

Agroforestry for enhanced land productivity and ecosystem services in rainfed areas

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Agroforestry is a land use system that integrates trees with agricultural production systems, enabling diversification to enhance productivity, profitability, diversity and ecosystem sustainability. It is the practice of using trees, shrubs and other plants to enhance land productivity and is an effective way to improve soil fertility, increase water infiltration and reduce erosion. Agroforestry plays an important role in the sustainability of rainfed areas, since high risk is involved with arable farming due to aberrant weather situations and other abiotic and biotic stresses resulting in uneconomic yields. Agroforestry is increasingly viewed as a system that provides ecosystem services, environmental benefits and economic commodities as part of multifunctional working landscapes.

Keywords: Agroforestry, Land productivity, Rainfed areas

AGROFORESTRY system is a land management system, which optimizes the land productivity by harnessing positive interactions between tree-crop-grass-livestock system in a unit area and time. The objective of agroforestry is to take advantage of the complimentary relationships between trees, crops and livestock in such a way that the productivity, stability and sustainability of the total system exceed individual component. In India, combined (irrigated and rainfed) total area under agroforestry is 7.45 million ha and can be extended to a potential of 21.56 million ha in rainfed area alone through adoption of improved and diversified agroforestry systems by 2025. There is a need for diversification in agriculture for improving productivity, profitability and sustainability through various ecosystem services. Agroforestry generates high income, minimizes risks in cropping enterprises, provides long-term investment opportunity and diversified land use. Continued adoption of agroforestry systems in rainfed areas will enhance farm productivity and the livelihoods of small and marginal farmers substantially.

Nurturing agroforestry in rainfed areas

- To utilize the available farm resources efficiently;
- To maximize the per unit production of food, fodder, fuel, livestock and other products. Besides,

it should be raised with a view to optimizing the productivity of biological and physical resources, viz. land, labour, livestock, soil moisture and solar radiation;

- To reduce pressure on protective and productive forests for meeting the local demands of fuelwood, fodder, building material, industrial timber etc, so that the existing forests can fully be spread for their protective and productive roles;
- To maintain the ecological balance;
- To check the soil erosion, conserve soil moisture and increase the soil fertility.

Ecosystem services from rainfed agroforestry practices

The integration of trees, agricultural crops, and animals into an agroforestry system has the potential to enhance soil fertility, reduce erosion, improve water quality, enhance biodiversity, increase aesthetics, and sequester carbon in rainfed areas. Generally, ecosystem services are grouped into three categories namely provisioning services, regulating services, and supporting services.

Provisioning services

Provisioning services are the products obtained from ecosystems, including genetic resources, food, energy, fibre and fresh water.

Food, fuel and fodder source: The small and marginal farmers in rainfed areas of India have long been practising agroforestry to meet their food, fodder and fuel requirements. Apart from ensuring food production, such systems also would enhance economic returns to the growers in the form of risk avoidance. The diverse products (fuelwood, fruits, vegetables, spices etc), which are available year-round in systems not only contribute to food security during the lean seasons but also ensure food diversity. Trees are also sources of mineral nutrients and vitamins for improving household nutritional security, especially for 'at-risk populations' (e.g. women and children) (Table 1).

Table 1. Nutritious fruit trees for integration in rainfed agroforestry

Species	Nutrient
<i>Anacardium occidentale</i>	Protein and fibre
<i>Ziziphus mauritiana</i>	Vitamin-C, Sodium and Potassium
<i>Embolica officinalis</i>	Vitamin-C, Sodium and Potassium
<i>Artocarpus heterophyllus</i>	Vitamin-B, C and Potassium
<i>Mangifera indica</i>	Vitamin-A and flavonoids
<i>Carica papaya</i>	Vitamin-C and flavonoids
<i>Acharas sapota</i>	Dietary fibre
<i>Aegle marmelos</i>	Vitamin-C, Potassium, Iron and flavonoids

Regulation services

Erosion control and soil conservation: Agroforestry practices provide vegetative cover and protection to the soil.

Pest and disease suppression in tree-crop interface: Pest suppression is a perennial challenge to farmers, and it is a very important ecosystem service. Agroforestry increases plant diversity and structural complexity, with implications on pest population dynamics.

Enhancing microclimate to offset climate variability: Trees in agroforestry systems can modify microclimatic conditions by providing shade and windbreak. The trees bring about a whole complex of environmental changes, affecting not just available light, but also air temperature, humidity, soil temperature, soil moisture content, wind movement, pest and disease complexes.

