

AGROFORESTRY: INTEGRATING TREES WITH CROP- AND LIVESTOCK-PRODUCTION SYSTEMS

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Summary

Agroforestry is a relatively new name for the old practice of growing trees and crops together. It was towards the latter part of the twentieth century that this age-old practice became recognized as a promising approach to land use as an interface between agriculture and forestry. In agroforestry, trees and/or shrubs (collectively called “trees”) are deliberately grown in association with agricultural crops or animals in some form of spatial mixture or temporal sequence in the same unit of land. The resulting systems will usually consist of crops and trees (agrisilviculture); trees and animals (silvopasture); or crops, trees, and animals (agrosilvopasture). Significant interactions, both ecological and economic, occur between the woody and nonwoody components. Thus, the essence of agroforestry can be expressed in four key “I” words: intentional, intensive, interactive, and integrated.

The widely recognized agroforestry practices in the tropics, in alphabetical order, are: alley cropping, homegardens, improved fallow, multipurpose trees on farm lands, shaded perennial associations, silvopasture, “taungya”, trees in soil conservation, and windbreaks. In the temperate regions, five major types have been identified: alley cropping, forest farming, riparian buffer strips, silvopasture, and windbreaks. While sustainable production of food and other products of subsistence farming is the main objective of agroforestry in the developing world, environmental amelioration is the main thrust in the industrialized world.

Agroforestry holds considerable promise as a land-use approach in both the developing and the developed world. Although substantial progress has been achieved in agroforestry research during the past two decades, the adoption rates of the new technologies have been low. Future efforts should therefore focus on not only generating technologies, but also improved methods of transferring them to the intended user and providing an enabling policy environment that facilitates agroforestry adoption. Furthermore, previously neglected topics, such as exploitation of indigenous fruit trees and the herbaceous components of the systems, should receive attention in future research. Agroforestry efforts of the future should also address larger-spatial-scale issues, such as carbon sequestration, water quality, and biodiversity conservation.

1. Introduction

Agroforestry is the purposeful growing of trees and crops in interacting combinations for a variety of objectives. Although such farming practices have been used throughout the world for a long time, agroforestry attained prominence as a land-use practice only since the late 1970s. Since then, substantial progress has been made in the science and practice of agroforestry. Today, acting as an interface between agriculture and forestry, agroforestry is considered to be a promising and sustainable approach to land use, especially in the developing countries of the tropics and subtropics. The objective of this chapter is to briefly present the essential features and forms of agroforestry and review the problems and prospects of its future development.

Agroforestry is a loosely defined term. Basically, it involves the deliberate growing of trees and shrubs, collectively called woody perennials or trees, on the same unit of land as agricultural crops or animals, either in some form of spatial mixture or temporal sequence. In the resulting systems, there is significant ecological and economical interaction between the woody and the nonwoody components. Thus, an agroforestry system normally involves two or more species of plants (or plants and animals), at least one of which is a woody perennial. The system will have two or more outputs and a production cycle of more than one year, and both its ecology and economics will be more complex than in a monocultural system of agriculture or forestry. The essence of agroforestry can be expressed in four key “I” words: intentional, intensive, interactive, and integrated. The term “intentional” implies that systems are intentionally designed and managed as whole units, and “intensive” means that the systems are intensively managed for productive and protective benefits. The biological and physical interactions among the system’s components (tree, crop, and animal) are implied in the term “interactive”, and “integrative” refers to the structural and functional combinations of the components as an integrated management unit. It is often emphasized that all agroforestry systems are characterized by three basic sets of attributes. These are: productivity (production of preferred commodities as well as productivity of the land’s resources); sustainability (conservation of the production potential of the resource base); and adoptability (acceptance of the practice by the farming community or other targeted clientele).

