E-Content

On

Agroforestry System and Management

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[For B. Sc. (Hons.) Forestry Ist Semester Students]

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Syllabus:

Agroforestry systems in different agro climatic zones- Tropical agroforestry, Temperate agroforestry, arid and semi-arid agroforestry and humid agroforestry- components, production and management techniques. Alley cropping- functional and structural attributes of alley cropping, soil management, choice of species- productivity of various Agroforestry systems. High-density short rotation plantation systems- choice of species, design, development and management. Silvicultural woodlots/energy plantations- choice of species, design, development and management. Different types of agroforestry systems- Silvi-agriculture, shelterbelts and windbreaks- design, aerodynamics and management, Silvopastoral systems- live fences; fodder trees and protein banks and Agri-silvopastoral systems- home gardens, hedge rows, Multistorey system and their mangement; Special systems- Apisilviculture, Silvisericulture, Aquaforestry etc. Agroforestry for wasteland development. Canopy management- Lopping, pruning, pollarding, and hedging. Diagnosis and design methods and approaches. Biophysical and ecological functions of agroforestry: Nutrient cycling and role of agroforestry in soil and water conservation- micro-site enrichment by trees, N fixation, improvement in soil physico-chemical properties and soil organic matter status, litter and fine root dynamics, nutrient pumping; beneficial effects of species mixture- rhizosphere and phillosphere effects. Carbon sequestrationClimate change mitigation and phytoremediation. Adverse effects of trees on soils - competition, allelopathy- Causes and mechanisms. Industrial Agroforestry- scope and potential in Indiamajor wood based industries- People's participation, rural entrepreneurship through Agroforestry and industrial linkages- contract farming- types and systems- successful contract farming models- timber transit rules for farm grown trees- Financial and socio-economic analysis of Agroforestry systems. Evaluation of tangible and intangible benefits- Agroforestry research and development in India- National Agroforestry Policy 2014- objectives and strategies.

Unit-Ist

Chapter 1

Agroforestry Agroclimatic Zones in India

India is divided into 15 agroclimatic zones by the Planning Commission and 21 agro-ecological regions by the National Bureau of Soil Survey and Land Use Planning (NBSS&LUP). Agroforestry systems are designed according to these zones, considering climate, soil, topography, and local farming practices.

Below is an overview of the major agroclimatic zones of India and the agroforestry systems suitable for each:

1. Western Himalayan Region

States: Jammu & Kashmir, Himachal Pradesh, Uttarakhand

Climate: Cold, temperate, and alpine

Agroforestry systems:

Agri-horticultural: Apple + field crops (wheat, barley, peas)

Silvi-pastoral: Populus spp., Robinia, Grewia + grasses (Setaria, Chrysopogon)

Agri-silvicultural: Poplar, Willow + vegetables

2. Eastern Himalayan Region

States: Arunachal Pradesh, Sikkim, parts of Assam, Meghalaya, Nagaland, Manipur, Mizoram, Tripura

Climate: Humid, tropical to subtropical

Agroforestry systems:

Shifting cultivation (Jhum) with multipurpose trees

Agri-horticultural: Orange, pineapple + annual crops

Silvi-pastoral: Alder-based (Alnus nepalensis + grasses)

3. Lower Gangetic Plain Region

States: West Bengal

Climate: Humid, tropical; high rainfall

Agroforestry systems:

Agri-horticultural: Mango, guava + cereals/pulses

Boundary plantations: Eucalyptus, *Acacia auriculiformis*

Silvi-pastoral: Leucaena + grasses

4. Middle Gangetic Plain Region

States: Eastern Uttar Pradesh, Bihar

Climate: Sub-humid tropical

Agroforestry systems:

Agri-silvicultural: Poplar, Subabul + wheat, paddy

Agri-horticultural: Mango, guava + pulses

Silvi-pastoral: Acacia, Dalbergia + fodder grasses

5. Upper Gangetic Plain Region

States: Western Uttar Pradesh

Climate: Semi-arid to sub-humid

Agroforestry systems:

Poplar-based system: Poplar + sugarcane, wheat

Eucalyptus-based plantations

Boundary planting: Shisham (Dalbergia sissoo), neem

6. Trans-Gangetic Plain Region

States: Punjab, Haryana, Delhi, Chandigarh

Climate: Semi-arid to sub-humid

Agroforestry systems:

Poplar-based system (Populus deltoides + wheat, paddy)

Eucalyptus-based system

Agri-silvicultural: Acacia nilotica, Prosopis cineraria + crops

7. Eastern Plateau and Hills

States: Chhattisgarh, Jharkhand, Odisha (parts), Madhya Pradesh (parts)

Climate: Sub-humid tropical

Agroforestry systems:

Agri-silvicultural: Teak, Bamboo, Acacia + millets/pulses

Silvi-pastoral: Leucaena + grasses

Agri-horticultural: Mango, cashew, litchi + crops

8. Central Plateau and Hills

States: Madhya Pradesh, Rajasthan (parts), Maharashtra (parts)

Climate: Semi-arid

Agroforestry systems:

Silvi-pastoral: Prosopis, Acacia + grasses

Agri-silvicultural: Neem, Babul + cereals/pulses

Boundary plantations: Eucalyptus, Cassia siamea

9. Western Plateau and Hills

States: Maharashtra, Madhya Pradesh, Gujarat (parts)

Climate: Semi-arid to dry sub-humid

Agroforestry systems:

Agri-silvicultural: Teak, Babul, Neem + sorghum/pulses

Horticulture-based: Mango, cashew + crops

10. Southern Plateau and Hills

States: Karnataka, Andhra Pradesh, Tamil Nadu (parts)

Climate: Semi-arid to dry sub-humid

Agroforestry systems:

Silvi-pastoral: Albizia, Leucaena + grasses

Agri-horticultural: Tamarind, mango + millets

Boundary plantations: Eucalyptus, Casuarina

11. East Coast Plains and Hills

States: Odisha, Andhra Pradesh, Tamil Nadu, Puducherry

Climate: Humid tropical coastal

Agroforestry systems:

Coastal shelterbelts: Casuarina, Cashew, Coconut

Agri-horticultural: Coconut, banana + paddy/pulses

12. West Coast Plains and Ghats

States: Maharashtra (coastal), Goa, Karnataka, Kerala

Climate: Humid tropical, high rainfall

Agroforestry systems:

Coconut-based multistorey: Coconut + cocoa + pineapple/banana

Arecanut-based systems

Homegardens: Multipurpose tree + fruit + crop combinations

13. Gujarat Plains and Hills

States: Gujarat (excluding arid Kutch)

Climate: Semi-arid

Agroforestry systems:

Agri-silvicultural: Acacia, Prosopis + castor, pearl millet

Horticultural: Mango, sapota + crops

14. Western Dry Region

States: Rajasthan (arid zone)

Climate: Arid, very low rainfall

Agroforestry systems:

Silvi-pastoral: Prosopis cineraria + Cenchrus, Lasiurus grasses

Agri-silvicultural: Khejri (Prosopis) + pearl millet, cluster bean

Windbreaks: Acacia, Azadirachta

15. Islands Region

States: Andaman & Nicobar Islands, Lakshadweep

Climate: Humid tropical

Agroforestry systems:

Multistorey systems: Coconut + arecanut + spices + tubers

Homegardens: Diverse tree + crop + livestock components

Chapter 2

Classification of agroforestry systems

the classification of agroforestry systems given by P. K. R. Nair (1987) is the most widely accepted and comprehensive system used globally.

He classified agroforestry systems based on three main criteria:

Structural basis

Functional basis

Ecological and Socio-economic basis

Structural basis

It refers to the composition of the components, including spatial arrangement of the woody component, vertical stratification of all the components, and temporal arrangement of the different components. Hence on the basis of structure agroforestry system can be grouped into two categories.

- Nature of components
- Arrangement of components

Nature of components: Based on nature of component agroforestry systems can be classified into following categories

Agrisilviculture systems/ silviagriculture/ agrosilviculture

Silvopastoral systems/ silvipastoral

Agrosilvopastoral systems/ agrisilvipastoral

Other systems

I. Agrisilviculture/Silviagriculture/Agrosilviculture: This system involves the conscious and deliberate use of land for the concurrent production of agricultural crops including tree, crops and forest crops. Based on the nature of the components this system can be grouped into various forms:

a) Improved fallow species in shifting cultivation

b) Taungya system

c) Multispecies tree gardens

d) Alley cropping (Hedgerow intercropping)

e) Multipurpose trees and shrubs on farmlands

f) Crops combinations with plantation crops

g) Agroforestry for fuelwood production

h) Shelter belts

i) Wind breaks

j) Soil conservation hedges etc.

a) Improved fallow species in shifting cultivation: Shifting cultivation:It is prevalent in many parts of Africa, Latin America, SouthEast Asia and Indian subcontinent.

• In India it is prevalent in Assam, Meghalaya, Jharkhand, Manipur, Orissa, Nagaland, Chattisgarh, M.P., Arunanchal Pradesh, Andhra Pradesh, Mizoram, Tripura, Kerala, West Bengal, Sikkim.

• It is known as 'jhuming' in North-east, 'khallu / kurwa' in Jharkhand and 'dahiya' or 'podo' in Orissa, Andhra Pradesh.

• In this system, forest patch is selected and cleared felled. The herbs, shrubs and twigs and branches (slashed vegetation) are burnt . Cultivation of crops is done for a few years until soil fertility declines. The site is than abandoned (fallow period) and new patch is selected for cultivation of crops. The site is again cultivated after giving rest for few years.

b) Taungya System of cultivation

• The taungya system was used primarily as an inexpensive means of establishing timber plantations but is finally a recognized AF system.

• The taungya (taung = hill, ya = cultivation) is a Burmese word coined in Burma in 1850. The system was introduced to India by Brandis in 1890 and the first taungya plantations were raised in 1896 in North Bengal.

• This is a modified form of shifting cultivation in which the labour is permitted to raise agri-crops in an area but only side by side with the forest species planted by it. The practice consists of land preparation, tree planting, growing agricultural crops for 1-3 years, until shade becomes too dense, and then moving on to repeat the cycle in a different area.

Types of Taungya

• **Departmental Taungya:** Under this, agricultural crops and plantation are raised by the forest department by employing a number of labourers on daily wages. The main aim of raising crops along with the plantation is to keep down weed growth.

• **Leased Taungya:** The plantation land is given on lease to the person who offers the highest money for raising crops for a specified number of years and ensures care of tree plantation.

• **Village Taungya:** This is the most successful of the three taungya systems. In this crops are raised by the people who have settled down in a village inside the forest for this purpose. Usually each family has about 0.8 to 1.7 ha of land to raise trees and cultivate crops for 3 to 4 years.

c) Multi-species tree Gardens:

• In this system of agroforestry, various kinds of tree species are grown mixed.

• The major function of this system is production of food, fodder and wood products for home consumption and sale.

d) Alley cropping (Hedge row intercropping):

• Alley cropping, also known as hedgerow intercropping,

• In this perennial, preferably leguminous trees or shrubs are grown simultaneously with an arable crop.

• The trees, managed as hedgerows, are grown in wide rows and the crop is planted in the interspace or 'alley' between the tree rows.

During the cropping phase the trees are pruned and leaves and twigs are used as mulch on the cropped alleys in order to reduce evaporation from the soil surface, suppress weeds and/or add nutrients and organic matter to the top soil.

• The primary purpose of alley cropping is to maintain or increase crop yields by improvement of the soil and microclimate and weed control. Farmers may also obtain

• The position and spacing of hedgerow and crop plants in an alley cropping system depend on plant species, climate, slope, soil conditions and the space required for the movement of people.

• Ideally, hedgerows should be positioned in an east to west direction so that plants on both sides receive full sunlight during the day.

• The spacing used in fields is usually 4 to 8 meters between rows and 25 cm to 2 meters between trees within rows. The closer spacing is generally used in humid areas and the wider spacing in sub-humid or semi-arid regions.

Promising species

Gliricidia sepium, Flemingia macrophylla, Leucaena, Calliandra calothyrsus, Erythrina subumbrans, Albizia saman, Pithecellobium dulce, Paraserianthes falcataria, Acacia spp., Paraserianthes falcataria and *Cajanus cajan*

f) Multipurpose trees and shrubs on farmlands:

• In this system various multipurpose tree species are scattered haphazardly or according to some systematic patterns on bunds.

• The major components of this system are multipurpose trees and other fruit trees and common agricultural crops.

• The primary role of this system is production of various trees products and the protective function is fencing and plot demarcation. Examples of multipurpose trees employed in agroforestry are:

Leucaena leucocephala, Acacia albida, Cassia siamea, Casuarina equisetifolia, Azadirachta indica, Acacia senegal, Cocos nucifera, etc.

g) Crop combinations with plantation crops:

(i) Perennial trees and shrubs such as coffee, tea, coconut and cocoa are combined into intercropping systems in numerous ways, including: (ii) Integrated multistory mixture of plantation crops; (iii) Mixture of plantation crops in alternate or other crop arrangement; (iv) Shade trees for plantation crops (v) Intercropping with agricultural crops.

- Tea (*Camilia sinensis*) is grown under shade of *A. chinensis, A. odoratissim, A. lebbek, A. procera, Acacia lenticularis, Derris robusta, Grevillea robusta, Acacia spp., Erythrina lithosperma, Indigofera tesmanii.*

- Coffee (*Coffea arabica*) is grown under the shade of *Erythrina lithosperma* as temporary shade while, permanent shade trees include *Ficus glomerata, F. nervosa, Albizia chinensis, A. lebbek, A moluccana, A. sumatrana, Dalbergia latifolia, Artocarpus integrifolius, Bischofia javanica, Grevillea robusta.*

- Cacao (*Theobroma cacao*) is grown under the shade of coconut and areca nut, and Dipterocarpus macrocarpa (in forest).

- Black pepper (*Piper nigrum*) is grown with support from Erithrina indica, Garuga pinnata, Spondias, Mangifera, Gliricidia maculate and Grevillea robusta.

- Small cardamom (Elettaria cardamomum) and large cardamom (*Ammomum subulatum*; *A. aromaticum*) grow in forests under temporary shade tree of *Mesopsis emini*.

h) Agroforestry for fuelwood production

- In this system, various multipurpose fuelwood/firewood species are interplanted on or around agricultural lands.

- The protective role is to act as fencing, shelter belts and boundary demarcation.

- Tree species commonly used as fuelwood are: *Acacia nilotica, Albizia lebbek, Cassia siamea, Casuarina equisetifolia, Dalbergia sissoo, Prosopis juliflora, Eucalyptus tereticornis*, etc.

i) Shelterbelt

- Shelterbelt is a wide belt of trees, shrubs and grasses, planted in rows which goes right across the land at right-angle to the direction of the prevailing winds to deflect air current, to reduce wind velocity and to give general protection to cultivated areas against wind erosion and desiccating effect of the hot winds in lee-ward side.

- A typical shelterbelt has a triangular cross-section which can be achieved by planting tall trees in the centre, flanked on both sides successively by shorter trees, tall shrubs and then low spreading shrubs and grasses.

Choice of species

• The choice of species to be raised in shelterbelt is governed by the climate, soil and topography of the area.

• It is better to raise local species because of their easy establishment.