Carbon storage: The incorporation of trees or shrubs in agroforestry systems can increase the amount of carbon sequestered compared to a monoculture field of crop plants or pasture.

Supporting services

Biomass transfer: The trees that can withstand pruning and have high rates of organic matter production can be combined in agroforestry systems. Woody species grown in alleys/hedges/bunds are able to transform less available inorganic forms of phosphorus into more available organic forms, as well as supply significant quantities of N and K, when their leaves are incorporated into the soil as biomass transfers.

Nutrient source and recycling from the subsoil: Ecological interactions of leguminous trees with crops

have several beneficial effects on soil fertility through nitrogen fixation, greater organic matter production, and recycling of nutrients. Such nutrients become an input upon being transferred to the topsoil via tree litter decomposition.

Water quality regulation: Trees with deep rooting systems in agroforestry systems can also improve ground water quantity and quality by serving as a safety net whereby excess nutrients that have been leached below the rooting zone of agronomic crops are taken up by tree roots. These nutrients are then recycled back into the system through root turnover and litterfall, increasing the nutrient-use efficiency of the system.

Functional biodiversity: Agroforestry plays major roles in conserving biodiversity, i.e. provides habitat for species that can tolerate a certain level of disturbance; helps preserve germplasm of sensitive species; helps reduce the rates of conversion of natural habitat by providing a more productive, sustainable alternative to traditional agricultural systems; provides connectivity by creating corridors between habitat remnants which may support the integrity of these remnants and the conservation of area-sensitive floral and faunal species; and helps conserve biological diversity by providing other ecosystem services such as erosion control and water recharge, thereby preventing the degradation and loss of surrounding habitat.

Agroforestry systems for food and nutritional security

There are various promising rainfed agroforestry systems in India. Appropriate agroforestry system for rainfed regions depend on the physical, economic and social considerations.

Agri-silviculture: Agri-silviculture is intercropping of annual food crops and woody perennials in a land use system that enhances productivity and ensures sustainability of land. Involving nitrogen-fixing tree species, the system offers immense possibilities of supplementing the nitrogen requirements of crops grown in association, besides providing rich organic matter and improving the soil structure preventing land degradation. Recommended systems for different rainfed areas in India are given in Table 2.



Agri-silviculture system (Neem with cowpea as intercrop)

Table 2. Promising agri-silviculture systems for different rainfed areas in India

State	Agroclimatic zone/AICRPDA centre/Major rainfed crop based production system	Trees	Crops
Maharashtra	Scarcity zone/Solapur/Rabi sorghum	<i>Azadirachta indica</i> (Neem) <i>Leucaena leucocephala</i> (Subabul) <i>Dalbergia sissoo</i> (Shisham)	Horsegram, pearl millet, mothbean, stylo, pigeonpea, sunflower
Rajasthan	Southern zone/Arja/Maize	<i>Prosopis cineraria</i> (Khejri) <i>Azadirachta indica</i> (Neem) <i>Acacia tortilis</i> (Israeli babool)	Greengram, sorghum, blackgram, horsegram, mustard, sesame
Karnataka	North eastern dry zone/Raichur/Rabi sorghum	<i>Melia dubia</i> (Mahaneem)	Pigeonpea, foxtail millet, pearl millet
	Central, eastern, and southern dryzone in Karnataka/ Bengaluru/ Finger millet	<i>Grevillia robusta</i> (Silver oak) <i>Acacia auriculliformis</i> (Black wattle) <i>Casuarina equisetifolia</i> (Beef wood)	Soybean, pearl millet, groundnut, pigeonpea, horsegram
Gujarat	North Sourashtra zone in Gujarat/ Rajkot/ Groundnut	<i>Leucaena leucocephala</i> (Subabul)	Groundnut, greengram, blackgram, soybean, pearl millet
Tamil Nadu	Southern Zone/ Kovilpatti/cotton	<i>Ailanthus excelsa</i> (Tree of heaven) <i>Casuarina equisetifolia</i> (Beef wood)	Blackgram, pigeonpea, sorghum, sunflower
Jammu	Low altitude subtropical zone/ Rakhdhiansar/Maize	<i>Grewia optiva</i> (Bhimal) <i>Leucaena leucocephala</i> (Subabul) <i>Albizia lebbek</i> (safed siris)	Greengram, wheat, gobhi sarson
Punjab	Kandi Region/Ballowal Saunkhri/ Maize	<i>Eucalyptus tereticornis</i> (Safeda) <i>Grewia optiva</i> (Bhimal) <i>Melia azedarach</i> (Dek)	Pearl millet, clusterbean, greengram, sunhemp, groundnut

