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AGROFORESTRY SYSTEMS IN MAJOR ECOLOGICAL ZONES OF THE TROPICS AND SUBTROPICS

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ABSTRACT

During the past five years, ICRAF, through its Agroforestry Systems Inventory (AFSI), has collected, evaluated, synthesized and disseminated information on existing agroforestry (AF) systems and practices from different parts of the tropics and subtropics. The systems have been classified according to various criteria such as their structure, function, socio-economic aspects, ecological spread, and so on. But the primary step in classifying them is on the basis of their structure; thus there are three basic types of AF systems:

agrisilvicultural (crops and trees),

silvopastoral (trees and pasture/animals), and

agrosilvopastoral (crops + pasture/animals + trees).

Under each of these major AF types, several systems have been recorded in the AFSI data base. But the distinct AF practices that constitute these systems are only a few; these are discussed in the paper.

An ecological analysis of the spread of various AF systems shows that the existence/adoption of an AF system in a given area is determined primarily by the ecological potential of the area, but socio-cultural and economic factors determine the complexity of the system and the degree of intensity of its management. From a purely ecological point, certain types of systems can be identified as characteristic of each major ecological region. Examples are:

humid/subhumid lowlands	:	- homegardens, - plantation crop combinations, - multilayer tree gardens, - alley cropping and other intercropping systems.
semi-arid/arid lands	:	- silvopastoral systems, - windbreaks/shelterbelts, - MPTs for fuel/fodder, - MPTs on farmlands.
highlands	:	- soil conservation hedges, - silvopastoral combinations, - plantation crop systems.

There are certain types of systems that are present in almost all ecological regions; however, the nature of components in each will vary from region to region depending on the ecological potential of the regions.

1. INTRODUCTION

ICRAF has just completed a global inventory of existing agroforestry systems and practices in different parts of the tropics and subtropics. Initiated in September 1982 with partial financial support from the United States Agency for International Development (USAID), the project had the general objective of increasing the understanding about the extent of existing agroforestry systems, and their various productive and protective roles in land use systems in the developing countries. The exercise consisted of collection, collation, synthesis, evaluation and storage of data, and publication of various results and outputs concerning the existing land use systems of relevance to agroforestry, and it involved a large number of institutions and individuals interested in and knowledgeable about agroforestry from all over the world. This project has gathered information on a few hundreds of agroforestry systems, and this information is available in the form of:

(i) Agroforestry System Descriptions, being serialized in Agroforestry Systems (published by Martinus Nijhoff, The Hague). (A list of the System Descriptions is attached as Annexure I);

(ii) a computerized Agroforestry Systems Register at ICRAF containing data entries on about 150 systems and/or practices;

(iii) various miscellaneous publications from the project (Annexure II); and

(iv) unpublished records at ICRAF.

Additional details of any aspect of the project can be obtained from the author.

This paper is based on this vast information base on agroforestry systems.

2. TYPES OF AGROFORESTRY SYSTEMS

In order to evaluate the existing agroforestry systems and develop action plans for their improvement, it is necessary to classify these systems and thus provide a practical and realistic framework. Depending on the main purpose to be served by a classification scheme, various criteria can be employed to classify the systems. The most common among these are the system's structure, functions, socio-economic scale and level of management and ecological (environmental) spread:

- structural basis -- refers to the composition of the components, including spatial admixture of the woody component, vertical stratification of the component mix and temporal arrangement of the different components;

- functional basis -- refers to the major function or role of the system, mainly of the woody components (these can be productive, e.g. production of food, fodder, fuelwood and so on), or protective (e.g. windbreak, shelterbelt, soil conservation and so on);

- socio-economic basis -- refers to the level of inputs of management (low-input) or intensity or scale of management and commercial goals (subsistence, commercial, intermediate);

- ecological basis -- refers to the environmental condition and ecological suitability of the systems, on the assumption that certain types of systems are more common in/appropriate for certain ecological conditions.

These approaches for classification of AF systems are summarised in Table 1.

TABLE 1 ABOUT HERE

These broad bases of classification of AF systems are by no means independent or mutually exclusive. Indeed it is obvious that they have to be interrelated because the structural and functional bases relate to the woody components in the systems whereas the socio-economic and ecological stratifications refer to the organization of systems according to certain defined conditions (socio-economic or ecological). And in any defined socio-economic or ecological situation, the systems should still have specific structure (composition and arrangement or components) and function/role.