• Exotics may also be used to improve the efficiency of the shelterbelts. Characteristics of tree spp. used for shelterbelt are as follows:

j) Windbreaks

• Wind break is a protective planting around a garden, a farm or a field to protect it against strong winds. • It usually consists of 2-3 rows of trees or shrubs, spaced at 0.5 m to 2.5 m apart, depending on the species.

k) Soil conservation hedges

•In this system the major groups of components are: multipurpose and/or fruit trees and common agricultural species.

•The primary role of multipurpose fruit trees and agricultural species is soil conservation and provision of various tree products.

•The following tree species are used for soil conservation: *Grevillea robusta, Acacia catechu, Pinus roxburghii, Acacia modesta, Prosopis juliflora, Alnus nepalensis, Leucaena leucocephala*, etc.

II) Silvi-Pastoral System (Trees + Pasture and /Or Animals)

• The production of woody plants combined with pasture is referred to as a silvipastoral system.

• The trees and shrubs may be used primarily to produce fodder for livestock or they may be grown for timber, fuelwood, and fruit or to improve the soil.

• A silvi-pastroal system is needed in dry areas, in order to meet out the demands of wood and fodder throughout the year. There are three main categories of silvicultural system - Protein bank - Live fence of fodder trees and hedges - Trees and shrubs on pasture land

A. Protein bank

(i) In this system various multipurpose trees (protein rich trees) are planted on or around farmlands and rangelands

(ii) For **cut and carry** fodder production to meet the fodder requirements of livestock during the fodder deficit period in winter.

(iii) These trees are rich in protein.

(iv) The trees planted in protein banks are *Grewia optiva, Bauhinia variegata, Morus alba, Artocarpus spp., Anogeissus latifolia, Cordia dichotoma, Dalbergia sissoo, Eutralobium saman, Zizyphus jujube*, etc.

B. Live fence of fodder trees and hedges

- In this system, various fodder trees and shrubs are planted as live fences to protect the property from stray animals
- To protect the farm property from biotic influences.
- The following trees are generally used: *Sesbania grandiflora, Gliricidia sepium, Erythrina abyssinica, Euphorbia spp., Acacia spp.* etc.

C. Trees and Shrubs on Pasture Land

In this system various tree and shrub species are scattered irregularly or arranged according to some systematic pattern,

III) Agrisilvopastoral/Agrosilvopastoral System (Crops + Tree + Grasses/Animals)

This system has been grouped into two subgroups:

A. Home gardens

B. Woody hedge rows for browsing, mulching, green manuring and soil conservation.

A. Home gardens (i) It is deliberate integration of trees, crop and animals in a same unit of land in some form of spatial and temporal sequence.

(ii) This is one of the oldest agroforestry practices found in high rainfall area of South and South-East Asia.

(iii) In India it is prevalent in Southern states like Kerala, Tamilnadu.

(iv) Aso common in North Eastern states like Tripura, Assam, West Bengal and part of Islands of Andaman and Nicobar.

(v) In India it is a common practice to plant trees around the habitation. (vi) It is also known as multilayered AFS

(vii) Area of homestead varies from 0.2-0.5ha

(viii)Tall tree/timber tree occupy the top most layer followed by fruit tree.

(ix) Small shrubs also form the parts of home garden.

(x) Shade loving vegetables find their place in the ground layer.

B. Woody Hedges for Browsing, Green Manuring, Mulching and Soil Conservation

(i) In this system various woody hedges especially

(ii) Fast growing

(iii) Good coppicing capacity planted in order to

(iv) Browse the animals

(v) Mulching purpose

(vi) Green manuring purpose

(vii) Soil conservation purpose

(viii) Aim is production of food, fodder, fuel-wood and soil conservation

IV) Other Specified Systems

I) Apiculture with Tree

(i) In this system nectar and pollen rich tree/shrubs are planted on the bunds of the farm.

ii) Some agriculture/oil seed crops are also grown.

(iii) *Mangifera indica, Vitex negundo, Melia azedarach, Azadirachta indica, Prunus salicina,Prunus armeniaca, Rubus ellipticus, Eucalyptus spp., Callistemon lanceolatus, Berberislycium, Toona ciliata,* etc.

(iv) Main purpose of this system is production of honey.

II) Aqua-forestry

(i) Aqua-forestry is very common in coastal regions (more evident along Andhra coast).

(ii) Farmers are cultivating fish and prawn in saline water and growing coconut and othertrees on bunds of ponds.

(iii)These trees help in producing litter-feed to fishery and generate extra income to farmers.

(iv)Now fish culture in mangroves is also advocated which forms a rich source of nutrition to aquatic life and breeding ground for juvenile fish, prawn and mussels.

(v) A well-balanced system of animal husbandry including goatry, poultry, duck-farming, turtlesand fishes in the small ponds in home-gardens make a balanced system of high moisture,energy and nutrient-use efficiency per unit area.

(vi)The leaves of many leguminous trees viz. *Gliricidia sepium, Leucaena, Moringa oleifera, Acacia nilotica* etc. have been found to serve as good fish feed when offered as pellets andimproved its productivity.

III) Multipurpose Wood Lots: In this system special location-specific MPTs are grown mixed or separately planted for variouspurposes such as wood, fodder, soil protection, soil reclamation, etc.

B) Agroforestry Systems Based Arrangement of Components

Arrangement of component refers to the plant component of the system even in agroforestry system involving animal the management of such animal according to definite plan such as rotational grazing scheme is in consideration more of the plant than animal. Such plant arrangement in multi species combination can involve dimension, space and time.

(i) Spatial arrangement of plant in agroforestry mixture can result – Mixed dense, e.g., homegardens – Mixed sparse, e.g. most systems of trees in pastures – Zonal-microzonal, macrozonal Spatial or zonal agroforestry varies from microzonal (such as alternate rows of plantcomponents) to macrozonal arrangements. An extreme form of the zonal arrangement isthe boundary planting of trees on edges of plots for fruits, fodder, fuel wood, fencing, soilprotection and windbreak.

(ii) Temporal arrangement of plant in agroforestry systems can take various forms such as **Coincident:** When two component woody and non woody components occupy the land together as coffee under shade tree and pasture under shade trees

Concomitant: When two component woody or non woody stays together for some part of life as in taungya

Intermittent(Space dominated): When annual crops are grown with perennial crops such aspaddy with coco nut

Interpolated(Space and time dominated): When different components occupy space during different time as in home garden

Overlapping Black and rubber Separate (time dominated): When component occupy space during separate timesuch as improved fallow species in shifting cultivation.

Functional basis

It refers to the major function or role of the system, usually furnished by thewoody components (these can be of a service or protective nature, e.g., windbreak, shelterbelt,soil conservation).

(i) Production: This system refers to the production of essential commodities (food, fodder, fuelwood,minor forest products, etc.), required to meet the basic needs of the society. It includes intercropping oftrees, home gardens, production of animals and fishes in association with trees etc.

(ii) Protective agroforestry system: This system primarily aims at ameliorating the land to improve climate resilient, reduce soil erosion, moisture conservation, provide shelter, shade, etc. e.g. wind breaks.

(iii) Multipurpose agroforestry system: Multipurpose agroforestry system ensures multipurpose production through optimizing both productive and protective functions, e.g. hedge row intercropping.

Ecological classification

The agroforestry system is related to various ecological factors viz., climatic, edaphic and physiographic ones. On the basis of ecological parameters, it can be classified as:

(i) Tropical: Vegetation in extreme climate such as high temperature, low humidity, and scarcity of water etc.,e.g. Tropical silvopasture.

(ii) Sub-tropical: Agroforestry system in optimal climatic condition, e.g. agroforestry in sub-tropical regions

(iii) Temperate: Agroforestry system in low temperature regions.

(iv) Sub-Alpine: Agroforestry systems in low and medium mountainous regions.

(v)Alpine: Agroforestry system in high mountainous regions.

Socio-economic classification

Based on socio-economic consideration, the agroforestry systems are classified based on cost / benefit relations, management options and technology used.

a) On the basis of cost / benefit relations

(i) Subsistence agroforestry system: This system aims at meeting the basis needs of small family having less holding and very little capacity for an investment. They may be some marginal surplus production for sale, e.g., shifting cultivation, scattered trees in the farms, homestead agroforestry.

(ii) Commercial agroforestry system: This system refers to large scale production on commercial basis. The main consideration is to sale the products, e.g., tea/coffee/cocoa plantations under shade trees. This system is managed by individuals, companies, industries, corporate bodies or government.

(iii) Intermediate agroforestry systems: This system is an intermediate between commercial and subsistence systems. It is practiced on small medium sized farms. The system aims at production of sufficient food, wood, fodder and other beneficial products, which are not enough to meet the needs of the family, but to earn money the surplus can be sold.e.g. fruit trees with agricultural crops.

Chapter 3

Agroforestry for Wasteland Development

Agroforestry — the intentional integration of trees, crops, and sometimes livestock on the same land — offers an effective, sustainable approach to **reclaiming and developing wastelands**. It enhances soil fertility, restores ecological balance, and generates income for local communities.

What Is Wasteland

- Wasteland refers to land that is degraded, unproductive, or underutilized due to factors like soil erosion, salinity, waterlogging, deforestation, or overgrazing.
- **Examples include:**
- Degraded forest lands
- Saline and alkaline soils
- Ravinous or gullied lands
- Shifting sand dunes
- Mine spoils and rocky areas

Role of Agroforestry in Wasteland Development

Agroforestry systems can **restore productivity** and **improve environmental quality** through the following mechanisms:

(a) Soil Conservation and Improvement

- Tree roots bind soil, reducing erosion.
- Leaf litter adds organic matter, improving structure and fertility.
- Nitrogen-fixing species (e.g., *Leucaena leucocephala*, *Gliricidia sepium*) enrich the soil.

(b) Water Management

- Tree cover increases infiltration and reduces surface runoff.
- Shallow-rooted crops and deep-rooted trees use water efficiently.

(c) Carbon Sequestration

- Trees capture CO_2, improving the carbon balance of degraded lands.

(d) Biodiversity Enhancement

- Mixed tree–crop systems restore habitat diversity.

(e) Livelihood Generation

- Provides products such as fuelwood, fodder, fruits, timber, and medicinal plants.

Agroforestry Systems for Different Types of Wastelands

Type of Wasteland	Recommended Agroforestry System	Example Species	Key Practices
Saline/Alkaline Soils	Silvopastoral / Shelterbelt	*Prosopis juliflora*, *Casuarina equisetifolia*, *Acacia nilotica*, *Sesbania bispinosa*	Gypsum application, salt-tolerant grasses (*Leptochloa fusca*)
Ravinous & Gullied Lands	Agri-horticultural / Silvi-horticultural	*Amla (Emblica officinalis)*, *Tamarindus indica*, *Dalbergia sissoo*, *Cenchrus ciliaris*	Contour bunding, trenching, planting on upper slopes
Sandy & Arid Lands	Agri-silvicultural / Windbreaks	*Acacia senegal*, *Ziziphus mauritiana*, *Azadirachta indica*, *Tecomella undulata*	Shelterbelts, mulching, drought-resistant crops
Waterlogged Areas	Tree–Fish–Crop system	*Eucalyptus tereticornis*, *Populus deltoides*, *Syzygium cumini*, rice–fish integration	Raised bunds, drainage channels
Mining Spoils / Rocky Lands	Silvicultural Reclamation	*Acacia auriculiformis*, *Albizia lebbeck*, *Cassia siamea*, *Leucaena leucocephala*	Soil amendment, trench planting, green manuring

Examples of Successful Agroforestry in Wasteland Development

- **Arid Zone (Rajasthan):** *Prosopis cineraria* with pearl millet and legumes improves soil fertility and yields.
- **Bundelkhand Region:** *Amla*–based agri-horticultural systems on ravinous land generate income and control erosion.
- **Mine Spoils (Jharkhand):** Planting *Acacia auriculiformis* and *Eucalyptus* restored degraded mining land.

Benefits Summary

Ecological	Economic	Social
Restores soil fertility	Diversified income	Employment generation

Ecological	Economic	Social
Reduces erosion & salinity	Sustainable fuel/fodder supply	Improves rural livelihoods
Enhances biodiversity	Increases productivity	Promotes community participation

Key Steps for Implementation

1. **Site assessment** – Soil type, water availability, and degradation level.
2. **Species selection** – Choose native, drought- and salinity-tolerant species.
3. **Land preparation and planting** – Adopt contour bunding, trenching, and pit planting.
4. **Management practices** – Water harvesting, mulching, and periodic pruning.
5. **Monitoring and maintenance** – Track soil quality, tree growth, and economic returns.

Benefits of Agroforestry in Wasteland Development

Ecological Benefits	Economic Benefits	Social Benefits
Reduces erosion and runoff	Provides timber, fruits, fodder	Employment generation
Improves soil fertility	Enhances farm income	Reduces migration
Sequesters carbon	Promotes sustainable resource use	Strengthens community resilience
Increases biodiversity	Reduces dependence on forests	Supports rural women through NTFPs

Unit II^nd^

Chapter 1

Canopy management in agroforestry system

In **agroforestry systems**, trees, crops, and sometimes livestock coexist on the same land. While this integration enhances productivity and sustainability, it also introduces **competition for sunlight, water, and nutrients**.

Definition

Canopy Management in agroforestry refers to the planned control of the size, shape, density, and spatial arrangement of tree canopies to optimize light interception, crop growth, and overall system productivity.

It includes all practices that influence the vertical and horizontal structure of vegetation in an agroforestry system.

Factors Affecting Canopy Management

Factor	**Influence on Canopy**
Tree species	Growth rate, leaf density, architecture
Tree age	Young trees allow more light; mature trees shade more
Plant spacing	Wider spacing = less canopy overlap
Pruning intensity & timing	Directly affects canopy density
Orientation of rows	Influences light interception (e.g., N–S vs E–W)
Climatic conditions	Sun angle, rainfall, temperature affect canopy growth

Canopy Architecture in Agroforestry

Understanding **canopy architecture** is key for management.

Components include:

- **Canopy shape:** spherical, conical, umbrella-shaped, etc.
- **Crown depth:** affects light penetration to understory crops.
- **Leaf density and orientation:** determines photosynthetic efficiency.
- **Branching pattern:** influences pruning requirements.

For example:

- *Acacia nilotica* → compact canopy (dense shade).

- *Dalbergia sissoo* → semi-open canopy (moderate shade).
- *Prosopis cineraria* → open canopy (light shade, ideal for arid agroforestry).

Techniques of Canopy Management

Choice of Species and Spacing

- Select species with **light, feathery, or open canopies** to allow light penetration (e.g., *Albizia lebbeck*, *Prosopis cineraria*).
- **Optimum spacing** reduces canopy overlap and competition.
    - Example: *Leucaena leucocephala* spaced at 5 m × 5 m for alley cropping.

Thinning :

Felling made in immature stand for the purpose of improving the growth and form of the trees that remain without permanently breaking the canopy. It is mainly done:

- To improve the hygiene of the crop by removing dead, drying and diseased trees. - To ensure best physical conditions of growth.

- To obtain a desired type of crop.

- To improve the stand composition and afford protection from the spread of insects and diseases.

- To improve the quality of wood. - Increase the net yield and financial return from the crop.

Pruning

Removal of live or dead branches or multiple leaders from standing trees for the improvement of the tree or its timber.

❖ Pruning the lower branches close to the trunk of tree makes small knotty core which gives clear straight grain timber.

❖ Removal of too many branches will retard the growth

❖ If pruning is left too late, the central core of knotty wood become large thus reducing value of tree.