In addition to agroforestry, several other terms with “forestry” endings became prominent in the late 1970s and 1980s as a consequence of increasing global interest in tree planting activities. These include “community forestry”, “social forestry”, and “farm forestry”. Although these terms have also not been defined precisely, they emphasize people’s participation in tree planting activities, not necessarily in association with agricultural crop and/or animals as in agroforestry, but with the social objectives ranking equally in importance with production objectives. Social forestry refers to using trees and/or tree planting specifically to pursue social objectives, usually betterment of the poor, through delivery of the benefits of trees and/or tree planting to the local people. Community forestry, a form of social forestry, refers to tree planting activities undertaken by a community on communal lands or the so-called common lands; it is based on the local people’s direct participation in the process, either by growing trees themselves, or by processing the tree products locally. Farm forestry, a term used mainly in Asia, refers to tree planting on farms.

The major distinction between agroforestry and these other terms is that while agroforestry emphasizes the interactive association between woody perennials and agricultural crops and/or animals for multiple products and services, the other terms refer to tree planting, often as woodlots. In practice, however, all these labels directly or indirectly refer to growing and using trees to provide food, fuelwood, fodder, medicines, building materials, and cash income. Only blurred lines, if any at all, separate them, and they all encompass agroforestry concepts and technologies. Therefore, in common land-use parlance, these different terms are often used as synonyms, and sometimes out of context.

2. History of Development

With the advent of industrialization, rapid advances were made in agriculture and forestry as commercial enterprises, with emphasis on production of single commodities during the mid- to late 1900s. For example, although institutional foundations for the development of high-yield agriculture in the United States were laid in the latter half of the nineteenth and early twentieth centuries, significant gains in food production came after World War II. Between 1940 and 1980, the combined production of 17 major food crops in the United States rose 142% with only a 3% increase in cultivated land. During this period, the percentage of the country's economically active population that depended on agriculture declined from over 40% to a mere 2%, and yet they produced abundant food supplies not only for domestic demand, but a huge exportable surplus. Similarly, since 1950, the area under forest plantations has increased substantially in the tropics. Thus, commercial monocultural production of a few preferred crop and timber species formed the basis of modern agriculture and forestry in the industrialized world. Indeed, it paid rich dividends too.

When the newly independent nations of the developing world were faced with the problem of feeding their millions, naturally the successful model of modern agriculture of the industrialized world was thought to be the best solution. Several food-production technologies were developed according to this model and tried in the tropics, and some of them resulted in substantial increases in agricultural production. The most significant among these is the so-called Green Revolution of the 1970s. Obviously, the traditional mixed production systems of raising food crops, trees, and animals together, as well as exploiting a multiple range of products from natural woodlots, did not fit into the single-commodity paradigm, and such systems were discouraged.

Serious doubts began to be expressed, however, about the relevance of the single-commodity strategies and policies promoting them. In particular, there was concern that the basic needs of the poorest farmers, especially those in the rural areas, were neither being considered nor adequately addressed. Soon it became clear that many of the technologies that contributed to the Green Revolution, such as irrigation systems, fertilizers, and pesticides, were not affordable to the poor farmer. It was also recognized that most tropical soils, which are poorer and more easily degraded than temperate-zone soils, were unable to withstand the impact of high-input technology. It was around the same time that the disastrous consequences of increasing rates of deforestation in the world's tropical regions became a matter of serious concern. Soon it was recognized that a major cause of deforestation was the search for more land to provide food and fuelwood for the rapidly increasing populations. Faced with these problems, land-use experts and institutions intensified their search for appropriate strategies that would be socially acceptable, enhance the sustainability of the production base, and meet the need for production of multiple outputs. These collective efforts led to studies of age-old practices based on combinations involving trees, crops, and livestock on the same land unit. The inherent advantages of traditional land-use practices involving trees—sustained yield, environmental conservation, and multiple outputs—were recognized quickly. Agroforestry thus began to come of age in the late 1970s; the event was institutionalized with the establishment in 1977 of the International Council (Centre,

since 1991) for Research in Agroforestry (ICRAF), in Nairobi, Kenya. Since then, ICRAF has been the world leader in tropical agroforestry research.

In the temperate region, agroforestry has had a slower beginning than in the tropics. During the 1970s and 1980s, agroforestry as a concept had very little support in the industrialized countries. But the situation has changed gradually and agroforestry has gained better acceptance in the 1990s. For example, faced with the environmental consequences of agricultural and forestry practices that focused on the economic bottom line, the American public is now demanding greater environmental accountability of land-use practices and the application of more ecologically and socially friendly management approaches. Agroforestry fits well into that mould.

