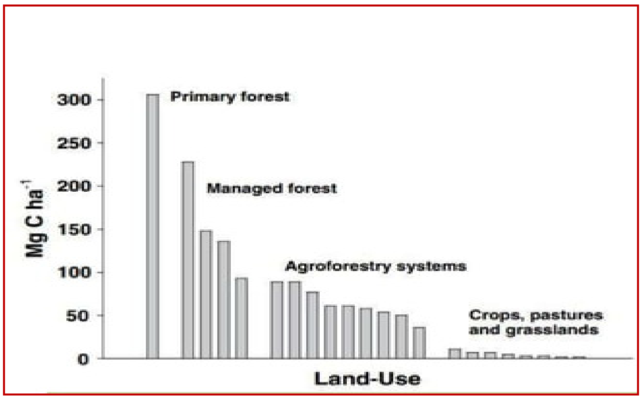


Fig. 7 : C stocks at maturity in different ecosystem of the humid tropics

(Verchot *et al.*, 2011)

Verchot *et al.* (2011) examined the climate change mitigation potential of agroforestry in humid and sub-humid tropics. The carbon stock at maturity was estimated in various ecosystems including primary forest, managed forest, agroforestry systems, crops, pastures and grasslands. It was reported that about 370 Mg C ha^{-1} is lost when primary tropical forests are converted to agricultural land or grassland. About half the carbon stocks of primary forests are found in managed forests. Compared to row crops, which only have about 10 Mg C ha^{-1}, agroforestry systems have 50–75 Mg C ha^{-1}. The C stored in aboveground biomass can therefore be significantly increased by changing row crops or pastures to agroforestry systems.

Table 6 : Average fluxes of N_2O and CH_4 in different land use system

Land use system	**N_2O (µg N m^{-2} ha^{-1})**	**CH_4 (µg C m^{-2} ha^{-1})**	**Source**
High input cropping	31.2	15.2	Palm *et al.*, 2002
Low input cropping	15.6	-17.5	Palm *et al.*, 2002
Cassava/Imperata	7.1	-14.8	Tsuruta *et al.*, 2000
Multistrata agroforestry	5.8	-23.3	Palm *et al.*, 2002
Rubber agroforestry	3.3	-27.5	Tsuruta *et al.*, 2000
Forest	5.0	-31.0	Palm *et al.*, 2002

Sumatra, Indonesia Mutuo *et al.*, 2005

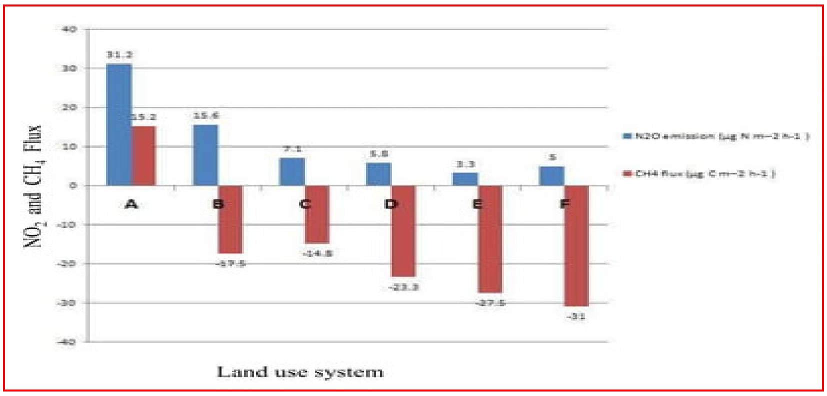


Fig. 8 : Fluxes of $N_2O$and CH_4

Mutuo *et al*. (2005) led a research to determine the impact of high input cropping, low input cropping, Cassava /Imperata, Multistata agroforestry, Rubber agroforestry and forests on average fluxes of N_2O and CH_4. It was found that high input cropping recorded maximum emission of N_2O (31.2 µg N m^{-2} h^{-1}) and CH_4 (15.2 µg N m^{-2} h^{-1}), whereas Rubber agroforestry recorded least emission of fluxes of N_2O (3.3µg N m^{-2} h^{-1}) and CH_4 (-27.5 µg N m^{-2} h^{-1}). These could be due to the fact that high input cropping includes only crops, while rubber agroforestry includes both trees and crops. Hence, lesser amount of N_2O and CH_4 has been released in rubber agroforestry system.

4. Technical Details

Study Area: 13 Municipalities of Benguet.

AF systems:12 no's (Chayote based, Chayote-coffee based, Chayote-Anthurium based, Anthurium based, banana based, Coffee based, Fruit plantation based, Pineapple based, Rice based, Tiger grass based, Triger grass-pineapple based, Sweet potato based, Cassava based