Pollarding

Pollarding consists of cutting a pole tree at some height above the ground level so that it produces new shoots from below the cut. Pollarding is done at a height of 2- 2.5 m above ground level; e.g. in *Salix spp., Hardwickia binata, Grewia optiva, Morus alba*, etc.

Lopping

Removal of one year shoots or fresh growth from entire crown of the tree/plant in order to get sufficient fodder for livestock is known as lopping. Lopping is extensively done in Morus, Grewia, Bauhinia, etc.

Coppicing

Cutting or heading back of main stem at 30 cm from the ground level.

Strong coppicers: *Acacia catechu, Albizia lebbek, Anogeissus latifolia*, etc. Good coppicers: *Aesculus indica, Chloroxylon swietinia, Hardwickia binata*, etc. Bad coppicers: *Adina cordifolia, Bambax ceiba,* etc. Non coppicers: All conifers. Bending: Restricting the development of bole to allow more food material to new leaf shoots. Bending and coppicing are useful when it is desirable to produce large quantity of foliage close to ground level.

Training

In agroforestry vertical spread of the tree is a desirable feature, therefore trees raised in agroforestry systems must be vertically trained to avoid shade and light competition to underground crop. Bushing: Horticulture operation commonly used to increase fruit production at a convenient height for harvesting.

Hedging

It is the practice of planting and maintaining rows of trees, shrubs, or bushes close together to form a living fence or barrier, which can serve as a boundary, shelter, or protective structure in agricultural and agroforestry systems.

The plants used for this purpose are called hedge plants, and the structure formed is known as a hedgerow.

Canopy Management Strategies for Different Systems

Agroforestry System	**Canopy Management Focus**	**Example Species**
Agri-silviculture	Maintain moderate canopy openness for crops	*Prosopis cineraria*, *Dalbergia sissoo*
Agri-horticulture	Manage fruit tree canopy to reduce crop shading	*Mangifera indica*, *Amla (Emblica officinalis)*
Silvipastoral	Low canopy height for fodder access	*Leucaena leucocephala*, *Acacia tortilis*
Alley Cropping	Regular pruning to reduce shading on alleys	*Gliricidia sepium*, *Leucaena leucocephala*
Windbreaks/Shelterbelts	Dense canopy on windward side, tapered leeward side	*Casuarina equisetifolia*, *Eucalyptus tereticornis*

Light Management through Canopy Control

- **Photosynthetically Active Radiation (PAR)** below 30% reduces crop yield.

- Tree pruning can **increase light interception by crops** up to 40–60%.
- Proper canopy management maintains **balanced light, temperature, and humidity** beneath trees, benefiting shade-tolerant crops like turmeric or ginger.

Examples of Successful Canopy Management

a) Prosopis cineraria in Rajasthan

- Natural umbrella-shaped canopy allows intercropping with pearl millet and legumes.
- Minimal pruning required — ideal for arid agroforestry.

b) Leucaena leucocephala in Alley Cropping

- Regular pruning every 45–60 days prevents excessive shading.
- Increases maize yield by 20–30%.

c) Mango-based Agri-horticultural Systems

- Annual pruning after harvest maintains open canopy for intercrops like cowpea or vegetables.

Chapter 2

AGROFORESTRY DIAGNOSIS AND DESIGN

Definition

Agroforestry D & D is a family of procedures for the diagnosis of land management problems and potentials and the design of agroforestry solutions. The ICRAF has developed an approach to assist agroforestry researchers and development fieldworkers to plan and implement effective research and development projects.

Key Features of D & D

i) **Flexibility:** D & D is a flexible discovery of procedure, which can be adopted to fit the needs and resources of different users
ii) **Speed:** D & D has been designed with the option of a 'rapid appraisal' application at the planning stage of a project with In-depth follow-up during project Implementation.
iii) **Repetition:** D & D is an open-ended learning process. Since initial designs can almost always be improved. The D & D process need not end until further Improvements are no longer necessary.

Basic logic of AF Diagnosis and Design

Basic question	Key factors to consider
Prediagnostic stage Which land-use system? How does the system work?	Distinctive combinations of resource technology and land-user objectives. Production objectives and strategy subsystems and components.
Diagnostic stage How well does the system work?	Problems in meeting objectives, causal factors, constraints, and intervention points.
Design and evaluation stage How can the system be improved?	Specifications for problem-solving or performance-enhancing interventions.
Planning stage How can the Improved technology be developed and disseminated?	D & D needs, extension needs.
Implementation stage How can the plan of action be adjusted to new information?	Feedback from research trials, independent farmer innovations etc.

Procedures of AF Diagnosis and Design

The procedures of AF D & D are usually done of two types:

1) 'Macro' D & D and 2) 'Micro D & D

i) MACRO D & D

An agroforestry research programme normally begins with a macro D & D exercise covering an entire ecological zone with I n a country. This consists of a rapid appraisal, based primarily on secondary information complemented by a few selected surveys in the field. by a few selected surveys in the field.

Macro D & D includes on assessment of existing land use system constraints, agricultural policies and institutional arrangement, current agroforestry practices and the potential for improving productivity and sustainability through agroforestry interventions. The study zone is a broad region chosen for its importance at the national level. Its selection is usually based on the following factors.

- Contribution to food production and the national economy;

- Population area

- Urgency of problems or importance of unexploited potential - Level of agricultural development and land use intensification

Typically, the D & D team comprises 5 to 10 specialists from biophysical and socioeconomic fields including soil science, agronomy, horticulture, animal science, forestry, agricultural economics and rural sociology or anthropology. All team members should have experience in both research and extension work. To ensure that the results of the D & D exercise are taken fully into account, the scientists who carry out the D & D should participate at least in the design and analysis and, better still, also in the implementation of the ensuing research programme.

Macro D&D is usually completed in about three months. This includes two to three days to plan the study and orient the team , two to three weeks to review and synthesis the secondary information , two to three weeks to conduct the field work , and four to sis weeks to analyse the information and prepare the report.

Macro D & D includes a detailed review of past and present agroforestryresearch and development programmes. The fieldwork component of a macro D & D normally consists of a visual appraisal of the study zone with the team sometimes traveling many kilometers in a few days in order to identify the extent pattern and problems of existing land-use systems. Team members interview researchers and extension workers and may conduct a few informal interviews with local land-users. Macro D & D is usually followed up by a national or regional workshop to analyse the common problems and potentials of land-use systems in the zone to identify agroforestry technologies with potential relevance for the zone as a whole, to identify specific land-use systems as the focus for future research and development efforts and to establish preliminary research requirements.

ii) MICROD & D

A central aspect of macro D & D is the delineation of land-use systems within the chosen ecological zone, leading to the selection of target systems for more detailed analysis by micro D & Ds. A land-use system is defined as a distinctive combination of crops, livestock, trees and other production components.

The primary focus of analysis is the management unit that makes decisions and shares resources, objectives, labour and products. Analysis of a land-use system comprises all the characteristics that affect its management and performance. These characteristics include the following:

- Location: Administrative and political divisions

- Environmental characteristics:

- Socio-economic characteristics

- Land-use

- Resources/supporting service

-Development activities and policies.

An important aspect of micro D & D is an analysis of the needs, objectives, and constraints of land-users. This step is based on interviews and field surveys. One major aspect of micro D & D is the analysis of existing knowledge and agroforestry practices.

What trees or shrubs are being used with what management procedures, with what objectives and obtaining what yields? Such analysis helps in defining strategies for working with target land-users.

The main objective during the initial D & D exercise is to assess how well the existing system is performing and meeting the needs of the land-users. Any performance gap can be evaluated by comparing present resources and outputs (what the farmers are actually producing) with biophysical potentials (for instance the yields obtained from on-station or onfarm experiments). This assessment must distinguish between problems that can be alleviated and those that cannot. The emphasis is on the problems that can be addressed by agroforestry. Potential interventions are identified and evaluated in terms of their capacity to relieve the identified constraints. In the first instance, all interventions are considered, not just those related to agroforestry.

For example, low soil fertility could be addressed by applying chemical fertilizers or manure or providing mulch from multipurpose trees or other plants. Each alternative is evaluated in terms of its technical potential and its feasibility in terms of resources and capabilities of the land users. As with macro D & D, the research team for a micro D & D comprises 5 to10 biophysical and social scientists. Again the exercise is usually completed in about three months. However, for the micro D & D, the fieldwork component entails more contact with farmers, often including a formal survey of 50 to 100 individuals with a semi structured questionnaire. In addition, the team may need to allocate considerable time to reviewing ongoing research and extension work in the selected land-use system. Promising agroforestry technologies may be sketched on the basis of results from micro D & D, but a full evaluation requires information about technology performance under the specific conditions of the land-use system. If a technology is well known and some farmers have already adapted it successfully, then it can be recommended for further extension. On the other hand, if the technology is new to the area and not well known or if it represents a major departure from the farmers' 'current practices, a research programme must be designed to test the components and management factors and make sure that the technology is well adapted to the target land-use system.

Criteria of Good Agroforestry Design A good agroforestry design should fulfill the following criteria:

i) Productivity: There are many different ways to improve productivity with agroforestry viz., increased output of tree products, improved yields of associated crops, reduction of cropping system inputs, increased labour efficiency, diversification of production, satisfaction of basic needs and other measures of economic efficiency or achievement of biological potential.

ii) Sustainability: By seeking improvements in the sustainability of production systems, agroforestry can achieve its conservation goals while appealing directly to the motivation of low income farmers , who may not always be interested in conservation for its own sake

iii) Adoptability: No matter how technically elegant or environmentally sound an agroforestry design may be, nothing practical is achieved unless it is adopted by its intended users. This means that the technology has to fit the social as well as environmental characteristics of the land-use system for which it is designed.

Unit IIIrd

Chapter 1

Biophysical and ecological functions of agroforestry

Nutrient Cycling in Agroforestry

Introduction

Nutrient cycling in agroforestry refers to the movement and transformation of nutrients (like nitrogen, phosphorus, potassium, and carbon) within a system that integrates trees, crops, livestock. Because trees and crops interact both above and below ground, agroforestry systems are more efficient at recycling and conserving nutrients than conventional monocropping systems.

It should be noted that the cycles for nitrogen, phosphorus, potassium, and other elements vary considerably, and should be considered separately. However, they all have some common characteristics as indicated in the model. The cycle consists of inputs into (gains), output from (losses), and internal turnover or transfer within the system as depicted in the forestry model of Figure 1. The paths of these gains, losses, and transfers are also similar: inputs come through fertilizer, rain, dust, organic materials from outside the system, and N2 fixation (for N) as well as weathering of rocks (for other elements); the principal outputs are derived from erosion, percolation (leaching), and crop harvest (for all nutrients), denitrification and volatilization (for N), and burning (for N and S). Forest ecosystems represent closed and efficient nutrient cycling systems, meaning that they have high rates of turnover, and low rates of outputs or losses from (as well as inputs into) the system; in other words, they are self-sustaining. On the other hand, common agricultural systems are often open or "leaky," meaning that the turnover within the system is relatively low and losses as well as inputs are comparatively high. Nutrient cycling in agroforestry systems falls between these two extremes; more nutrients in the system are re-used by plants (compared to agricultural systems) before being lost from the system. The major difference between agroforestry and other land-use systems lies in the transfer or turn-over of nutrients within the system from one component to the other, and the possibility of managing the system or its components to facilitate increased rates of turn-over without affecting the overall productivity of the system.

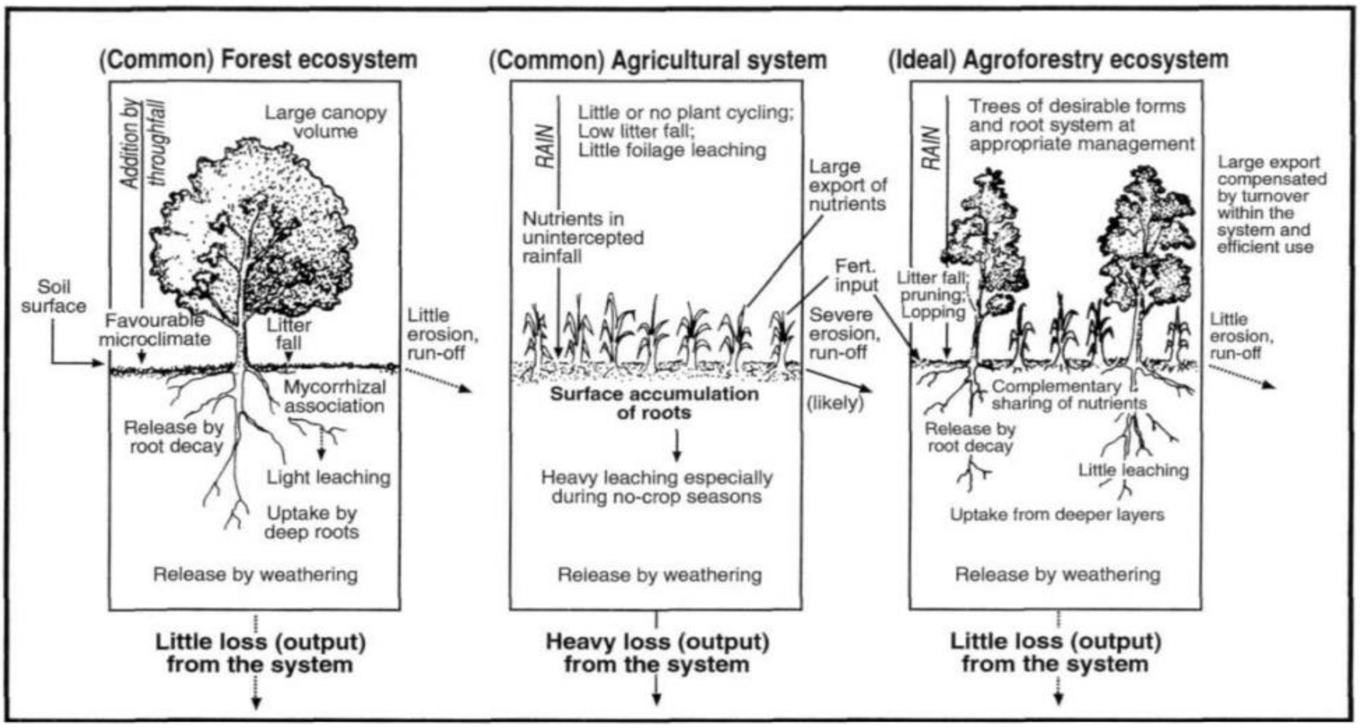

Figure 1: Schematic representation of nutrient relations and advantages of "ideal" agroforestry systems in comparison with common agricultural and forestry systems. Source: Nair (1984).

Soil Organic Matter in Agroforestry

Soil Organic Matter (SOM) refers to all organic materials found in soil — including plant and animal residues, living organisms, and decomposed humus. In agroforestry systems, where trees, crops, and sometimes livestock coexist, the continuous input of organic materials from different sources greatly enhances SOM compared to conventional monocropping systems.

2. Sources of Soil Organic Matter in Agroforestry

Source	Description	Example
Leaf litter and prunings	Trees shed leaves, twigs, and bark that decompose on the soil surface.	Litter from *Gliricidia sepium*, *Leucaena leucocephala*, *Grevillea robusta*.
Root biomass and turnover	Roots die and decay, adding carbon and nutrients underground.	Deep-rooted trees contribute to subsoil organic matter.