3. Agroforestry Systems and Practices

3.1 Nature and Classification

Considering that the term agroforestry encompasses land-use systems in which woody perennials are purposefully grown or retained in crop or animal production fields, a wide range of traditional systems that possess these attributes have been recognized from different parts of the world. A major characteristic of these systems is their location specificity. Each is a specific local example of the association or combination of the components, characterized by the plant species and their arrangement and management, and environmental and socioeconomic factors. In spite of the large variations among them, broad similarities have also been recognized among the systems. For example, all these systems are composed of three basic groups of components or constituents: the woody perennials (trees), herbaceous and other agricultural species (crops), and/or livestock. Depending on the system's composition of these components, agroforestry systems have been grouped broadly into three: agrisilvicultural (crops and trees), silvopastoral (trees and pasture/animals), or agrosilvopastoral (crops, trees, and pasture/animals). Another way of looking at the systems is based on the temporal arrangements of the components. Thus, the term simultaneous system is used when the trees and crops exist together on the same unit of land during the same period of time; similarly, when the trees and crops are separated in time (such as when one alternates with the other), it is a sequential system.

Because the systems are site-specific and are described by the local conditions, several hundred agroforestry systems have been identified. However, they all consist of a much smaller number of specific patterns of component arrangements in space and time, and these are called agroforestry practices. Thus, in spite of the large number of agroforestry systems, the number of distinct agroforestry practices, of which these systems are composed, is small. Same or similar such practices are found in various systems in different situations. The common agroforestry practices and their brief descriptions are given in Table 1. It may be noted that both the systems and the practices are known by similar names; but the systems are related to the specific locality or the region where they exist, or other descriptive characteristics that are specific to it. For example, growing coffee (*Coffea* sp.) under the shade of the timber tree *Cordia alliodora* in Costa Rica, and growing cacao (*Theobroma cacao*) under the shade of coconuts (*Cocos nucifera*) in Kerala, India, are two examples of the same (or similar) practice, but they

represent different systems. Even if the components are the same, the systems could be different depending on the differences in socioeconomic conditions in the two locations. In spite of these subtle differences, in common usage, the words “systems” and “practices” are used synonymously in agroforestry just as in other land-use forms. To make matters worse semantically, the same “base” word is retained even after a traditional system or practice may have been improved through scientific intervention. For example, there are traditional fallows, enriched fallows, and improved fallows; and traditional intercropping and hedgerow intercropping. Another anomaly in the use of these terms is the variants or “forms” of the same practice in different contexts. For example, the term alley cropping as used in the tropics is different from temperate-zone alley cropping although conceptually they are similar. The former is a form of hedgerow intercropping where the hedgerows of trees and shrubs are pruned periodically and the role of hedgerows is to support crop production in the alleys. The latter, on the other hand, is a form of tree-row intercropping in which the trees are a major source of economic return and are seldom pruned.

The lack of universally acceptable definitions of agroforestry terms need not be a matter of great concern; the concept is more important than the definition. This problem is not unique to agroforestry. The terms agriculture and forestry and several terms used in each are also not well defined; moreover, universally acceptable nomenclature is lacking even in long-standing scientific disciplines such as soil science.

Agroforestry practice	Brief description
Tropical agroforestry	
Alley cropping (hedgerow intercropping)	Fast-growing, preferably leguminous woody species grown in crop production fields; the woody species are periodically pruned at low height (<1.0 m) to reduce shading of crops; the prunings are applied as mulch into the alleys as a source of organic matter and nutrients, or used as animal fodder
Taungya	Growing agricultural crops during the early stages of establishment of forestry (timber) plantations
Homegardens	Intimate multistory combinations of a large number of various trees and crops in homesteads; livestock may or may not be present
Improved fallow	Fast-growing, preferably leguminous, woody species planted and left to grow during the fallow phase of shifting cultivation; the woody species cause site improvement and may yield economic products
Trees in soil conservation and reclamation	Trees on terraces, raisers, etc., with or without grass strips; use of trees for reclamation of saline, acidic, or otherwise degraded lands
Multipurpose trees (MPTs) on farms and rangelands	Fruit trees and other MPTs scattered haphazardly or according to some systematic planting arrangements in crop or animal production fields; trees provide fruits, fuelwood, fodder, timber, etc.
Pasture under plantations (a form of silvopasture)	Cattle grazing on pasture under widely spaced rows of plantation species