Nevertheless, in AF land-use systems, there are only three basic sets of components that are managed by man, viz, woody perennials, herbaceous plants and animals. Therefore, a simple and logical first step in classifying AF systems is to use this component composition as the basis, which will give three basic types of AF systems (Nair, 1985):

- agrisilvicultural (crops -- including tree/shrub crops -- and trees),
- silvopastoral (pasture/animals + trees), and
- agrosilvopastoral (crops + pasture/animals + trees).

Other specialized AF systems such as apiculture with trees, aquaculture in mangrove areas, multipurpose tree lots, and so on, can also be specified.

A generalized picture of the component composition of these basic types of AF systems is given in Fig. 1.

FIGURE 1 ABOUT HERE

This categorization of AF systems into three major types is so fundamental that any one of these can conveniently be used as a prefix to other terms emanating from other efforts to classify/group AF systems in order to explicitly express the basic composition of constituents of any such system. For example, there can be an agrisilvicultural system for food production, a commercial silvopastoral system for fodder and food production in lowland sub-humid (or dry) tropics, an agrosilvopastoral system for food production and soil conservation in highland humid tropics, and so on. Therefore it seems logical, compatible and pragmatic to accept the nature of components as the basic criterion in the classification of agroforestry systems.

3. AGROFORESTRY PRACTICES AND TECHNOLOGIES

A further evaluation of the organization of these various AF systems shows that an AF system consists of extensively practised AF practice(s), thus forming a significant form of land-use in a locality or area, and described according to the system's biological composition and arrangement, level of technical management, or socio-economic features. An AF practice, on the other hand, denotes a specific agroforestry combination in a land-management unit, and consists usually of arrangements of AF components in space and/or time. Several such practices are involved in the constitution and maintenance of an AF system.

Although several AF systems have been recorded from around the world, the distinctive AF practices that constitute these systems in various ecoregions and locations are only few. These most commonly found AF practices and their essential characteristics are listed in Table 2.

TABLE 2 ABOUT HERE

The scale of management and extent of adoption of these different practices in any particular system will vary considerably depending upon a number of factors. Any of these practices can become an AF

system when it is developed or spread to such an extent in a specific local area so as to form a distinct land utilization type in that area. One essential point to note here is that an AF practice can be found to exist even in a non-agroforestry land use systems. An example is the practice of growing rows of Sesbania grandiflora on the bunds of rice paddies in Java, Indonesia. This woody species is harvested for its leaves as green manure, its flowers are eaten as a vegetable, it provides firewood and it adds to the fertility of the soil underneath through biological fixation of atmospheric nitrogen. Thus the woody species interacts ecologically and economically with the crop (rice) production system; in other words, it is an AF practice in a crop production system.

Another term that is commonly used in all land use systems including agroforestry is "technology", and it is usually used in combination with a particular production system or land-use system as the prefix; thus, agricultural technology, wood production technology, agroforestry technology, and so on. The word or suffix "technology" in this sense indicates an improvement or innovation, usually through scientific intervention, that can be applied with advantage in the management of the system or practice concerned. The inputs that are used for developing such technologies can sometimes be the most significant aspects, and these are called input technologies; e.g., improved varieties of plants, agrochemicals, and so on.

Most, if not all, of the practices mentioned in Table 2 need to be improved scientifically and developed into modern agroforestry technologies. The success potential of an AF practice (and therefore an AF system) depends on the extent to which such technologies have been perfected, and made use of in the management of the practice (or the system).

4. ECOLOGICAL SPREAD OF MAJOR AGROFORESTRY SYSTEMS

4.1. Ecological Zones of Agroforestry Significance in the Tropics and Subtropics

The major physical parameters that determine the ecology of a location in the tropics are rainfall (quantity and distribution) and temperature regimes. Altitude also is important because of its influence not only on temperature, but also on land relief characteristics. The FAO Agro-Ecological zones inventory divides tropics into "warm", "moderately cool", "cool" and "cold" climates depending on the climatic (mainly temperature) regime during the "growing period". These growing periods refer to a few selected agricultural crops (that are seasonal) and therefore do not necessarily reflect the growing periods of perennial species (although it can be argued that the agricultural growing period represents the peak growing seasons of the perennial species also in most cases).