Source	Description	Example
Root exudates	Sugars and organic acids secreted by roots feed soil microbes.	Enhances microbial activity and humus formation.
Animal manure	In silvopastoral systems, livestock droppings enrich the soil.	Cattle manure, goat droppings.
Crop residues	Crop roots and stems after harvest decompose in soil.	Maize stover, legume residues.

3. Processes Influencing SOM Dynamics in Agroforestry

1. Decomposition:

Microorganisms break down organic inputs (litter, roots, manure) into simpler compounds.

2. Humification:

Part of the decomposed material is converted into stable humus, which resists further decay.

3. Nutrient cycling:

As SOM decomposes, nutrients such as nitrogen (N), phosphorus (P), and sulfur (S) are released back into the soil for plant uptake.

The **Nitrogen Cycle** is the natural process by which **nitrogen (N)** moves between the atmosphere, soil, plants, animals, and microorganisms.

Although nitrogen gas (**N_2**) makes up about **78% of Earth's atmosphere**, it is **inert** and cannot be used directly by most plants.
Through a series of **biological and chemical transformations**, nitrogen is converted into forms that can be absorbed by plants — and later returned to the atmosphere.

Major Steps in the Nitrogen Cycle

Step	Process	Description	Responsible Organisms/Agents
1. Nitrogen Fixation	Conversion of atmospheric N_2 ammonia (NH_3) or ammonium (NH_4^+).	Makes nitrogenavailable to plants.	*Rhizobium*, *Azotobacter*, *Clostridium*, blue-green algae, lightning,

Step	Process	Description	Responsible Organisms/Agents
			industrial fixation.
2. Nitrification	Conversion of NH_4^+ → nitrite (NO_2^-) → nitrate (NO_3^-).	Converts ammonium into a plant-available form.	*Nitrosomonas* (NH_4^+ → NO_2^-), *Nitrobacter* (NO_2^- → NO_3^-).
3. Assimilation	Plants absorb NO_3^- or NH_4^+ and use it to form proteins, amino acids, and nucleic acids.	Incorporates nitrogen into living tissues.	Plants and microorganisms.
4. Ammonification (Mineralization)	Conversion of organic nitrogen (from dead matter and waste) → NH_4^+.	Returns nitrogen to the soil after decomposition.	Decomposers such as bacteria and fungi.
5. Denitrification	Conversion of NO_3^- → N_2 gas, returning nitrogen to the atmosphere.	Closes the nitrogen cycle loop.	*Pseudomonas*, *Clostridium* (anaerobic bacteria).

Forms of Nitrogen in the Cycle

Form	Chemical Symbol	Availability to Plants
Nitrogen gas	N_2	Not directly available
Ammonia	NH_3	Readily converted to usable forms
Ammonium	NH_4^+	Readily absorbed by plants
Nitrite	NO_2^-	Intermediate form (toxic in high concentrations)
Nitrate	NO_3^-	Major form absorbed by most plants

Form	Chemical Symbol	Availability to Plants
Organic N	Proteins, amino acids	Released after decomposition

Nitrogen Cycle in Agroforestry Systems

Agroforestry systems **enhance and stabilize the nitrogen cycle** through several mechanisms:

Process	Agroforestry Contribution
Biological Nitrogen Fixation (BNF)	Leguminous trees (e.g., *Leucaena*, *Gliricidia*, *Sesbania*) host *Rhizobium* bacteria in root nodules that fix atmospheric N_2.
Organic Matter Input	Litterfall and root decay add organic nitrogen to soil, which undergoes ammonification and mineralization.
Reduced Nitrogen Loss	Tree roots reduce leaching and runoff of nitrates.
Enhanced Microbial Activity	Diverse root systems and litter increase microbial biomass, speeding up nitrogen transformations.
Efficient Nutrient Recycling	Trees capture deep-soil nitrates and recycle them through litter decomposition (nutrient pumping).

Phosphorus (P) cycle

The phosphorus (P) cycle is the biogeochemical process by which phosphorus moves through the lithosphere (rocks), soil, water, and living organisms.

Unlike nitrogen or carbon, phosphorus does not have a gaseous phase, so it primarily cycles through rocks, soil, water, and organisms — making it a sedimentary cycle.

Phosphorus is a vital nutrient for all living things because it forms part of:

- DNA and RNA
- ATP (energy molecules)
- Phospholipids (cell membranes)
- Enzymes and proteins

2. Major Steps in the Phosphorus Cycle

Step	Process	Description
1. Weathering of Rocks	Phosphate minerals (like apatite) are broken down by weathering and erosion.	Releases inorganic phosphate (PO_4^{3-}) into the soil and water.
2. Absorption by Plants	Plants take up phosphate ions ($H_2PO_4^-$, HPO_4^{2-}) from soil solution.	Phosphorus enters the food chain.
3. Consumption by Animals	Animals obtain phosphorus by eating plants or other animals.	Used in bones, teeth, and cellular energy transfer.
4. Decomposition (Mineralization)	Dead plants, animals, and waste decompose, releasing organic phosphorus back into the soil as inorganic phosphate.	Done by bacteria and fungi.
5. Sedimentation	Phosphates washed into water bodies settle and form sedimentary rock layers over time.	Geological uplift may later expose these rocks to restart the cycle.

3. Forms of Phosphorus in the Environment

Form	Location	Availability
Inorganic phosphate (PO_4^{3-})	Soil, water	Readily available to plants
Organic phosphorus	Living organisms, detritus	Released upon decomposition
Mineral phosphorus	Rock phosphate	Slowly released through weathering
Sedimentary phosphorus	Ocean sediments	Locked for long geological periods

4. The Phosphorus Cycle in Agroforestry Systems

Agroforestry systems play a crucial role in conserving and recycling phosphorus, especially in tropical and degraded soils where phosphorus availability is often low.

Mechanism	Role in Phosphorus Cycling
Deep root systems (nutrient pumping)	Trees absorb phosphorus from deeper soil layers and bring it to the surface through litterfall.
Litterfall and root decay	Return organic phosphorus to the topsoil, enhancing P availability.
Mycorrhizal associations	Fungal partners of trees and crops increase phosphorus uptake efficiency by expanding the root's absorbing area.
Reduced erosion and runoff	Tree cover protects soil from erosion, preventing phosphorus loss with topsoil.
Organic matter buildup	Increases phosphorus retention and slow release, reducing fixation.
Manure and leaf mulch	Supply organic P that mineralizes over time.

Potassium (K) cycle

The potassium cycle describes how potassium (K) moves between rocks, soil, water, plants, and microorganisms in an ecosystem.

Unlike nitrogen or phosphorus, potassium does not form complex compounds or a gaseous phase — it cycles mainly within the soil–plant system.

Potassium is one of the three primary macronutrients (N–P–K) essential for plant growth. It plays a major role in:

- Enzyme activation
- Photosynthesis
- Osmoregulation and water balance
- Disease resistance and stress tolerance

Forms of Potassium in Soil

Form	Location	Availability to Plants
Mineral K	Locked in primary minerals (feldspar, mica).	Very slow release (unavailable).
Non-exchangeable K (Fixed K)	Trapped between clay layers (illite, vermiculite).	Slowly available.
Exchangeable K	Adsorbed on clay and organic matter surfaces.	Readily available to plants.
Solution K	Dissolved in soil water.	Immediately available (but easily leached).

3. Main Processes in the Potassium Cycle

Process	Description	Direction of Flow
Weathering	Release of K^+ ions from minerals by chemical and physical breakdown.	Rock → Soil solution
Plant uptake	Roots absorb K^+ from the soil solution.	Soil → Plant
Litterfall and root turnover	Dead leaves and roots return K to soil.	Plant → Soil
Leaching and runoff	K^+ lost from soil by water movement, especially in sandy or degraded soils.	Soil → Water bodies
Fixation and release	K^+ trapped or released from clay minerals.	Soil exchange sites ↔ Clay minerals

Potassium Cycling in Agroforestry Systems

Agroforestry systems are very efficient at recycling and conserving potassium due to the interactions among trees, crops, and soil.

Mechanism	Agroforestry Contribution
Deep nutrient uptake (nutrient pumping)	Deep-rooted trees extract potassium from subsoil layers and return it to the surface via litterfall and pruning residues.
Litterfall and organic matter addition	Continuous supply of K from decomposing leaves and twigs enriches topsoil.
Reduced leaching	Tree roots stabilize soil, increase infiltration, and reduce K losses.
Enhanced microbial activity	Decomposition of litter and root exudates promotes K mineralization and recycling.
Soil structure improvement	Organic matter and root networks improve cation exchange capacity (CEC), helping retain more exchangeable K.

Importance of Potassium in Agroforestry

Function	Description	Impact
Photosynthesis & energy regulation	K activates enzymes needed for carbohydrate formation.	Promotes healthy plant growth.
Water regulation	Controls stomatal opening and closing.	Improves drought resistance.
Disease resistance	Enhances plant immune response.	Reduces pest and disease stress.
Nutrient balance	Helps balance nitrogen and phosphorus metabolism.	Improves crop yield and quality.
Soil fertility maintenance	Through recycling and reduced leaching.	Ensures long-term sustainability.

6. Example

In an agroforestry system with *Gliricidia sepium* and maize:

- Deep tree roots uptake potassium from lower soil layers.
- Litterfall from *Gliricidia* decomposes on the soil surface, releasing K^+.
- Maize roots then absorb this recycled potassium. This natural cycle reduces the need for external K fertilizers.

4. **Soil aggregation:**

Organic matter binds soil particles, improving structure and reducing erosion.

4. Benefits of SOM in Agroforestry Systems

Function	Description	Impact
Improved soil fertility	SOM slowly releases nutrients through mineralization.	Supports long-term crop and tree growth.
Enhanced soil structure	Organic matter acts as a binding agent for soil particles.	Promotes aeration, drainage, and root development.
Water retention	SOM increases the soil's ability to hold moisture.	Reduces drought stress.
Microbial activity	SOM provides food for beneficial soil organisms.	Enhances nutrient cycling and disease suppression.
Erosion control	Litter cover and improved aggregation prevent soil loss.	Conserves fertile topsoil.
Carbon sequestration	Agroforestry soils store more carbon than croplands.	Mitigates climate change.

2. Key Components of Nutrient Cycling in Agroforestry

1. **Inputs of Nutrients**

- **Biological nitrogen fixation (BNF):** Leguminous trees such as *Leucaena leucocephala* or *Gliricidia sepium* fix atmospheric nitrogen through symbiotic Rhizobium bacteria.
- **Litterfall and prunings:** Decomposing leaves, twigs, and roots release nutrients into the soil.
- **Animal manure:** In silvopastoral systems, livestock waste adds organic nutrients.
- **Atmospheric deposition and dust:** Add small but continuous nutrient inputs.

2. **Internal Transfers**

   - **Root interactions:** Deep tree roots absorb nutrients from subsoil layers and bring them to the surface through leaf litter — known as **nutrient pumping**.

- **Mycorrhizal associations:** Fungi associated with roots improve nutrient uptake efficiency.
- **Decomposition and mineralization:** Microbes break down organic matter, releasing nutrients in plant-available forms (e.g., nitrate, phosphate).

3. **Outputs and Losses**

- **Crop harvests** remove nutrients from the system.
- **Leaching and runoff** can occur, but trees help **reduce these losses** by improving soil structure and water infiltration.

3. Mechanisms Enhancing Nutrient Cycling

Mechanism	Process	Result
Litterfall and root decay	Tree litter decomposes and returns nutrients to soil.	Increases soil organic matter and fertility.
Deep rooting and nutrient pumping	Trees uptake nutrients from deep soil layers inaccessible to crops.	Reduces nutrient loss to leaching.
Biological nitrogen fixation (BNF)	Leguminous trees fix atmospheric nitrogen.	Adds new nitrogen to the system naturally.
Microbial activity	Enhanced by organic inputs from trees.	Accelerates nutrient turnover and humus formation.
Reduced erosion and runoff	Tree cover protects soil surface.	Prevents nutrient loss with topsoil.

4. Benefits of Efficient Nutrient Cycling in Agroforestry

- **Improved soil fertility** through continuous replenishment of nutrients.
- **Reduced need for chemical fertilizers**, lowering costs and environmental impact.
- **Sustained productivity** of crops and trees over time.
- **Enhanced soil biological activity** and organic matter content.
- **Greater resilience** of the agro-ecosystem to degradation and climate stress.

5. Example

Alley Cropping System:

Leguminous trees (e.g., *Gliricidia sepium*) are planted in rows with crops like maize between them.

- Trees are pruned regularly; their leaves decompose and release nutrients.
- Deep tree roots capture leached nutrients and recycle them to the topsoil.
- Result: Sustainable nutrient supply and reduced fertilizer dependence.

Nutrient Pumping

Definition

Nutrient pumping is the biological process by which deep-rooted trees and shrubs absorb nutrients (and sometimes water) from deeper layers of the soil profile and return them to the surface through leaf litter, root decay, and pruning residues.

In simple terms:

Trees act as **natural nutrient pumps**, bringing up nutrients that crops cannot reach, and recycling them into the topsoil.

How Nutrient Pumping Works

Step	Process	Description
1. Deep nutrient uptake	Tree roots penetrate deep into the soil (sometimes several meters).	Absorb nutrients such as N, P, K, Ca, Mg from subsoil layers.
2.Nutrient translocation	These nutrients are transported upward through the tree's vascular system to leaves, stems, and branches.	Nutrients become part of plant tissue.
3.Litterfall and root turnover	When leaves, twigs, and roots die and decompose, nutrients are released near the soil surface.	Returns nutrients to the topsoil.
4. Crop uptake	Shallow-rooted crops absorb these recycled nutrients.	Increases soil fertility and productivity.

Example of Nutrient Pumping in Agroforestry

In an **agroforestry alley cropping system**, *Gliricidia sepium* trees are planted in rows with maize in between:

1. *Gliricidia* roots reach deep soil layers and absorb nutrients (especially nitrogen, potassium, and calcium).

2. The trees are **pruned regularly**, and the leaves are used as **green mulch** on the soil surface.
3. As the mulch decomposes, nutrients are released into the upper soil layer.
4. **Maize** roots (which are shallow) then utilize these nutrients — improving growth without extra fertilizer.

Nutrients Commonly "Pumped" by Trees

Nutrient	Importance	Example Tree Species
Nitrogen (N)	Promotes vegetative growth and protein formation.	*Leucaena leucocephala*, *Gliricidia sepium* (also fix N_2).
Phosphorus (P)	Supports root and flower development.	*Sesbania sesban*, *Faidherbia albida*.
Potassium (K)	Improves stress tolerance and photosynthesis.	*Grevillea robusta*, *Eucalyptus spp.*
Calcium (Ca)	Important for cell wall formation.	*Ficus* species.
Magnesium (Mg)	Central atom in chlorophyll.	*Acacia* and *Casuarina* species.

Rhizosphere Nutrient Pumping in Agroforestry

Mechanisms:

1. **Deep Root Uptake:**

- Trees in agroforestry (e.g., *Gliricidia sepium*, *Leucaena leucocephala*, *Faidherbia albida*) have deep roots that extract nutrients (especially nitrate, potassium, calcium, magnesium) from **subsoil layers** unreachable by crops.
- These nutrients are brought to the surface via **leaf fall and root turnover** → enriching the topsoil.