Shaded perennial-crop systems	Integrated multistory mixtures of tree crops such as coconut, cacao, coffee, and rubber with other tree crops, shade trees, and/or herbaceous crops
Protein banks (a form of silvopasture)	Production of protein-rich tree fodder on farms/rangelands for cut-and-carry fodder production
Shelterbelts and windbreaks	Use of trees to protect fields from wind damage, sea encroachment, floods, etc.
Temperate-zone agroforestry	
Alley cropping	Trees planted in single or grouped rows in herbaceous (agricultural or horticultural) crops in the wide alleys between the tree rows
Forest farming	Utilizing forested areas for producing specialty crops that are sold for medicinal, ornamental, or culinary uses
Riparian buffer strips	Strips of perennial vegetation (tree/shrub/grass) planted between croplands/pastures and streams, lakes, wetlands, ponds, etc.
Silvopasture	Combining trees with forage (pasture or hay) and livestock production
Windbreaks	Row trees around farms and fields, planted and managed as part of crop or livestock operation to protect crops, animals, and soil from wind hazards

Table 1: Major Agroforestry Practices in the Tropics and the Temperate Regions

3.2 Tropical and Temperate Systems

Within the tropics, the complexity of agroforestry systems is intense in the lowland humid and subhumid tropics, where the climatic conditions generally favor rapid growth of a large number of plant species. Homegardens, shaded perennial systems (or plantation-crop combinations) and multilayer tree gardens are common in such regions with high human populations, while less intensive systems, such as taungya and shifting cultivation, are common in areas with less population density. In the semiarid tropics also, the nature of agroforestry systems is influenced by population pressure: homegardens and multilayer tree gardens are found in the relatively wetter areas; windbreaks and shelterbelts, and multipurpose trees on croplands are found in the drier regions. In the highland tropics (with favorable rainfall regimes), sloping lands and rolling topography make soil erosion an issue of major concern; consequently, soil conservation is one of the main objectives of agroforestry in these regions. Shaded perennial systems, use of woody perennials in soil conservation, improved fallows, and silvopastoral systems are the major forms of agroforestry in these tropical highlands. Several other specific systems also exist in the tropics; for example, apiculture with trees, aquaculture involving trees and shrubs, and woodlots of multipurpose trees.

Alley cropping, forest farming, riparian buffer strips, silvopasture, and windbreaks are the five major agroforestry practices recognized in North America (Table 1). Other temperate-zone agroforestry systems include the ancient tree-based agriculture involving a large number of multipurpose trees such as chestnuts (*Castanea* spp.), oaks (*Quercus* spp.), carob (*Ceratonia siliqua*), olive (*Olea europa*), and figs (*Ficus* spp.) in the Mediterranean region. The “dehesa” system of land use, involving grazing under

oak trees with strong linkages to recurrent cereal cropping in rangelands, is also a very old system in this region. However, compared with tropical systems, the temperate-zone agroforestry systems are less complex and diverse.