From the agroforestry point of view, the major ecological regions recognized in the FAO State of Food and Agriculture Reports (SOFA) are more relevant: these are temperate, mediterranean, arid and semi-arid, sub-humid tropical (lowland), humid tropical (lowland) and highland. These classes, excepting the first (and possibly the second), represent the tropical and subtropical lands of agroforestry significance where agroforestry systems exist or have a potential. These major ecological regions of the tropics and subtropics are presented in Fig. 2, and the main characteristics

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FIGURE 2 ABOUT HERE

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of these major agroecological regions (mainly adapted from Young, 1986), are summarized in Table 3.

TABLE 3 ABOUT HERE

4.2. Agroforestry Systems in Lowland Humid and Sub-humid Tropics

Characterized by hot, humid climates for all or most of the year, and an evergreen or semi-evergreen vegetation, the lowland humid and sub-humid tropics (but referred to as humid-tropics) is by far the most important ecological region in terms of the total human population it supports, extent of area and diversity of agroforestry and other land-use systems. Because of the climatic conditions that favour rapid growth of a large number of plant species, various types of agroforestry plant associations can be found in areas with high human population. Various forms of homegardens, plantation crop combinations, and multilayer tree gardens are common in such regions. In areas with low population density, such as the low selvas of Latin America, trees on rangelands and pastures, other silvopastoral systems, improved fallow in shifting cultivation areas, multipurpose tree woodlots, etc. are the major AF systems. Examples of AF systems in humid tropical lowlands about which ICRAF has data entries in the computerised AFSI database are included in Table 4.

TABLE 4 ABOUT HERE

The lowland humid tropics also represents areas under natural rainforests. In such areas, cutting of rainforest at rates much faster than natural or managed regeneration is a common problem. This causes shortening of fallow periods in shifting cultivation cycles and resultant loss of soil productivity and accelerated soil erosion. The potential of appropriate agroforestry systems to combat these problems needs to be exploited in future land-use strategies in this zone.

4.3. Agroforestry Systems in Semi-arid and Arid Tropics

Extending over the savanna and Sudano-Sahelian zone of Africa, the cerrado of South America and large areas of the Indian subcontinent, the semi-arid and arid tropics are characterised by one or two wet

seasons (Koppen Aw or Aw′ respectively) and at least one long dry season. Drought is a hazard in the drier parts of the zone.

The main agroforestry systems in this zone also depend on the human population pressure; homegardens and multilayer tree gardens are common in the wetter areas with high population pressure. But generally speaking, the most predominant AF systems in this zone are:

- various forms of silvopastoral systems,
- windbreaks and shelterbelts, and
- multipurpose trees on crop lands, notably Acacia albida-based systems in Africa and Prosopis-based agrisilvicultural systems in the Indian sub-continent.

(Table 4).

Fuelwood shortage is a major problem in most parts of the semi-arid and arid tropics. Agroforestry potentials in fuelwood production are well documented (e.g., Nair, forthcoming). Similarly, desertification and fodder shortage, that are the other major ecological problems in this zone, could be tackled to some extent through the agroforestry approach.

4.4. Agroforestry Systems in Tropical Highlands

Approximately 20% of the tropical lands are at elevations from 900 to 1800 m, in about half of the Andean highlands of Central and South America, parts of Venezuela and Brazil, the mountain regions of the Caribbean, many parts of East and Central Africa, the Cameroons, the Deccan Plateau of India and some parts of the southeast Asia mainland. The altitude exceeds 1800 m in about 3% of the tropical area in the Andes, the Ethiopian and Kenyan Highlands, northern Burma and parts of PNG. In the subtropical regions, the most important highlands are in the Himalayan region.

These highland tropics with significant agroforestry potential are humid or sub-humid, such areas with dry climates being of very low potential.

Land-use problems in the highlands are similar to those in humid or dry lowlands depending on the climate, with the addition that sloping lands and steep terrains make soil erosion an issue of major concern. Moreover, the overall annual temperatures are low in the highlands (for every 100 m increase in elevation in the tropics, there is a decline of 0.6°C in the mean annual temperature), which affect the growth of certain lowland tropical species.

The main AF systems in tropical highlands are:

- production systems involving plantation crops such as coffee and tea in commercial as well as small-holder systems,
- use of woody perennials in soil conservation and soil fertility maintenance,
- improved fallows, and
- silvopastoral combinations

(Table 4).