2. **Root Exudation and Microbial Activation:**

- Tree and crop roots release exudates (organic acids, amino acids, sugars) that **stimulate rhizosphere microbes**.
- These microbes:
  - **Fix nitrogen** (e.g., Rhizobium, Azospirillum),
  - **Solubilize phosphorus** (e.g., phosphate-solubilizing bacteria),
  - **Mobilize micronutrients** (e.g., Fe, Zn).

3. **Mycorrhizal Networks:**
   - Mycorrhizal fungi form **common mycorrhizal networks** (CMNs) between trees and crops.
   - These networks **transfer nutrients and carbon** between species, acting like underground nutrient highways.
4. **Litter Decomposition:**
   - Tree litter (leaves, twigs) decomposes in the rhizosphere, releasing nutrients slowly into the soil.
   - This **enhances organic matter**, **soil structure**, and **microbial diversity**.

Benefits:

- Increases nutrient availability (N, P, K, Ca, Mg).
- Reduces leaching losses.
- Enhances soil fertility and microbial biomass.
- Sustains long-term productivity.

Phyllosphere Nutrient Pumping in Agroforestry

Mechanisms:

1. **Canopy Nutrient Cycling:**
   - Tree canopies intercept atmospheric dust, rain, and aerosols containing nutrients (N, S, Ca, Mg).
   - Microbes on leaf surfaces (phyllosphere bacteria and fungi) **fix atmospheric nitrogen** or **metabolize nutrients**, contributing to foliar nutrient availability.
2. **Leaf Wash-off and Throughfall:**
   - During rain, nutrients and microbial metabolites from the phyllosphere wash down to the soil as **throughfall** or **stemflow**, enriching the topsoil below.
3. **Microbial Activities:**
   - Phyllosphere microbes (e.g., *Methylobacterium*, *Pseudomonas*, *Cyanobacteria*) can:
     - Fix N_2,
     - Produce vitamins and growth hormones,
     - Decompose organic debris (pollen, dust, waxes),
     - Facilitate foliar nutrient uptake.
4. **Atmospheric Nutrient Capture:**

- Tree canopies trap atmospheric nitrogen and other micronutrients that would otherwise be lost — an important nutrient input in nutrient-poor tropical soils.

Benefits:

- Enhances nutrient capture from the atmosphere.
- Enriches soil through canopy nutrient deposition.
- Improves nutrient use efficiency.
- Supports crop nutrition beneath tree canopies.

Integrated Nutrient Pumping in Agroforestry

Component	Mechanism	Nutrients Mobilized	Outcome
Tree Roots (Rhizosphere)	Deep nutrient uptake & root exudation	N, P, K, Ca, Mg	Nutrient transfer from deep to topsoil
Mycorrhizae & Microbes	Nutrient solubilization & fixation	N, P, Fe, Zn	Enhanced nutrient bioavailability
Leaf Canopy (Phyllosphere)	Atmospheric nutrient capture & microbial fixation	N, S, trace elements	Nutrient input via throughfall
Litterfall & Decomposition	Organic matter breakdown	N, P, C	Soil fertility maintenance

Chapter 2

Soil and Water Conservation

Soil and water conservation refers to the management practices that prevent soil erosion, reduce water loss, and maintain the health and productivity of land and water resources.

Healthy soil and sufficient water are the foundation of sustainable agriculture -and agroforestry plays a key role in protecting both.

Objectives of Soil and Water Conservation

- To reduce soil erosion by wind and water
- To maintain or improve soil fertility
- To enhance water infiltration and groundwater recharge
- To reduce surface runoff and flooding
- To sustain agricultural productivity over the long term
- To protect ecosystems and water bodies from sedimentation and pollution

Major Soil Degradation Problems

Problem	Description	Effect
Water erosion	Loss of topsoil due to rainfall and runoff.	Decreased fertility and productivity.
Wind erosion	Blowing away of fine soil particles in dry regions.	Soil loss and desertification.
Nutrient leaching	Downward movement of nutrients beyond root zone.	Nutrient depletion.
Soil compaction	Heavy machinery or overgrazing compresses soil.	Reduced infiltration and aeration.
Decline in organic matter	Due to continuous cultivation and poor residue management.	Poor soil structure and fertility.

Role of Agroforestry in Soil and Water Conservation

Agroforestry — the deliberate integration of **trees, crops, and sometimes livestock** — is one of the **most effective natural systems** for conserving both soil and water.

A. Soil Conservation Mechanisms

Mechanism	Description	Example
1. Erosion control	Tree roots hold soil particles together and prevent detachment.	Contour hedgerows of *Leucaena leucocephala*.
2. Ground cover and litter	Tree leaves and crop residues cover the soil, reducing raindrop impact and evaporation.	Shaded coffee systems, mulch from *Gliricidia*.
3. Improved soil structure	Roots and organic matter increase soil porosity and aggregation.	Alley cropping with nitrogen-fixing trees.
4. Nutrient recycling (nutrient pumping)	Deep roots bring nutrients from subsoil to the surface.	*Faidherbia albida* parklands.
5. Increased soil organic matter	Litter and root decay add carbon, improving fertility.	Silvopastoral systems.

B. Water Conservation Mechanisms

Mechanism	Description	Example
1. Increased infiltration	Tree roots and organic matter create channels for water to enter the soil.	Shelterbelts and windbreaks.
2. Reduced runoff	Tree cover slows down water movement on slopes.	Contour hedgerows in hilly areas.
3. Groundwater recharge	Deep roots guide water to lower soil layers.	Agroforestry buffer strips near streams.
4. Microclimate improvement	Shade reduces evaporation and maintains soil moisture.	Shade-grown cocoa or coffee systems.
5. Water purification	Vegetation filters sediments and pollutants from runoff.	Riparian agroforestry systems.

5. Agroforestry Practices that Aid Soil and Water Conservation

Agroforestry Practice	Soil and Water Benefits
Alley cropping	Hedgerows control erosion; prunings act as mulch.
Windbreaks / Shelterbelts	Reduce wind erosion and moisture loss.
Contour hedgerows	Slow runoff, trap sediments, enhance infiltration.
Silvopastoral systems	Tree cover prevents compaction and provides shade for livestock.
Riparian buffers	Protect waterways from sediment and nutrient pollution.
Home gardens / Multistrata systems	Continuous canopy and litter cover protect soil year-round.

Unit IVth

Chapter 1

Carbon Sequestration and Climate Change Mitigation in Agroforestry

Climate change is mainly driven by the increasing concentration of **greenhouse gases (GHGs)** — especially **carbon dioxide (CO_2)**, **methane (CH_4)**, and **nitrous oxide (N_2O)** — in the atmosphere due to human activities like deforestation, fossil fuel burning, and intensive agriculture.

Agroforestry, the intentional integration of **trees with crops and/or livestock**, is a powerful **nature-based solution** that helps **mitigate climate change** by:

1. **Sequestering carbon** in biomass and soils.
2. **Reducing emissions** from agriculture and deforestation.
3. **Improving resilience** of farming systems to climate variability.

What is Carbon Sequestration?

Carbon sequestration is the process of **capturing and storing atmospheric carbon dioxide (CO_2)** in vegetation, soils, and other carbon pools.

In agroforestry systems, carbon is sequestered mainly through:

- **Photosynthesis** → CO_2 is absorbed by trees and crops to produce biomass.
- **Storage in biomass** → Carbon accumulates in tree trunks, branches, roots, and litter.
- **Storage in soils** → Decomposed organic matter increases soil organic carbon.

Carbon Pools in Agroforestry Systems

Carbon Pool	Description	Example
Aboveground biomass	Carbon stored in stems, branches, and leaves of trees and shrubs.	*Grevillea robusta*, *Faidherbia albida*.
Belowground biomass	Carbon in roots and associated soil biota.	Deep-rooted species like *Acacia spp.*
Litter and dead wood	Carbon from fallen leaves, twigs, and decomposing wood.	Forest floor mulch layer.

Carbon Pool	**Description**	**Example**
Soil organic carbon (SOC)	Carbon stored in humus and organic matter.	Enhanced by litter decomposition and root turnover.

Mechanisms of Carbon Sequestration in Agroforestry

Mechanism	**Description**
1. Photosynthetic fixation	Trees and crops absorb CO_2 and convert it into organic carbon through photosynthesis.
2. Biomass accumulation	Trees act as carbon "sinks," storing carbon in wood and foliage for decades.
3. Litterfall and root turnover	Dead plant material decomposes, adding carbon to the soil.
4. Soil carbon stabilization	Organic matter binds with soil particles, storing carbon in stable forms (humus).
5. Reduced decomposition and erosion	Tree cover reduces soil disturbance and organic carbon loss.

Carbon Sequestration Potential of Agroforestry Systems

Agroforestry System	**Carbon Storage Potential (t C/ha/yr)***	**Remarks**
Silvopastoral systems	1–5	Carbon stored in trees and pasture biomass.
Alley cropping	2–8	High soil carbon due to litter input.
Home gardens (multistrata)	5–12	Large biomass and soil carbon.
Windbreaks / Shelterbelts	1–3	Limited area but continuous carbon input.

Agroforestry System	Carbon Storage Potential (t C/ha/yr)*	Remarks
Woodlots / Boundary planting	4–10	High aboveground carbon per unit area.

*Values vary with species, soil type, and management practices.

Agroforestry and Climate Change Mitigation

Agroforestry contributes to **climate change mitigation** through several direct and indirect mechanisms:

A. Direct Mitigation Effects

Action	Impact
CO_2 absorption and storage	Removes CO_2 from the atmosphere and stores it as biomass and soil carbon.
Reduced fossil fuel use	Trees provide renewable energy (fuelwood) and timber, reducing pressure on natural forests.
Lower fertilizer use	Nitrogen-fixing trees supply natural nutrients, reducing N_2O emissions from fertilizers.

B. Indirect Mitigation Effects

Action	Impact
Microclimate regulation	Tree shade reduces soil temperature and evapotranspiration.
Reduced erosion and runoff	Conserves soil carbon and nutrients.
Diversified income sources	Encourages sustainable land use and discourages deforestation.

Carbon Sequestration Pathways in Agroforestry (Simplified Flow)

Atmospheric CO_2

↓ (Photosynthesis)

Plant Biomass (Trees + Crops)

↓ (Litterfall, root turnover)

Soil Organic Carbon (Humus)

↓ (Stable storage)

Long-term Carbon Sequestration

Examples of Agroforestry Systems with High Carbon Sequestration

Region	System	Key Species	Carbon Benefit
India	*Leucaena* alley cropping	*Leucaena leucocephala*	Adds 6–8 t C/ha/yr in biomass and soil.
Africa (Sahel)	Parkland agroforestry	*Faidherbia albida*	Increases soil carbon and crop yield.
Latin America	Home gardens	*Inga*, *Gliricidia*, fruit trees	Stores >100 t C/ha total.
Southeast Asia	Multistrata cacao system	*Shade trees + cacao*	Enhances soil organic matter and biodiversity.

Co-Benefits Beyond Carbon Storage

Benefit	Description
Enhanced biodiversity	Trees provide habitats for flora and fauna.
Improved soil fertility	Litter decomposition enriches soil nutrients.
Water conservation	Trees improve infiltration and reduce runoff.
Climate resilience	Shade and root systems buffer crops against drought and heat stress.
Livelihood diversification	Timber, fruits, fodder, and fuelwood provide additional income.

Challenges and Limitations

Challenge	Explanation
Measurement difficulty	Quantifying soil and biomass carbon precisely is complex.
Land tenure issues	Farmers may lack ownership incentives for tree planting.
Initial investment costs	Tree establishment requires time and resources.
Trade-offs	Competition for light and water between trees and crops if poorly managed.

Carbon Credits and Agroforestry

A carbon credit is a tradable certificate or permit that represents the removal or reduction of one metric ton (1 tonne) of carbon dioxide (CO_2) or its equivalent (CO_2e) from the atmosphere.

In simple terms:

1 carbon credit = 1 tonne of CO_2 (or equivalent GHG) **avoided, reduced, or sequestered**.

Carbon credits are part of **market-based mechanisms** designed to **reduce global greenhouse gas emissions** and **mitigate climate change**.

Types of Carbon Credits

Type	Description	Example
Compliance Credits	Created and traded under government-regulated systems (like the Kyoto Protocol or EU Emissions Trading System).	Companies buy credits to meet legally binding emission reduction targets.
Voluntary Credits	Created under voluntary carbon markets (VCMs), where individuals or companies offset emissions voluntarily.	A company funds a tree-planting project to offset its carbon footprint.

Carbon Markets

Type	Description
Regulated (Compliance) Market	Operates under international or national emission trading schemes (ETS). Entities must offset emissions legally.
Voluntary Market	Businesses, NGOs, or individuals voluntarily buy credits to offset emissions and promote sustainability.

- **Verra (VCS – Verified Carbon Standard)**
- **Gold Standard**
- **Climate Action Reserve (CAR)**
- **Plan Vivo Standard** (commonly used for smallholder agroforestry projects)

How Carbon Credits Work

1. **Emission Reduction/Removal Activity** — A project (like tree planting, renewable energy, or improved land use) reduces or captures CO_2.
2. **Measurement & Verification** — Independent auditors measure how much CO_2 is reduced or sequestered.
3. **Certification** — Verified credits are issued under recognized standards.
4. **Trading** — Credits are sold to companies or individuals who wish to offset their emissions.
5. **Retirement** — Once used to offset emissions, the credit is retired to prevent double counting.

Agroforestry and Carbon Credits

Agroforestry projects are **excellent sources of carbon credits** because they sequester carbon while providing **multiple co-benefits** (biodiversity, livelihoods, and soil conservation).

A. How Agroforestry Generates Carbon Credits

Step	Activity	Result
1. Establishment	Farmers plant trees with crops/livestock.	CO_2 is absorbed by trees (biomass carbon).
2. Growth phase	Trees increase in biomass and organic matter.	Carbon stored above and below ground.

Step	Activity	Result
3.Soil improvement	Litter and root turnover increase soil organic carbon.	Long-term carbon storage.
4. Verification	Carbon gains measured and certified.	Credits issued based on net CO_2 captured.

Benefits of Carbon Credits from Agroforestry

Category	Benefit
Environmental	Carbon sequestration, biodiversity enhancement, soil and water conservation.
Economic	Additional income for farmers through sale of carbon credits.
Social	Employment generation, community participation, improved livelihoods.
Climate	Helps meet national and global emission reduction targets.

Co-Benefits and SDG Linkages

Agroforestry-based carbon projects support multiple **UN Sustainable Development Goals (SDGs):**

SDG	Link
SDG 13	Climate Action — Reduces CO_2 emissions.
SDG 15	Life on Land — Restores degraded lands.
SDG 1 & 8	No Poverty & Decent Work — Provides new income sources.
SDG 2	Zero Hunger — Improves agricultural productivity.
SDG 6	Clean Water — Reduces runoff and improves watershed health.

Future Outlook

- Agroforestry is recognized under **REDD+** (Reducing Emissions from Deforestation and Forest Degradation) and **Nationally Determined Contributions (NDCs)**.

- Growing interest in "nature-based carbon solutions" means carbon credits from agroforestry are becoming highly valued due to their triple benefits: Climate mitigation + Livelihood support + Biodiversity conservation.