*Melia dubia* based agri-silviculture systems at Raichur, Karnataka

Alley/Hedge row cropping

Alley/Hedge row cropping: Alley cropping, also known as hedge row intercropping is an agroforestry practice in which food (arable) crops are grown in alleys formed by hedge rows of trees or shrubs. The hedge rows are cut back at crop planting and kept pruned during the cropping season to prevent shading and to reduce competition with food crops. The hedge rows are allowed to grow when there are no crops and are normally pruned during the season. The pruned material is either used as mulch, fodder or source of nitrogen for crops. Tree species of *Leucaena*, *Gliricidia*, *Sesbania* and *Cassia* can be planted in alley-cropping system. Short duration crops such as pearl millet and sorghum are compatible with *Leucaena leucocephala* and *Gliricidia sepium* than long duration species such as castor and pigeonpea.

Agri-horti system: Agri-horti system is adopted

in arable lands having fruit trees/shrubs along with annual crops in the interspaces of fruit trees. The system provides higher income per unit area. Under rainfed situations, mango, lime, lemon, guava, pomegranate, gooseberry, jamun, wood apple and tamarind can be grown in areas having more than 600 mm annual rainfall while custard apple, ber, phalsa, karonda and jamun can be grown in areas where the annual rainfall is less than 500 mm. Agroecology-specific agri-horti systems are being developed at AICRPDA centres (Table 3).

Agroforestry system for forage production

Silvi-pastoral system: In silvi-pastoral system, trees and shrubs are combined with livestock and pasture for forage and fuel-wood production on the same unit of land for optimizing land productivity, conserving plants, soils and nutrients and producing forage, fuel

Table 3. Agri-horti systems for different rainfed areas of India

State	Agroclimatic zone/ AICRPDA centre/Major rainfed crop based production system	Trees	Crops
Maharashtra	Western Vidharbha zone /Akola/ Cotton	<i>Annona muricata</i> (Hanuman Phal) <i>Ziziphus mauritiana</i> (Ber) <i>Limonia acidissima</i> (Wood apple)	Greengram, blackgram, pigeonpea, soybean
	Central Maharashtra Plateau/ Parbhani /Cotton	<i>Annona squamosa</i> (Custard apple) <i>Emblica officinalis</i> (Aonla) <i>Moringa oleifera</i> (Drumstick)	Greengram, blackgram, soybean
	Scarcity zone/Solapur/Rabi sorghum	<i>Psidium guajava</i> (Guava) <i>Punica granatum</i> (Pomegranate) <i>Ziziphus mauritiana</i> (Ber)	Pearlmillet, pigeonpea, sunflower, horsegram, mothbean
Rajasthan	Southern zone/Arja/Maize	<i>Emblica officinalis</i> (Aonla) <i>Ziziphus mauritiana</i> (Ber)	Maize, blackgram, sorghum, mustard, sesamum
Madhya Pradesh	Malwa plateau/Indore/Soybean	<i>Psidium guajava</i> (Guava) <i>Emblica officinalis</i> (Aonla)	Pigeonpea, Cowpea, chickpea
Karnataka	Central, eastern and Southern dry zones/ Bengaluru/Finger millet	<i>Annona squamosa</i> (Custard apple) <i>Emblica officinalis</i> (Aonla)	Maize, horsegram, fieldbean, cowpea, foxtail millet,
	Northern dry zone/Vijayapura/rabi sorghum	<i>Achras sapota</i> (Sapota) <i>Psidium guajava</i> (Guava) <i>Tamarindus indica</i> (Tamarind)	Greengram, sunflower, pearlmillet, safflower, pigeonpea
Andhra Pradesh	Scarce rainfall zone/ Ananthapuramu/Groundnut	<i>Syzigium cumini</i> (Jamun) <i>Emblica officinalis</i> (Aonla) <i>Ziziphus mauritiana</i> (Ber) <i>Sapindus mukorossi</i> (Soap nut)	Groundnut, Pigeonpea, greengram, <i>Stylosanthes hamata</i>
Gujarat	Northern Gujarat zone/S.K. Nagar/Groundnut	<i>Emblica officinalis</i> (Aonla) <i>Moringa oleifera</i> (Drumstick)	Pearlmillet, fodder sorghum, castor, cowpea, <i>Stylosanthes hamata</i>
	North Sourashtra zone/ Rajkot/ Ground nut	<i>Annona squamosa</i> (Custard apple)	Pearlmillet, sorghum, greengram, blackgram, pigeonpea
Jammu	Low altitude subtropical zone/ Rakhdhiansar/Maize	<i>Psidium guajava</i> , (Guava)	Gobhi sarson, maize, wheat
Tamil Nadu	Southern zone/Kovilpatti/Cotton	<i>Annona squamosa</i> (Custard apple) <i>Achras sapota</i> (Sapota)	Greengram, blackgram, pearlmillet, maize, sorghum
Chattisgarh	Bastar Plateau zone/ Jagdhapur/Rice	<i>Mangifera indica</i> (Mango)	Sorghum, sesamum, Maize, cowpea, blackgram, kodo millet
Punjab	Kandi Region/Ballawal Saunkhri/Maize	<i>Emblica officinalis</i> (Aonla) <i>Psidium guajava</i> (Guava)	Lentil, wheat, taramira, blackgram, pearlmillet