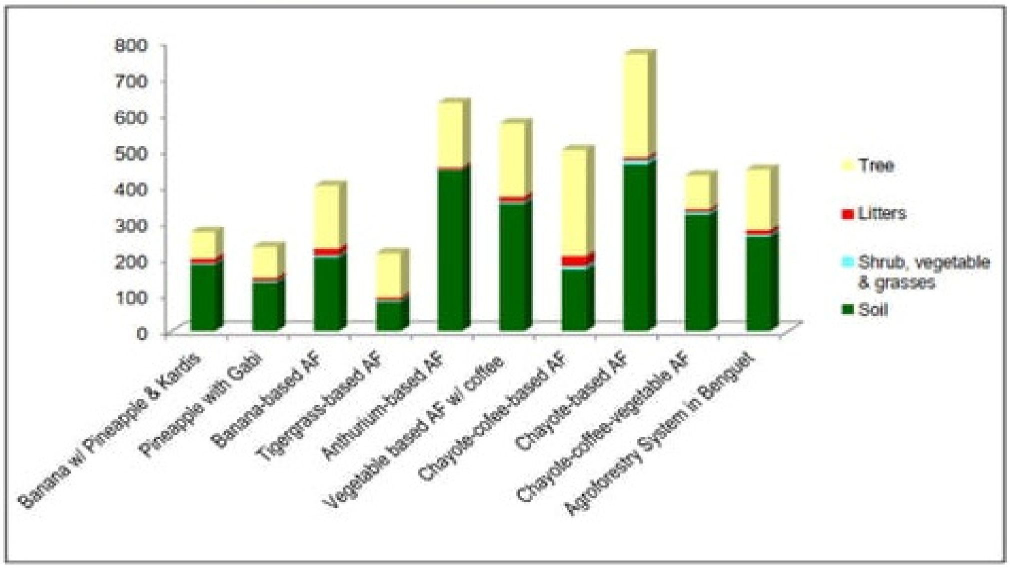


Fig. 9 : CO_2 Sequestration Potential of the different AF systems surveyed

Parao *et al.,* 2015

A study conducted by Parao *et al*. (2015) to analyse the Carbon Sequestration Potential of twelve agroforestry systems. Chayote based, Chayote-coffee based, Chayote-Anthurium based, Anthurium based, banana based, Coffee based, Fruit plantation based, Pineapple based, Rice based, Tiger grass based, Triger grass-pineapple based, Sweet potato based and Cassava based agroforestry systems were the systems taken into consideration. Among the systems, it was found that the Chayote based agroforestry system recorded maximum sequestration of Carbon, as it consisted of various trees like Eucalyptus, coffee, etc. besides growing chayote.

Table 7 : Benefits observed by integrating silvipasture with *Brachiaria brizantha* (Bread Grass)

Benefits observed from *Brachiaria brizantha*	Land owner Observation %
Reduced erosion	96
Greater drought resistance	100
Increased forage production during dry season	98
Increased number of livestock per unit area	100
Increased milk production	92
Improved calf health	96

Esparza ,Costa Rica

Oelbermann *et al.,* 2011

Oelbermann *et al*. (2011) observed the benefits of integration of silvipasture with *Brachiaria brizantha* (Bread grass). The efficiency of land system was enhanced due to the positive impacts cited in the table below. These could be the reason for decrease in negative effects of climate change, when silvipasture system is incorporated with Bread grass.

Table 5 : Total C storage under agro-forestry systems in different regions of the country

Region	Agro-forestry system and components	Total C storage (t C/ha)
Semi-aridregion	Silvi-pastoral system (age 5 years)	
	(Babul) *Acacia nilotica*+ natural pasture	9.5-17.0
	Acacia nilotica+ established pasture	19.7
	(Sisoo) *Dalbergia sissoo*+ natural pasture	12.4
	Dalbergia sissoo + established pasture	17.2
	Hardwickia binate + natural pasture	16.2
	Hardwickiabinata + established pasture	17.0
	Acacia/Dalbergia/Prosopis+ *Desmostacya*	6.8-18.5
	Acacia/Dalbergia/Prosopis + *Sporobolus*	1.5-12.3
Central India	Block plantations (age 6 years) (Gamari) *Gmelinaarborea*	24.1-31.1
Arid region (Rajasthan)	Agri-silvicultural system (age 8 years)	
	Emblica officinalis + *Vignaradiata*	12.7-13.0
	Hardwickia binata + *Vigna radiata*	8.6-8.8
Arid region (Rajasthan)	*Colophospermum mopane* + *Vigna radiata*	4.7-5.3
Semi-arid region	Agri-silvicultural system (age 11 years)	
	Dalbergia sissoo + crop	26.0
North-westernHimalayas	Silvi-pastoral system	2.17
	Agri-horti-pastoral	1.15
	Horti-pastoral	1.08

Dhyani *et al.* 2008

Case Study: Silvipastoral System

- Comparative studies conducted by NRCAF on biomass production from natural grassland.
- Woody species as *Albizia amara, Dichrostachys cinerea* and *Leucaena leucocephala* with *Chrysopogon fulvus* as grass and *Stylosanthes hamata* and *Salvia scabra* as legume.
- Revealed that rate of biomass carbon stored in this system was 6.72 tC/ha/yr, two times more than 3.14 tC/ha/yr from natural grassland.

Rohith *et al.*, 2019

Hon'ble Chief Minister of Assam Announced Govt Plan to Increase State's Forest & tree Cover From 36% to 38% in next 5 Years:

- Assam Government, USAID Launches Initiative to Increase Forest Cover
- The Assam Government and the US Agency for International Development (USAID) on 18th October, 2022 launched the "Trees Outside Forests in India (TOFI)" Programme in Assam, to rapidly expand the forest cover, improve the resilience of farming systems and augment farmers' revenue.

Northeast Today, The Sentinel 19th Oct., 2022

Future thrust:

- Integration of Agroforestry with sericulture
- Appropriate feed systems with tree fodder for livestock develop for different ecological seasons
- Morethrust be given to agroforestry research on dryland farming

Conclusion

- Agroforestry enhance the uptake of CO_2 or reduce its emission and has the potential to remove a significant amount of CO_2 from the atmosphere, if the trees are harvested, accompanied by replanting of same and/or other area, and sequestered carbon is locked through non-destructive use of such wood.
- Agroforestry systems are promising land use system to increase aboveground and belowground C stock to mitigate greenhouse gas emissions.
- By providing carbon credit and carbon trading, Agroforestry will contribute to income generation.

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