Summary Table: Agroforestry and Carbon Credits

Aspect	**Description**
What it is	Payment for sequestering or reducing CO_2 emissions through tree–crop systems.
How it works	Verified projects earn tradable carbon credits.
Main benefits	Environmental protection + Income generation.
Best suited systems	Agroforestry, silvopasture, afforestation/reforestation.
Challenges	Costly verification, long timeframes, market access.

Chapter 2

Phytoremediation in Agroforestry

Introduction

Phytoremediation is the use of plants and trees to remove, detoxify, or stabilize pollutants (such as heavy metals, pesticides, organic contaminants, and excess nutrients) from soil, water, or air.

When applied within agroforestry systems, phytoremediation combines pollution control with productive land use, improving both environmental health and farm sustainability.

In simple words:

Phytoremediation = "Cleaning the environment using plants"
Agroforestry phytoremediation = "Using trees + crops to clean the environment sustainably"

Mechanisms of Phytoremediation

Mechanism	Description	Example
1. Phytoextraction	Plants absorb contaminants (e.g., heavy metals) through roots and accumulate them in shoots/leaves.	*Populus*, *Brassica juncea* for Pb, Cd, Zn.
2. Phytostabilization	Roots immobilize contaminants in the soil, preventing leaching or erosion.	*Vetiver grass*, *Casuarina equisetifolia*.
3. Phytodegradation	Plants or their root-associated microbes break down organic pollutants (e.g., hydrocarbons, pesticides).	*Eucalyptus*, *Willow* species.
4. Rhizofiltration	Roots absorb or adsorb contaminants (mostly heavy metals) from contaminated water.	*Sunflower*, *Poplar*.
5. Phytovolatilization	Plants take up volatile contaminants and release them into the atmosphere in less toxic forms.	*Populus deltoides* (for selenium, mercury).

Why Agroforestry is Ideal for Phytoremediation

Agroforestry integrates **trees, crops, and sometimes livestock**, creating a **diverse, resilient ecosystem** that enhances phytoremediation effectiveness.

Agroforestry Feature	Contribution to Phytoremediation
Deep-rooted trees	Access and extract contaminants from deeper soil layers.
High biomass production	Allows accumulation of larger amounts of contaminants.
Continuous canopy cover	Reduces erosion and surface runoff of pollutants.
Rich rhizosphere activity	Enhances microbial degradation of contaminants.
Organic matter addition	Improves soil health and contaminant binding capacity.

Types of Contaminants Remediated through Agroforestry

Type of Contaminant	Source	Agroforestry Role
Heavy metals (Pb, Cd, Zn, Ni, Cu)	Mining, industry, sewage sludge	Trees extract or immobilize metals.
Excess nutrients (N, P)	Fertilizer runoff, animal waste	Trees and grasses absorb nutrients, prevent eutrophication.
Pesticides & hydrocarbons	Agriculture, oil spills	Degraded by rhizosphere microbes.
Salinity and sodicity	Irrigation misuse, poor drainage	Trees like *Eucalyptus* and *Casuarina* improve soil structure and salt balance.

Examples of Phytoremediation Tree Species in Agroforestry

Tree Species	Type of Contaminant	Mechanism	System Type
Eucalyptus camaldulensis	Salinity, hydrocarbons	Phytodegradation, stabilization	Windbreaks, buffer strips

Tree Species	Type of Contaminant	Mechanism	System Type
Populus deltoides (Poplar)	Heavy metals, nitrates	Phytoextraction, rhizofiltration	Riparian agroforestry
Acacia nilotica	Heavy metals (Pb, Cd)	Phytostabilization	Silvopastoral systems
Casuarina equisetifolia	Salinity, heavy metals	Phytostabilization	Coastal agroforestry
Leucaena leucocephala	Nutrient excess, pesticides	Phytodegradation	Alley cropping
Vetiveria zizanioides (Vetiver grass)	Heavy metals, organic pollutants	Phytostabilization	Contour hedgerows, buffer strips

Agroforestry Systems Suitable for Phytoremediation

System	Application
Riparian buffer strips	Trees and grasses along waterways filter nutrients and pollutants from runoff.
Silvopastoral systems	Trees stabilize soils contaminated by livestock waste.
Windbreaks and shelterbelts	Trap airborne dust and pollutants.
Contour hedgerows	Control erosion and stabilize contaminated slopes.
Reclamation forestry	Trees rehabilitate degraded mine spoils and industrial lands.

7. Process of Phytoremediation in Agroforestry (Simplified Flow)

Contaminated soil / water

↓

Tree and crop roots absorb or immobilize pollutants

↓

Microbes in rhizosphere break down organic toxins

↓

Pollutants stored in plant biomass or converted to less harmful forms

↓

Cleaner soil and water + Improved ecosystem health

Benefits of Phytoremediation in Agroforestry

Benefit Type	Description
Environmental	Cleans soil and water; prevents further contamination; restores degraded lands.
Soil health	Increases organic matter, microbial activity, and nutrient balance.
Economic	Generates income from timber, fodder, or fuelwood during remediation.
Social	Improves local environment and reduces health risks for communities.
Climate	Enhances carbon sequestration while cleaning pollutants.

Case Studies / Examples

Country	System / Species	Result
India	*Eucalyptus* and *Acacia* on saline soils	Reduced soil salinity and improved crop yield.
China	*Poplar* and *Willow* near industrial sites	Absorbed Zn, Cd, and Pb efficiently.
Kenya	*Grevillea robusta* in agroforestry buffers	Reduced nutrient and pesticide runoff into rivers.
Brazil	*Vetiver* and *Leucaena* on mining spoils	Stabilized soil and promoted regeneration.

Limitations / Challenges

Challenge	**Description**
Slow process	Takes years for significant contaminant removal.
Disposal of contaminated biomass	Must be handled safely (incineration or composting).
Metal toxicity	High contaminant levels can harm plants.
Site specificity	Plant species must be selected based on soil and pollutant type.
Monitoring requirement	Needs scientific assessment for long-term effectiveness.

Chapter 3

Adverse Effects of Trees on Crops in Agroforestry

While **agroforestry** aims to integrate trees and crops for mutual benefits (such as nutrient cycling, shade, and microclimate regulation), **negative interactions** can occur when:

- Trees and crops **compete for limited resources**, or
- Trees **release inhibitory substances** or **modify microclimate** unfavorably.

These negative interactions are often referred to as **“tree–crop competition”** or **“adverse tree–crop interactions.”**

Major Adverse Effects of Trees on Crops

Type of Effect	Description	Examples
1. Competition for light (shading)	Tree canopies intercept sunlight, reducing the light available for crops.	Shading by tall species like *Eucalyptus* or *Acacia* reduces yield of sun-loving crops like maize or wheat.
2. Competition for water	Tree roots extract water from the same soil layers as crops, causing water stress.	*Prosopis juliflora* and *Eucalyptus* dry out soil near crops in arid regions.
3. Competition for nutrients	Tree roots absorb soil nutrients (especially N, P, K) that crops also need.	*Leucaena* may compete for nitrogen with shallow-rooted crops in low-fertility soils.
4. Allelopathy (chemical inhibition)	Some trees release toxic biochemicals (allelochemicals) through leaves, roots, or litter that suppress crop growth.	*Eucalyptus*, *Acacia auriculiformis*, *Casuarina* release allelopathic compounds affecting germination and root growth.
5. Physical interference	Tree roots or branches physically obstruct crop management or mechanization.	Roots from boundary trees interfere with plowing and weeding.
6. Microclimate modification	Dense tree cover may reduce temperature variation and air flow, increasing humidity and disease risk for some crops.	Shaded, moist conditions may favor fungal diseases in groundnut or beans.

Type of Effect	Description	Examples
7. Harboring pests and diseases	Some tree species serve as alternate hosts for crop pests or pathogens.	*Leucaena* can harbor psyllids; fruit trees may harbor insects that attack nearby crops.
8. Reduction in effective cropping area	Tree trunks, canopy spread, and root zones occupy space that could otherwise be used for crops.	Wide tree spacing reduces usable crop land area.
9. Increased labor and management complexity	Managing tree pruning, litter, and root competition requires more effort and knowledge.	Improper pruning leads to excess shade and debris accumulation.

Key Effects

A. Light Competition (Shading)

- Trees intercept sunlight before it reaches the crops.
- Affects **photosynthesis**, especially for **C_4 crops** (e.g., maize, sorghum) which need high light.
- Shade-tolerant crops (e.g., turmeric, ginger, coffee) can tolerate or benefit from partial shade.

Example:
Under *Eucalyptus* or *Acacia*, maize yield may drop by **30–60%** due to reduced solar radiation.

B. Water Competition

- Tree roots (especially shallow ones) compete with crops for moisture.
- In dry or semi-arid areas, trees may deplete soil moisture rapidly, leaving little for crops.

Example:
Eucalyptus camaldulensis can lower soil moisture by extracting deep water, reducing nearby crop productivity.

C. Nutrient Competition

- Both trees and crops draw from the same nutrient pool.
- Tree litterfall can add nutrients long-term, but short-term competition often dominates.

- Deep-rooted trees may absorb nutrients from subsoil layers, but if their roots spread laterally, they outcompete shallow-rooted crops.

D. Allelopathic Effects

- Some trees release toxic organic compounds (phenolics, terpenes, flavonoids) that inhibit crop seed germination, root elongation, or nutrient uptake.

Common Allelopathic Trees:

Tree	**Affected Crops**	**Source of Allelochemicals**
Eucalyptus spp.	Maize, legumes, vegetables	Leaf litter, root exudates
Acacia auriculiformis	Rice, maize	Leaves and bark
Casuarina equisetifolia	Grasses, pulses	Needles and litter
Prosopis juliflora	Cereals, legumes	Roots and pods

E. Microclimate Modification

- Dense canopy → less sunlight, lower temperature fluctuations, higher humidity.
- High humidity → favorable for diseases (fungal, bacterial).
- Reduced air flow → poor pollination or increased pest populations.

F. Harboring of Pests and Diseases

- Trees can serve as **alternate hosts** or **breeding grounds** for crop pests.
- Example: Fruit trees attract insects that also damage vegetable crops.

Factors Influencing the Severity of Adverse Effects

Factor	**Influence**
Tree species	Deep-rooted vs. shallow-rooted; evergreen vs. deciduous.
Crop species	Shade-tolerant vs. light-demanding.
Tree spacing and arrangement	Wider spacing reduces competition.

Factor	Influence
Climate and soil	Competition is higher in dry or nutrient-poor soils.
Management practices	Pruning, root barriers, and fertilization can reduce negative effects.

Mitigation and Management Strategies

Problem	Management Option
Light competition	Regular pruning, choosing deciduous or light-canopy species.
Water competition	Select deep-rooted trees; apply mulching; maintain adequate spacing.
Nutrient competition	Apply organic or inorganic fertilizers; integrate nitrogen-fixing trees.
Allelopathy	Avoid allelopathic species near sensitive crops; compost litter before use.
Pest issues	Regular monitoring; integrated pest management (IPM).
Physical interference	Root pruning; maintain appropriate tree–crop distance.

Examples of Tree–Crop Interactions

Tree Species	Crop	Nature of Interaction	Remarks
Eucalyptus tereticornis	Maize, wheat	Strong competition (water, light, allelopathy)	Avoid in crop zones.
Acacia nilotica	Sorghum, millet	Moderate shading, some N addition	Good in dry zones if well spaced.

Tree Species	Crop	Nature of Interaction	Remarks
Leucaena leucocephala	Maize, beans	Nutrient competition but N fixation benefit	Manage with pruning.
Faidherbia albida	Millet, sorghum	Positive — leaf fall during crop season adds nutrients	Excellent parkland species.

Adverse Effects of Trees on Crops

Adverse Effect	Cause	Result
Light competition	Dense canopy	Reduced photosynthesis and yield
Water competition	Extensive root system	Crop water stress
Nutrient competition	Shared rooting zone	Reduced crop nutrition
Allelopathy	Toxic compounds from trees	Poor germination and growth
Pests/diseases	Alternate hosts	Increased pest incidence
Microclimate alteration	Shade and humidity	Disease risk and yield loss
Physical obstruction	Roots/branches	Difficult land management

Unit Vth

Chapter 1

Industrial Agroforestry

Industrial agroforestry refers to the purposeful integration of trees (often faster-growing, commercial timber or pulp species) with agricultural land use, specifically marketed into **industrial supply chains** (e.g., pulp & paper, plywood, furniture, biomass energy) rather than merely subsistence or farm-use trees. See for example a review of such a value-chain in India.

Why India Has Strong Potential

1. **Large unmet demand for wood & raw material for wood-based industries**

- According to one source: India's tree cover outside forests (TOF) has potential industrial wood production of ~915 lakh m³ per year, which meets about 85% of the country's industrial wood demand.
- Commercial agroforestry is already being practiced — circa 5 million ha producing ~100 million m³ timber/pulpwood.
- Many industrial wood-based sectors (pulp, plywood, matchwood, furniture) face raw-material shortages and therefore opportunities for farm-based supply.

2. **Large area available for agroforestry expansion**

- One remote sensing study: approx 75.6 million ha of cropland in India are highly suitable (category S1) for agroforestry, though current agroforestry extent is much less.
- Agroforestry systems can also be integrated into existing farms, boundaries, bunds, wastelands etc., thus making additional area accessible.

3. **Policy & institutional support increasing**

- The National Agroforestry Policy, 2014 (NAP) in India explicitly recognises agroforestry including industrial tree production.
- Several states and institutions (e.g., Tamil Nadu Agricultural University – TNAU) have developed models specifically for "industrial agroforestry" linking farmers and industry value chains.

4. **Economic & livelihood benefits**

- Industrial agroforestry offers alternate income streams for farmers through tree crops in addition to annual crops, enhancing resilience.
- Value chain innovations (contract tree farming, assured buy-back, quality seedling supply) are helping build attractiveness.

Major Value Chains & Business Models

- **Pulp & Paper / Industrial wood**: Short-rotation clones of eucalyptus, poplar, melia, etc. grown by farmers for purchase by pulp & paper mills.
- **Timber / Furniture / Plywood**: Trees such as teak, Acacia, melia grown on farms for supply to timber/ply industries.
- **Bioenergy / Biomass**: Plantation of fast-growing trees producing biomass (wood chips, briquettes) for energy or industrial fuel. For example, the review of industrial agroforestry mentions value-added use of plantation residues for briquettes.
- **Contract tree farming / Consortium models**: Farmers enter contracts with industry guaranteeing buy-back and price support; institutional mechanisms (Consortium for Industrial Agroforestry – CIAF) facilitate raw-material security.

Key Success Factors & Enablers

- Quality planting material (clonal/ improved stock), good silvicultural practices for high yield.
- Organized supply chains from farm to industry (procurement, transport, processing).
- Assurance of buy-back and stable markets (farmers require confidence).
- Suitable land-use planning: matching tree species with site, avoiding negative competition with crops.
- Legal/ regulatory clarity (tree rights, transit rules, felling permissions) for trees outside forests. Mentioned as part of NAP.
- Integration with agronomic crops so farmers have annual income while trees grow.
- Value-addition and diversification (not just raw logs but biomass products, briquettes, etc.) to enhance farmer income.