Custard apple based agrihorti system at Rajkot

wood, timber on a sustainable basis. Trees and grasses in this system often contribute substantial quantities of leaf fodder especially in arid and semi-arid regions as top feeds and contribute towards alleviation of fodder

scarcity during the lean periods of fodder availability (Table 4 and 5).

Agroforestry system for industrial biomass production

Wood lot: Growing wood lots has been on the rise due to shortage of fuelwood, timber and demand for poles or pulpwood in industry. In semi-arid regions of India, the block plantations of *Leucaena leucocephala*, *Casuarina equisetifolia* and species of *Eucalyptus* are very common due to multiple uses and demand for pulp wood and poles from paper mills, and other industries in the surrounding vicinity. The wood lots are being raised mostly on large farms to avoid the risks of crop failures and due to increase in labour costs. In Prakasam and Nellore districts of Andhra Pradesh, *Leucaena* block plantation is very popular. In Guntur and Krishna districts of Andhra Pradesh, *Eucalyptus* and *Leucaena* are grown in block plantations as a replacement to tobacco. In these areas, farmers have realised that *Leucaena* is



Rainfed silvi-pasture systems (*Leucaena* + *Cenchrus*; Mango with *Cenchrus* + *Stylo*)

Table 4. Suitable tree species for integration in pasture lands in rainfed areas

Tree	Part used	Utility
<i>Prosopis chilensis</i> (syn. <i>P. juliflora</i>)	Pods	Livestock top feed
<i>Acacia senegal</i>	Pods	Top feed and vegetable. Gum production.
<i>Acacia tortilis</i>	Leaves and pods	Livestock top feed
<i>Calligonum polygonoides</i>	Leaves and pods	Livestock top feed
<i>Prosopis cineraria</i>	Leaves and pods	Livestock top feed
<i>Ziziphus nummularia</i>	Leaves	Livestock top feed
<i>Acacia nilotica</i>	Leaves and pods	Livestock top feed
<i>Azadirachta indica</i> and <i>Albizia lebbbeck</i>	Leaves and pods	Livestock top feed

Table 5. Suitable grass species for rainfed agroforestry in India

Condition	Species
Extreme arid	<i>Lasiurus sindicus</i> <i>Panicum turgidum</i>
Sand dunes of arid and semi-arid/ sandy loam soils	<i>Lasiurus sindicus</i> <i>Cenchrus ciliaris</i> <i>Cenchrus setigerus</i>
Arid and semi-arid red gravelly soil/sloppy lands	<i>Chrysopogon fulvus</i>
Semi-arid clay soil with higher moisture status	<i>Iseilema laxum</i> <i>Panicum maximum</i>
Semi-arid loamy soil with higher moisture status	<i>Dichanthium annulatum</i>

superior to eucalyptus for its favourable effects on soil fertility.

Agroforestry system for energy and biofuel production

Rainfed areas provide an excellent opportunity for generating biofuels where arable cropping has not been successful or profitable in view of deterioration of resources. In marginal, undulating and problem soils, biofuel plantations. *Pongamia* is the ideal species. in such situations. *Pongamia* can be grown in areas with low rainfall of 500–2500 mm. Suitable intercrops are pigeonpea, short duration legumes in *kharif* and

chickpea in *rabi* are ideal crops during the initial 3–4 years.

Agroforestry system for medicinal and aromatic plants

Bush farming: Shrub based systems are important in rainfed agriculture for utilization of fallow, and marginal lands. Bushes provide food, fruits, fuelwood and botanicals. Shrubs are perennials with short canopy compared to the trees. They offer least competition with associated crop for moisture and light. The potential bushes for rainfed areas are henna, bixa, indigo, curry leaf, etc (Table 6).