The nature, complexity, and objectives of agroforestry systems vary considerably between the two regions. As a general observation, ecological and climatic factors determine the major type of agroforestry systems in a given area, but the system's complexity and management intensity increase in direct proportion to the population density and land productivity of the area. The climatic conditions in many parts of the tropics favor longer production cycles within a year or other relevant time span, and a large diversity of species. Therefore, agroforestry systems are more numerous and diverse in the developing countries of the tropics and subtropics than in the industrialized countries. Besides, socioeconomic factors such as human population pressure, availability of labor, land holding size, land tenure, and proximity to markets have a major influence on the nature and form of agroforestry systems. As a consequence, considerable variations are found among systems existing in similar agroclimatic conditions. In general, tropical agroforestry systems are characterized by small family-farms, subsistence food crops, and emphasis on the role of trees in improving soil quality of agricultural lands. On the other hand, the driving force of agroforestry in the industrialized nations is environmental protection. Emphasis on monocultural production systems of agriculture and forestry in these countries has led to reduced biodiversity and loss of forest resources and wildlife habitat, increased erosion, non-point source pollution of groundwater and rivers, greenhouse gas emission, and social changes such as deterioration of family farms. It has been widely recognized that opportunities must be created to alleviate these problems by bringing together sustainability and competitiveness to strengthen the rural farming sector and that agroforestry offers solutions to some of these problems. For example, the diversification of farm production through agroforestry allows access to several markets at annual and periodic intervals, stabilizing income and increasing global competitiveness. Also, diversity of the production system can promote lower inputs, conserve resources such as soil, aid pest control, and reduce pollution from farm chemicals. Furthermore, current trends such as the decline of the family farm and the "farm crisis" arising from the ending of commodity subsidies, make agroforestry an attractive land-use option for private landowners.

Issues	Relative importance	
	Tropics	Temperate
Tree integration and management: Deliberate planting of trees for specific products Tree management for specific products other than the end use	Common Common	Rare Low, rare
Food, fodder, and fuelwood supply	High	Low
Women's involvement	High	Low
Economic nature: Subsistence Commercial	High Low	Low High

Non-market benefits: Carbon sequestration and climate change Biodiversity conservation Ecotourism and recreation	High Low Low	High High High
Property rights: Private property rights Land holding size Open access arrangement Communal property arrangement	Low Small High High	High Large Low Low
Markets: Outputs Inputs	Thin Thin	Established Established
Institutional niche	Better	Poor
Research support	Better	Low
Macroeconomic policies: Exchange rates Interest rates Price policies	Controlled Controlled Controlled	Market based Market based Market based

Table 2: Ecological, socioeconomic, and institutional issues relating to agroforestry systems in the tropical and temperate regions

In summary, the primary objectives of tropical agroforestry systems are to exploit the role of trees on farms to provide products (such as fuelwood, poles, timber, animal fodder, food, fruits, and medicines), and ecosystem services (such as nutrient input and cycling, and soil erosion control). In the temperate zone, environmental amelioration and enhanced economic returns from tree-production systems are the key motivations. Functionally and operationally, there are major differences between the tropical and temperate systems, as summarized in Table 2.

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Biographical Sketch

P. K. Ramachandran Nair, Professor of Agroforestry at the University of Florida, USA, is a pioneering researcher and educator in agroforestry. He has B.Sc., M.Sc., and Ph.D. degrees in agronomy from different universities in India; has been a postdoctoral soil scientist at the Rothamsted, England, and a Senior Fellow of the Alexander von Humboldt Foundation at Göttingen University, Germany, from where he received a Dr.Sc.Agr. Before joining the University of Florida in 1987, Dr. Nair worked as multiple-cropping agronomist at the Plantation Crops Institute in Kasaragod in southern India for five years, and as a founder member and principal scientist at the International Centre for Research in Agroforestry (ICRAF), Nairobi, Kenya, for about 10 years. Dr. Nair has traveled extensively to more than 100 countries, undertaken field research, and conducted training courses in more than 25 countries in Africa, Asia, and Latin America. At the University of Florida, he has supervised 30 students (past and present) at Masters, Ph.D., and postdoctoral levels, and has conducted several training courses and hosted more than 20 professionals on exchange visits from different parts of the world. His publications include several books, book chapters, and journal articles. His college-level textbook, *An Introduction to Agroforestry* (1993), has been translated into Spanish and Japanese. As an acknowledged world leader in agroforestry, his advice and contributions as presentations and committee assignments are sought on a regular basis by

professional communities the world over. Dr. Nair has provided his services as a consultant to several international institutions, including specialized UN agencies and the World Bank. He has been the Editor-in-Chief of *Agroforestry Systems* since 1994, and has served as an editor of *Plant and Soil* for six years. He is a Fellow of the American Society of Agronomy (ASA), and recipient of ASA International Agronomy Award, 2000.