Challenges & Constraints

- Long gestation period: Trees take time to mature; farmers may need interim income.
- Land-holding fragmentation: Many Indian farms are small; convincing smallholders to devote land to tree crops can be challenging. See one note: small/ marginal farmers find it more challenging.
- Competition for land: Tree crops may compete with food crops; need to manage tree-crop interactions carefully.
- Supply chain issues: Lack of organized procurement, transport, processing infrastructure especially in many regions.
- Legal/regulatory hurdles: Transit, felling, ownership rights of trees outside forests could be cumbersome.
- Technical gaps: Lack of quality seedlings, improved clones, agronomic guidelines for many species.

- Market risk: Price volatility, demand fluctuations in wood/ biomass industries.
- Environmental risk: Poorly chosen species might alter soil/water dynamics, or have adverse effects (which must be managed).
- Smallholder risk: For small farmers, risk of tree crop failure (disease, pests) may be high without support.

Strategic Opportunities Going Forward

- Focus on **short-rotation tree species** (2-5 years) for quicker returns in industrial agroforestry.
- Develop **farmers + industry consortia** — contract tree farming models that guarantee market access, technical support, planting material and credit.
- Expand **value-addition** (biomass briquettes, pellets, engineered wood, laminated plywood) to raise farmer returns and diversify markets.
- Combine agroforestry with **carbon sequestration / ecosystem service payments** (trees produce value beyond timber — carbon credits, water conservation, biodiversity).
- Target **problem lands / degraded lands / bunds / field boundaries** which may not be in prime cropping but can host tree crops, thus not competing with food crops.
- Strengthen **extension systems** and seedling nurseries, ensure availability of quality clones stock, training farmers in silviculture.
- Encourage **land records & tree rights clarity** so that farmers feel secure investing in tree crops.
- Map high-suitability zones (like the S1 suitability category) and promote agroforestry there (e.g., Eastern Plains according to the suitability study).
- Encourage **integration of crops + trees + livestock** (multifunctional agroforestry) so that farmers have diversified income streams.
- Leverage **government schemes / subsidies / incentives** to lower the initial investment barrier for farmers adopting industrial agroforestry.

Scope & Potential in India (Summary)

- Industrial wood production: The potential is large — up to ~915 lakh m^3 per year of industrial wood from trees outside forests, with agroforestry playing a major role.
- Expansion area: With ~75.6 million hectares of cropland classified as highly suitable for agroforestry (S1) & considerable area still untapped, there is strong room for growth.
- Farmer adoption: Commercial agroforestry systems covering ~5 million ha currently exist; large room to scale further.

- Employment & livelihood: More tree crops on farms generate additional employment (nurseries, plantations, harvesting, processing) and income.
- Meeting industrial raw material shortage: As natural forest felling is restricted, farm-based plantation trees can supply industries sustainably.

Major Wood-Based Industries

Wood-based industries are industries that use **wood or its derivatives** as their **primary raw material** to produce goods for construction, paper, furniture, fuel, and other purposes.

In India, these industries play a vital role in:

- Generating employment,
- Supporting rural and industrial economies,
- Reducing pressure on natural forests through **farm-grown trees** from **agroforestry**.

Chapter 2

Major Wood-Based Industries in India

Wood-based industries are an important part of India's industrial and rural economy. They use timber and other forest resources to produce a wide range of goods — from paper and furniture to plywood and handicrafts.

Here's a summary of the major wood-based industries in India:

1. Plywood and Veneer Industry

- Overview: Uses timber logs to produce plywood, blockboards, veneers, and laminated sheets.
- Major centers:
  - Assam (Tinsukia, Jorhat)
  - Kerala
  - Andhra Pradesh
  - Haryana
  - Punjab
  - Uttar Pradesh
  - West Bengal
- Key companies: Century Plyboards, Greenply Industries, Kitply Industries.
- Raw materials: Timber species like teak, gurjan, eucalyptus, and poplar.

2. Paper and Pulp Industry

- Overview: Uses wood, bamboo, and agricultural residues to produce paper, cardboard, and pulp products.
- Major centers:
  - West Bengal (Titagarh, Naihati)
  - Tamil Nadu (Erode, Tiruchirapalli)
  - Uttar Pradesh (Saharanpur)
  - Maharashtra (Ballarpur)
  - Andhra Pradesh (Rajahmundry)
- Key companies: Ballarpur Industries Ltd (BILT), ITC Paperboards, JK Paper Ltd.
- Raw materials: Bamboo, eucalyptus, sal, and mixed hardwoods.

3. Furniture and Joinery Industry

- Overview: Produces furniture, doors, windows, cabinets, and other wood-based household and office products.
- Major centers:
  - Kerala (notably for rosewood and teak furniture)
  - Rajasthan (hand-carved furniture)
  - Jammu & Kashmir (walnut wood)
  - Punjab (handcrafted and modular furniture)
  - Delhi, Mumbai, Bangalore (modern furniture hubs)
- Key companies: Godrej Interio, Durian, Featherlite, Nilkamal (wood-plastic furniture).

4. Match and Small Wood Products Industry

- Overview: Produces matchsticks, wooden toys, packing boxes, and household items.
- Major centers:
  - Tamil Nadu (Sivakasi – matches)
  - Andhra Pradesh (Eluru)
  - Maharashtra
  - Kerala
- Raw materials: Softwoods and small timber species.

5. Saw Milling and Timber Industry

- Overview: The oldest and most widespread wood-based sector, providing raw materials to other industries.
- Major centers: Across India — especially in Assam, Kerala, Uttar Pradesh, and Maharashtra.
- Role: Supplies processed wood for construction, furniture, packaging, and transport sectors.

6. Handicrafts and Wood Carving Industry

- **Overview: Traditional and artisanal industry producing decorative and utility items.**
- **Major centers:**
  - Saharanpur (UP) – rosewood carving
  - Jaipur and Jodhpur (Rajasthan) – artistic furniture

- Channapatna (Karnataka) – wooden toys
- Kashmir – walnut wood carving
- Kerala – sandalwood and rosewood products

7. Fiberboard, Particleboard, and MDF Industry

- Overview: Uses wood waste and residues to make engineered wood products like MDF (medium-density fiberboard).
- Major centers: Tamil Nadu, Gujarat, Punjab, and Uttarakhand.
- Key companies: Action TESA, Greenlam Industries, Archidply.

Economic and Environmental Notes

- Wood-based industries contribute significantly to employment and exports (especially furniture and handicrafts).
- Many industries have shifted to plantation wood and agro-forestry sources to reduce pressure on natural forests.
- The government regulates the industry through Forest Conservation Act (1980) and promotes sustainable forest management.

Government Support and Policies

- **National Agroforestry Policy (2014)** — promotes industrial agroforestry and raw material linkages.
- **Sub-Mission on Agroforestry (SMAF)** under the National Mission for Sustainable Agriculture.
- **Ease of transit rules** for farm-grown timber species in many states (U.P., Haryana, Tamil Nadu, etc.).
- **Public–private partnerships (PPP)** between industries and farmers (e.g., TNPL, ITC).

Future Scope

- Growing demand for **timber, pulpwood, veneer, and biomass** due to construction, packaging, and renewable energy growth.
- Potential to expand **industrial agroforestry** on 20–30 million hectares of farmland.
- Development of **short-rotation, high-yield clones** for poplar, eucalyptus, melia, and casuarina.
- Integration of **carbon credits and green labeling** to make wood industries more sustainable.

Chapter 3

People's Participation and Rural Entrepreneurship in Agroforestry

Agroforestry is the *intentional integration of trees, crops, and/or livestock* on the same land for ecological and economic benefits.
For agroforestry to succeed at scale, it requires **active people's participation** — farmers, rural youth, women, cooperatives — and the development of **rural entrepreneurship** to make tree-based systems profitable and self-sustaining.

People's Participation in Agroforestry

Meaning

People's participation refers to the active involvement of local farmers, communities, and stakeholders in planning, implementing, managing, and monitoring agroforestry programs.

Importance

- Local ownership and sustainability: Participation creates a sense of responsibility and long-term commitment to maintaining trees and agroforestry systems.
- Use of traditional knowledge: Farmers' indigenous knowledge enhances the relevance and success of agroforestry models.
- Better decision-making: Inclusive approaches ensure that community needs and ecological realities guide interventions.
- Conflict resolution: Participation helps balance competing interests over land, water, and forest resources.

Modes of Participation

- Consultative participation: Farmers are consulted during planning and decision-making.
- Collaborative participation: Joint implementation of projects with shared responsibilities.
- Empowering participation: Communities initiate and manage agroforestry activities independently.

Rural Entrepreneurship in Agroforestry

Rural entrepreneurship in agroforestry involves creating business opportunities based on the production, processing, and marketing of tree-based and farm-based products — such as timber, fruits, medicinal plants, honey, bamboo, and biofuel.

Potential Areas

- Tree nurseries and seedling production
- Value-added processing: Timber, fruit jams, herbal products, bamboo crafts, etc.

- Agroforestry-based livestock systems
- Eco-tourism and carbon credit ventures
- Bioenergy and essential oil production

Benefits

- Income diversification: Reduces dependency on a single crop.
- Employment generation: Especially for women and youth.
- Resource conservation: Trees improve soil fertility, water retention, and biodiversity.
- Resilience: Provides economic and ecological security against climate shocks.

Link Between Participation and Entrepreneurship

- Participatory planning helps identify locally suitable tree and crop species, ensuring better market fit.
- Community cooperatives can collectively manage processing units, market products, and access credit.
- Skill development and training enable farmers to transition from subsistence to entrepreneurial agroforestry.
- Institutional support (NGOs, government, research institutions) enhances both participation and entrepreneurship through extension services and capacity building.

Strategies for Promotion

- Capacity building: Training programs on tree management, marketing, and financial literacy.
- Policy support: Incentives, subsidies, and clear land-use rights.
- Market linkages: Establishing cooperatives and value chains for agroforestry products.
- Public–private partnerships (PPP): Encouraging investment in processing and marketing infrastructure.
- Research and innovation: Developing high-yielding and climate-resilient tree-crop combinations.

Chapter 4

Role of Rural Entrepreneurship in Agroforestry

Rural entrepreneurship transforms agroforestry from a subsistence activity into a profitableenterprise.
It involves value addition, processing, and marketing of tree-based products.

Link Between People's Participation and Rural Entrepreneurship

Relationship	Explanation
Participation → Ownership	When people are part of planning, they take responsibility for managing tree resources.
Ownership → Entrepreneurship	As communities gain confidence, they develop enterprises around tree-based products.
Entrepreneurship → Sustainability	Profitable enterprises motivate people to protect and expand agroforestry systems.
Sustainability → Rural Development	Creates jobs, income, and ecological stability.

Examples of People's Participation and Rural Entrepreneurship in India

Example	Type	Key Outcomes
TNPL & TNAU Industrial Agroforestry Model (Tamil Nadu)	Farmer–industry partnership	Farmers grow pulpwood (*Eucalyptus*, *Melia dubia*) for TNPL under buy-back contracts — steady income and employment.
Poplar-based Agroforestry (Punjab, Haryana, UP)	Farmer entrepreneurship	Farmers produce poplar for plywood industries — community nurseries and sawmills create local jobs.
Women's SHGs in Jharkhand and Odisha	Community participation	Women collect, process, and market NTFPs like honey, tamarind, and sal leaves.
Bamboo-based Enterprises in Assam & Tripura	Rural craft entrepreneurship	Local artisans earn income from bamboo furniture and eco-products.

Example	Type	Key Outcomes
Agroforestry Nursery Networks in Madhya Pradesh	Youth-led ventures	Entrepreneurs produce and sell tree seedlings to nearby farmers.

Institutional and Policy Support

Institution / Policy	Contribution
National Agroforestry Policy (2014)	Promotes farmers' participation and industrial linkages.
Sub-Mission on Agroforestry (SMAF)	Financial support for tree planting by individuals and groups.
Farmer Producer Organizations (FPOs)	Facilitate collective marketing and value addition of agroforestry products.
National Rural Livelihood Mission (NRLM)	Promotes women's entrepreneurship in forestry-based livelihoods.
NABARD & KVKs	Provide training, credit, and technical assistance to rural entrepreneurs.
Consortium for Industrial Agroforestry (CIAF)	Links industries, farmers, and research institutions.

Benefits of People's Participation and Rural Entrepreneurship in Agroforestry

Benefit	Explanation
Economic empowerment	Additional income through tree products and small enterprises.
Employment generation	Local jobs in nurseries, harvesting, processing, and marketing.
Reduced migration	Rural employment opportunities prevent urban migration.
Resource sustainability	Community ownership leads to responsible land management.

Benefit	Explanation
Women empowerment	SHGs and cooperatives enhance women's decision-making and income.
Climate resilience	Trees improve soil fertility, water retention, and carbon sequestration.
Industrial linkage	Provides raw material to wood-based industries sustainably.

Challenges

Challenge	Description
Lack of awareness	Farmers may not know the benefits of agroforestry-based enterprises.
Financial constraints	Limited credit access for small entrepreneurs.
Market fluctuations	Prices for timber and NTFPs can be unstable.
Policy gaps	Delays in tree felling and transit permits in some states.
Skill and technology gap	Need for training in processing, marketing, and business management.

Strategies to Enhance People's Participation and Entrepreneurship

1. **Capacity building and training** through KVKs, NGOs, and universities.
2. **Formation of SHGs, cooperatives, and FPOs** for collective strength.
3. **Easy credit access** through NABARD, NRLM, and microfinance.
4. **Market linkages** — connect farmers directly to industries (contract farming).
5. **Promote value addition** — instead of selling raw wood, focus on furniture, pellets, or processed goods.
6. **Involve women and youth** through specialized training and grants.
7. **Awareness campaigns** on economic and environmental benefits of agroforestry.
8. **Integrate with government schemes** like SMAF, PMEGP, and NRLM for financial support.

Case Example – Tamil Nadu Industrial Agroforestry Model

- Developed by **TNAU** and **Tamil Nadu Paper Limited (TNPL)**.

- **Participatory approach:** Farmers involved in planning and species selection (*Melia dubia*, *Casuarina*, *Eucalyptus*).
- **Entrepreneurship link:** Farmers form **consortia** for collective selling and value addition.
- **Outcome:** Over **50,000 farmers** benefited; sustainable raw material supply to industries and increased rural income.

Unit VI^th

Chapter 1

Financial and Socio-Economic Analysis of Agroforestry Systems

Agroforestry systems—where trees are integrated with crops and/or livestock—offer not only ecological but also **economic and social advantages**. Evaluating their performance requires a combination of **financial analysis** (profitability and investment returns) and **socio-economic analysis** (impacts on people, livelihoods, and communities).

Purpose of Analysis

The goal is to assess:

- **Financial viability** → whether agroforestry provides better returns than conventional farming.
- **Socio-economic impact** → how it improves livelihoods, employment, and social well-being.

2. Financial Analysis

a. Key Indicators

Indicator	Formula / Description	Interpretation
Net Present Value (NPV)	$NPV = \sum_{t=0}^{n} \frac{B_t - C_t}{(1+r)^t}$	Value of future benefits minus costs, discounted to present.
Benefit–Cost Ratio (BCR)	$BCR = \frac{\text{Present Value of Benefits}}{\text{Present Value of Costs}}$	BCR > 1 indicates profitability.
Internal Rate of Return (IRR)	Discount rate at which NPV = 0	Measures rate of return on investment.
Payback Period	Years required to recover initial cost	Shorter payback = quicker recovery.

b. Cost Components

- **Establishment costs:** Land preparation, seedlings, planting, irrigation setup.
- **Maintenance costs:** Weeding, pruning, fertilizers, pest control.
- **Opportunity costs:** Temporary reduction in annual crop yields during early years.
- **Harvesting and transport costs:** For timber, fruits, or fodder.

c. Benefit Components

- Sale of timber, fuelwood, fruits, fodder, NTFPs (non-timber forest products).
- Improved soil fertility → higher yields of intercrops.
- Reduced input costs (shade, microclimate benefits).
- Long-term value appreciation (carbon credits, ecosystem services).