Table 6. Potential bushes for rainfed areas of South India Peninsula

Common name	Scientific name	Economic part	Use
Annato	<i>Bixa orellana</i>	Seed	Food colorant
Henna	<i>Lawsonia inermis</i>	Leaf	Cosmetic
Indigo	<i>Indigofera tinctoria</i>	Leaf	Textile
Curry leaf	<i>Murraya koenigii</i>	Leaf	Spice
Senna	<i>Cassia angustifolia</i>	Leaf, pod	Laxative
Aloe vera	<i>Aloe vera</i>	Leaf	Cosmetic, medicinal

Agroforestry systems for protection

Boundary plantation: Growing trees on farm boundaries is a common practice in India. Boundary plantations help as shelter-belts and wind-breaks, particularly in fruit orchards. Trees which are grown as boundary plantations or live hedge include *Acacia nilotica*, *Dalbergia sissoo* and *Prosopis juliflora*; *Dalbergia sissoo* and *Wendlandia exserta* (in Bihar); *Acacia nilotica*, neem and *Eucalyptus* (in Gulbarga and Raichur districts, Karnataka).

Live fence: Live fencing around plantations of fruit plants and croplands is essential in areas where the entry of cattle and wild animals and trespassing is rampant. Apart from their protective role (serving as a barrier/wind breaks), live fences play an important role in environment management (shade, mulch, nutrient

trap, soil and water conservation and wildlife habitat), and also provide fuelwood, fodder, medicine and food. Farmers in rainfed areas prefer multiple species in several rows with dry thorny twigs of species like *Ziziphus mauritiana*, *Ziziphus nummularia*, *Acacia nilotica* etc. Further, aloe, cactus and sisal plantations along farm boundary are common in north India. In rainfed regions, several cactoides and *Agave sisalana* are quite commonly grown on farms bunds. The common species are: *Gliricidia sepium*, *Agave sisalana*, *Cactus* spp, *Opuntia* spp, *Prosopis juliflora*, *Balanites aegyptiaca*, *Pithecellobium dulce*, *Lawsonia inermis*, *Carissa carandas*, and *Parkinsonia aculeata*.

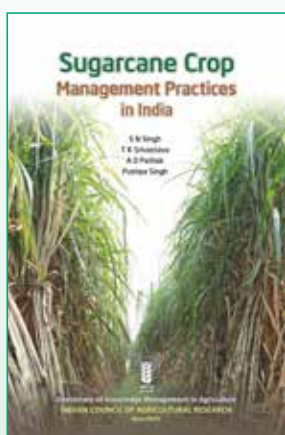
Wind breaks and shelterbelts: In rainfed agriculture, wind breaks/shelterbelts gained importance as they reduce wind velocity and change microclimate, thus improve crop yields. Tree species recommended for wind breaks are *Casuarina equisetifolia* and *Acacia auriculiformis*.

SUMMARY

Agroforestry is a system of trees, shrubs and perennial crops intercropped with each other to form an ecological unit. Integration of perennials into the arable systems provides multiple benefits besides additional income to the farmers. Diversification of arable cropping systems with agroforestry in rainfed areas is an adaptation strategy. Among the several tree-based systems, short-rotation intensive systems with mix of multi-utility tree species have the potential to rationalize the utilization of scanty farm resources in marginal and degraded lands which are not suitable for intensive cropping. Tree based agroforestry systems have large potential, provided well established markets and value additions will be a win-win situation.

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Sugarcane Crop Management Practices in India



A single publication collating sugar-cultivation practices in different states of India is still unavailable. The present textbook is penned by the eminent scientists of ICAR-Indian Institute of Sugarcane Research, an umbrella institute under ICAR, dedicated to research on fundamental and applied aspects of sugarcane. The Book attempts to address sugarcane cultivation practices in Indian states. The book comprehensively presents the recent cultivation practices of 17 states with detailed description on climatic conditions, soil, sugarcane-based cropping systems, preparatory tillage/field preparation, planting methods and geometry, fertilizer and manures, their time and method of application, irrigation/water management, intercultural operations, weed management, plant-protection strategies, harvesting, jaggery making, ratoon management, cultivation economics and constraints in sugarcane cultivation in a simple and lucid way. Each chapter caters to a

single state. Since the information pertaining to sugarcane management practices being followed in different states of the country is not available at one place, this textbook will be a knowledge resource for the vast network of sugarcane research, training, extension and development activities. This book will serve the purpose of different stakeholders and interested readers and go a long way in nurturing the interest of sugarcane farmers across the states for sustained sugarcane productivity.

TECHNICAL SPECIFICATIONS

No. of pages : i-viii + 466 • Price : ₹ 1200 • ISBN No. : 978-81-7164-242-7

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