Socio-Economic Analysis

a. Employment and Income

- Agroforestry creates **more labor opportunities** in planting, maintenance, and harvesting.
- Provides **year-round income** from diversified outputs (wood, crops, fruits, fodder).
- Reduces vulnerability to crop failure by **income diversification**.

b. Livelihood Security

- Acts as a **safety net** during drought or market shocks.
- Improves **food, fuel, and fodder security** for smallholders.
- Enhances **asset base** (trees as long-term capital).

c. Social Benefits

- Strengthens **community cooperation** through group plantations and farmer producer organizations (FPOs).
- Supports **gender inclusion**—women often manage nursery, NTFP collection, and small-scale processing.
- Encourages **local entrepreneurship** (timber, fruit, honey, charcoal, handicrafts).

d. Environmental Co-Benefits

- Increases **soil fertility and water retention**.
- Reduces **erosion and deforestation pressure**.
- Contributes to **carbon sequestration** and climate change mitigation.

Comparative Economic Advantage

Aspect	**Agroforestry**	**Monocropping / Traditional Farming**
Income Stability	Diversified, less risk	Highly seasonal, weather dependent
Return Period	Medium to long term	Short term

Aspect	Agroforestry	Monocropping / Traditional Farming
Labor Use	More distributed across the year	Peak-season concentrated
Environmental Benefit	Positive (carbon, soil)	Often negative
Resilience	High	Low

Tools and Methods Used

- **Cost–Benefit Analysis (CBA)**
- **Partial Budgeting / Sensitivity Analysis** (e.g., timber price or yield variation)
- **Socio-economic surveys & participatory rural appraisal (PRA)**
- **Livelihood Impact Assessment Frameworks** (income, assets, social capital, food security).

Policy and Institutional Implications

- Need for **credit and insurance** products for tree-based systems.
- **Market linkages and value chains** for timber and NTFPs.
- **Incentives or subsidies** for long-term tree crops.
- Recognition of **carbon and ecosystem service benefits** in national accounting.

Chapter 2

Evaluation of Tangible and Intangible Benefits of Agroforestry

Agroforestry—the deliberate integration of trees with crops and/or livestock—generates a wide range of benefits that are both tangible (directly measurable and marketable) and intangible (indirect, often non-market ecosystem and social services). A comprehensive evaluation must account for economic, environmental, and social dimensions of these benefits.

Concept Overview

Type of Benefit	Description	Examples
Tangible Benefits	Directly measurable, have a market value, contribute to household income.	Timber, fuelwood, fruits, fodder, crops, animal products.
Intangible Benefits	Indirect or non-market benefits that improve the ecosystem or social well-being.	Soil conservation, biodiversity, carbon sequestration, aesthetics, social cohesion.

Tangible Benefits of Agroforestry

These are **quantifiable outputs** that contribute directly to income generation and livelihood improvement.

a. Tree-Based Products

- **Timber and poles:** Eucalyptus, poplar, teak, casuarina, etc. for construction and industry.
- **Fuelwood:** From pruning and thinning operations.
- **Fruits and nuts:** Mango, guava, moringa, tamarind, cashew, etc.
- **Non-timber forest products (NTFPs):** Gums, resins, honey, medicinal plants, essential oils.
- **Fodder and leaves:** Subabul, gliricidia, and other leguminous trees used for livestock feed.

b. Crop and Livestock Outputs

- Intercrops like wheat, pulses, vegetables, or spices grown between tree rows.
- Livestock productivity improvements through better shade, fodder, and microclimate regulation.

c. Financial Returns

- **Increased farm income** due to diversified products and reduced risk.
- **Regular cash flow:** Crops/NTFPs provide short-term income; trees provide long-term returns.
- **Higher land productivity:** Total output value per hectare usually exceeds that of monocropping.

Intangible Benefits of Agroforestry

These are **non-market ecosystem and social services** that indirectly contribute to sustainable development.

a. Environmental Benefits

1. **Soil Fertility and Conservation**
    - Tree litter and nitrogen-fixing species improve soil organic matter and nutrients.
    - Root systems reduce erosion and improve soil structure.
2. **Water Regulation**
    - Improved infiltration and groundwater recharge.
    - Reduced surface runoff and flooding.
3. **Carbon Sequestration**
    - Trees store atmospheric CO_2 in biomass and soil.
    - Can generate **carbon credits** in climate finance markets.
4. **Biodiversity Enhancement**
    - Provides habitats for birds, pollinators, and beneficial insects.
    - Acts as ecological corridors between forest patches.
5. **Microclimate Regulation**
    - Shade moderates temperature extremes and reduces evapotranspiration.

b. Socio-Economic and Cultural Benefits

1. **Livelihood Security**
    - Provides a safety net during crop failure or market shocks.
2. **Employment Generation**
    - Creates rural jobs in nursery, planting, pruning, harvesting, and processing.
3. **Community and Social Cohesion**

- Encourages cooperative management (e.g., community woodlots, farmer groups).

4. **Cultural and Aesthetic Values**
    - Trees enhance landscape beauty, heritage, and local identity.
5. **Health and Nutrition**
    - Fruits, nuts, and medicinal plants improve household nutrition and healthcare.

Methods of Evaluation

Type of Benefit	Evaluation Method	Indicators / Tools
Tangible	Cost–Benefit Analysis (CBA), Net Present Value (NPV), Benefit–Cost Ratio (BCR), Market price valuation.	Timber yield, crop output, income, IRR.
Intangible	Non-market valuation methods.	Contingent valuation, replacement cost, shadow pricing, participatory ranking, ecosystem service valuation.

Examples of Non-Market Valuation:

- **Carbon sequestration value:** Monetary value of CO_2 captured (₹/ton of carbon).
- **Soil conservation value:** Cost saved from reduced soil erosion.
- **Aesthetic or biodiversity value:** Willingness-to-pay (WTP) surveys.

Integrated Economic Valuation

A holistic evaluation combines both benefit types to estimate **Total Economic Value (TEV):**

$$\text{TEV} = \text{Direct Use Value} + \text{Indirect Use Value} + \text{Option Value} + \text{Non-Use Value}$$

Component	Examples in Agroforestry
Direct Use Value	Timber, crops, fodder, fruits, fuelwood.
Indirect Use Value	Soil fertility, water conservation, carbon storage.
Option Value	Potential for future uses (e.g., medicinal plants, ecotourism).
Non-Use Value	Cultural, heritage, and biodiversity values.

Unit VIIth

Chapter 1

Research & Development (R&D) in agroforestry in India

Research & Development (R&D) in agroforestry in India, covering the historical evolution, current national framework, key institutes and programmes, major research themes, innovations, constraints, and future directions.

Historical evolution

- Formal agroforestry research in India began in the early 1980s under the Indian Council of Agricultural Research (ICAR) via the All-India Coordinated Research Project on Agroforestry (AICRP-AF) around 1983.
- The National Research Centre for Agroforestry was established in 1988 at Jhansi, Uttar Pradesh.
- On December 1, 2014, this was upgraded to the ICAR-Central Agroforestry Research Institute (ICAR-CAFRI), reflecting growing importance of agroforestry research.

National framework & major programmes

- The AICRP-AF covers ~37 centres across agro-climatic zones of India, providing demonstration, research, and farm-linkages.
- Key research programmes under ICAR-CAFRI include:
  - **Agroforestry System Research (ASR)**: tree-crop combinations, integration with livestock etc.
  - **Tree Improvement Research (TIR)**: germplasm, clones, biotechnology of agroforestry species.
  - **Carbon & Climate Change Research (CCCR)**: agroforestry's role in climate mitigation/adaptation.
  - **Agroforestry Extension Research (AER)**: technology transfer, value chains, socio-economics.
- Collaboration with international institutes: e.g., CIFOR-ICRAF (Centre for International Forestry Research & World Agroforestry) is active in India, working with ICAR and state governments.
- Policy integration: Several states have developed or are developing state-specific agroforestry/tree-outside-forest policies (for example, Assam recently).

Key Institutes & Research Centres

Some prominent R&D institutions:

- ICAR-CAFRI, Jhansi, Uttar Pradesh — national centre for agroforestry research.

- Indian Council of Forestry Research and Education (ICFRE) — develops agroforestry models across different agro-climatic zones.
- Agroforestry Research Centre (AFRC), GBPUAT Pantnagar (in Uttarakhand) — regional research centre in Tarai/Bhabar region.
- State-level research institutes, university departments and ICAR institutes collaborating under AICRP-AF.

Major Research Themes & Innovations

a) Tree-Crop/Tree-Crop-Livestock Systems

Research has developed models such as poplar + wheat, eucalyptus + pulses, silvi-horticulture, silvi-pasture.

b) Tree Improvement & Quality Planting Material

Selection of clones (for example poplar clone PP-5 in India) and genotypes of species adapted to agroforestry.

c) Climate Change Adaptation & Mitigation

Agroforestry is being studied for carbon sequestration potential, micro-climate regulation, resilience of farming.

d) Ecosystem Services & Valuation

Research into soil health, water regulation, biodiversity benefits and linking to agroforestry systems.

e) Technology & Monitoring

Use of remote sensing, GIS, participatory approaches for monitoring tree cover in farmland and integrating into carbon finance.

f) Extension, Value Chains & Business Models

Moving from demonstration to farm adoption — value chain development, farmer producer organisations, nursery accreditation of QPM (quality planting material).

Achievements & Impact

- Development of region-specific agroforestry technologies (for Indo-Gangetic plains, hills, dry zones).
- Release of improved planting materials, clones and genotypes suitable for agroforestry.
- Expansion of research network across India enabling agro-climatic coverage.
- Greater international recognition of India's agroforestry research base.
- Emerging linkages to carbon markets, technology applications.

Future Directions & Emerging Trends

- Greater focus on **trees outside forests** (farm woodlots, agroforestry) and integrating agroforestry into mainstream agriculture policy.
- Linking agroforestry to **carbon-finance** and ecosystem service markets, thereby providing extra income streams to farmers.
- Use of digital technology (remote sensing, drones, GIS) for monitoring agroforestry cover, productivity, and for decision support.
- Strengthening **quality planting material** supply chains, nursery accreditation, certification of clones & germplasm.
- Value chain development for agroforestry produce (timber, NTFPs, fruits) and business models with farmers' organisations.
- Inter-disciplinary research linking trees, crops, livestock, climate resilience, livelihood aspects.
- Policy research aiming to harmonise agriculture and forestry laws, transit rules, incentivisation of agroforestry on private land.

Relevance for Practitioners & Researchers

- For farmers/extension: The research provides tested models of tree–crop systems suited to different zones.
- For policy-makers: Evidence from R&D supports frameworks for agroforestry adoption, subsidies, incentives.
- For researchers: Plenty of opportunities in site-specific adaptation, ecosystem service quantification, business models, digitisation.
- For industry/private sector: Scope for partnerships in value-chain development, planting material supply, carbon projects.

Chapter 2

Agroforestry policy 2014

The National Agroforestry Policy of India is a comprehensive policy framework designed to improve agricultural livelihoods by maximizing agricultural productivity for mitigating climate change. The Government introduced this policy in February 2014

Background and Need

Before 2014, agroforestry in India lacked a clear institutional and policy framework. Although practiced traditionally by millions of farmers, it faced barriers such as:

- Complex regulations on tree felling and transit,
- Lack of quality planting material,
- Weak market linkages,
- Poor coordination between agriculture and forestry sectors.

Recognizing these issues—and the potential of trees on farmlands for livelihood, sustainability, and climate resilience—the **Government of India (GoI)** approved the **National Agroforestry Policy (NAP)** in **February 2014**.

The policy aligns with:

- **National Forest Policy (1988)**,
- **National Environment Policy (2006)**, and
- **National Action Plan on Climate Change (NAPCC, 2008)**.

Vision

"To encourage and expand tree plantation in combination with crops and livestock to improve productivity, income, employment, and livelihood security of rural households, while maintaining ecological balance and national resilience."

Objectives

1. Encourage and expand tree planting in farmland and community land.
2. Protect and stabilize ecosystems through increased tree cover.
3. Meet the demand for timber, fuel, fodder, fruits, and NTFPs from non-forest sources.
4. Integrate agroforestry into agricultural policies and programs.
5. Promote climate change mitigation and adaptation.
6. Create employment and income opportunities, particularly in rural areas.

Key Policy Thrust Areas

Area	Policy Strategy / Intervention
Institutional Setup	Establishment of a **National Agroforestry Mission / Board (NAFB)** under the Ministry of Agriculture for coordination and implementation.
Regulatory Simplification	Simplify felling and transit rules for farm-grown trees; harmonize regulations across states.
Quality Planting Material (QPM)	Establish seed orchards, nurseries, and certification systems for quality germplasm.
Research, Extension & Capacity Building	Strengthen ICAR, ICFRE, and SAUs for R&D; promote training and technology dissemination.
Financial Support & Incentives	Integrate agroforestry in rural development schemes (e.g., MGNREGA, NRLM, RKVY).
Insurance & Credit	Develop risk management, insurance products, and credit access for long-rotation tree crops.
Marketing & Value Addition	Develop value chains, processing industries, and market access for agroforestry produce.
Information System	Establish a national database for agroforestry species, area, and production.
Environmental Services	Recognize agroforestry's contribution to carbon sequestration, biodiversity, and soil conservation.

Institutional Mechanism

- **National Agroforestry Mission (NAFM):**

The Department of Agriculture & Farmers Welfare (DA&FW) coordinates implementation with line ministries, state governments, research institutions, and farmers' organizations.

- **Nodal Agency:**

The ICAR-Central Agroforestry Research Institute (CAFRI), Jhansi, acts as the national technical support institution.

Integration with National Schemes

Agroforestry has been mainstreamed into major government programs:

- **National Mission for Sustainable Agriculture (NMSA)**

- **Pradhan Mantri Krishi Sinchayee Yojana (PMKSY)**
- **National Rural Employment Guarantee Act (MGNREGA)**
- **Rashtriya Krishi Vikas Yojana (RKVY)**
- **National Mission for a Green India (GIM)**
- **National Bamboo Mission (NBM)**

Expected Outcomes

- Increase **tree cover on farmlands** to achieve the national goal of **33% green cover**.
- Enhance **livelihoods and resilience** for small and marginal farmers.
- Reduce pressure on natural forests by meeting **timber and fuelwood demand** from farm sources.
- Contribute to **carbon sequestration**, **biodiversity conservation**, and **climate adaptation**.

Achievements Since 2014

- Formation of **Sub-Mission on Agroforestry (SMAF)** under NMSA in 2016–17.
- **Simplification of tree transit rules** in several states (Haryana, Punjab, Tamil Nadu, Karnataka, etc.).
- Promotion of **quality planting material** and **nursery accreditation** programs.
- Increased **research coordination** through ICAR-CAFRI and AICRP on Agroforestry.
- Inclusion of **agroforestry in carbon markets** and **Green Credit Program (2023)** initiatives.

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