4.5. Agro-ecological Analysis of Existing Agroforestry Systems

The existence of an AF system/practice in a particular area is determined not only by the environmental and agro-ecological factors, but also by socio-economic considerations. In different areas with identical agro-climatic conditions, factors such as human population pressure, availability of labour and other production resources, proximity and accessibility to market sources, etc. are the main determinants to the types and forms of agroforestry systems. Even in the case of systems that are widespread in most ecological and geographical regions such as shifting cultivation and

taungya, these systems have very many variants that are specific to certain defined situations. As a general rule, it can be said that while the ecological factors determine the major type of an AF system in a given locality, the complexity of the system and the degree of intensity of its management increase in direct proportion to the population intensity and land productivity of the area. A typical example is the spread of the multispecies, multistoried homegarden systems. Though found mostly in humid lowlands, the homegardens are common in pockets of high population density in other ecological regions also. Analysing the structural and functional aspects 10 selected homegarden systems from different ecological regions, Fernandes and Nair (1986) found that although the average size of the homegarden units is less than 0.5 ha, the units are composed of a large number of woody and herbaceous species, carefully structured to form 3-5 vertical canopy strata, and each component having a specific place as well as function in the multispecies complex.

There are some functional aspects of specific AF practices that are emphasized or necessitated in specific agroecological situations. For example, the functional emphasis of AF systems in sloping lands is erosion control and soil conservation; in wind-prone areas, woody species are successfully used in agroforestry practices of shelterbelts and windbreaks; the emphasis is on fuelwood production in areas with fuelwood shortage; there are also specific agroforestry approaches for the reclamation of degraded lands and other waste lands (such as highly eroded lands, areas with high levels of salinity/alkalinity, etc.)

The ecological potential of an area is undoubtedly the prime factor that decides the adoption and spread of specific AF systems in different parts. The preponderance of homegardens and other multispecies mixes in fertile lowlands and high potential areas at one end of the ecological scale and extensive silvopastoralism at the other end, with various systems in between gives a spectrum of

agroecological adaptability and spread of various AF systems. This is schematically presented in Fig. 3.

FIGURE 3 ABOUT HERE

Fig. 3 represents a very rough approximation to show the general pattern of existence of the major agroforestry systems in different ecological regions. It does not include all AF systems, nor does it fully portray the relative spread (in terms of areas involved) or the level of management of the various systems. A further step in this direction is to indicate the major known areas of concentration of important agroforestry systems in the tropics and subtropics, i.e., something like a "map of the agroforestry situation in the tropics and subtropics". This is attempted in Fig. 4.

FIGURE 4 ABOUT HERE

The 'map' (Fig. 4) represents areas with relative abundance of specified agroforestry systems, but does not identify localized systems as well as systems whose presence is relatively less significant in an area. For example, as mentioned earlier, "multipurpose trees on farmlands" can be found in almost all ecological and geographical regions. But there are only a few such systems that make them distinctly unique agroforestry systems. Examples include the arid zone systems involving Acacia albida (Miehe, 1986; Poschen, 1986) and Prosopis (Shankarnarayan and Harsh, 1987)). Thus, only some such "multipurpose trees on farmlands" systems have been studied and/or described in some detail, and thus gone into ICRAF's AFSI data records. The mention of the existence of any of these systems on Fig. 4 therefore is mainly an indication that AFSI records are available on it. Indeed, innumerable location-specific agroforestry systems and practices do exist all over the tropics and subtropics and many of them are

important in various ways. But, most of them may not often be significant enough in terms of their individual importance in the overall economy and land-use pattern of the area where they exist, and thus may not merit a special mention on such a much condensed and abstract global map.

This 'map' (Fig. 4) is an improvement over Fig. 3 in that geographical spread of the systems is shown in relation to the ecological conditions in different places. One significant feature that emerges from this is that irrespective of the socio-cultural differences in different geographical regions, the major types of agroforestry systems are structurally similar in areas with identical ecological characteristics. The level of intensity at which these different systems are managed will, obviously, be different in various situations.

ACKNOWLEDGEMENTS

This paper is based on data gathered by ICRAF's Agroforestry Systems Inventory (AFSI). Useful discussions were held with T. Darnhofer and A Young of ICRAF on Section 4.1.

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A. General references

1. Annexure I: Agroforestry System Descriptions

2. Annexure II: Miscellaneous publications from AFSI

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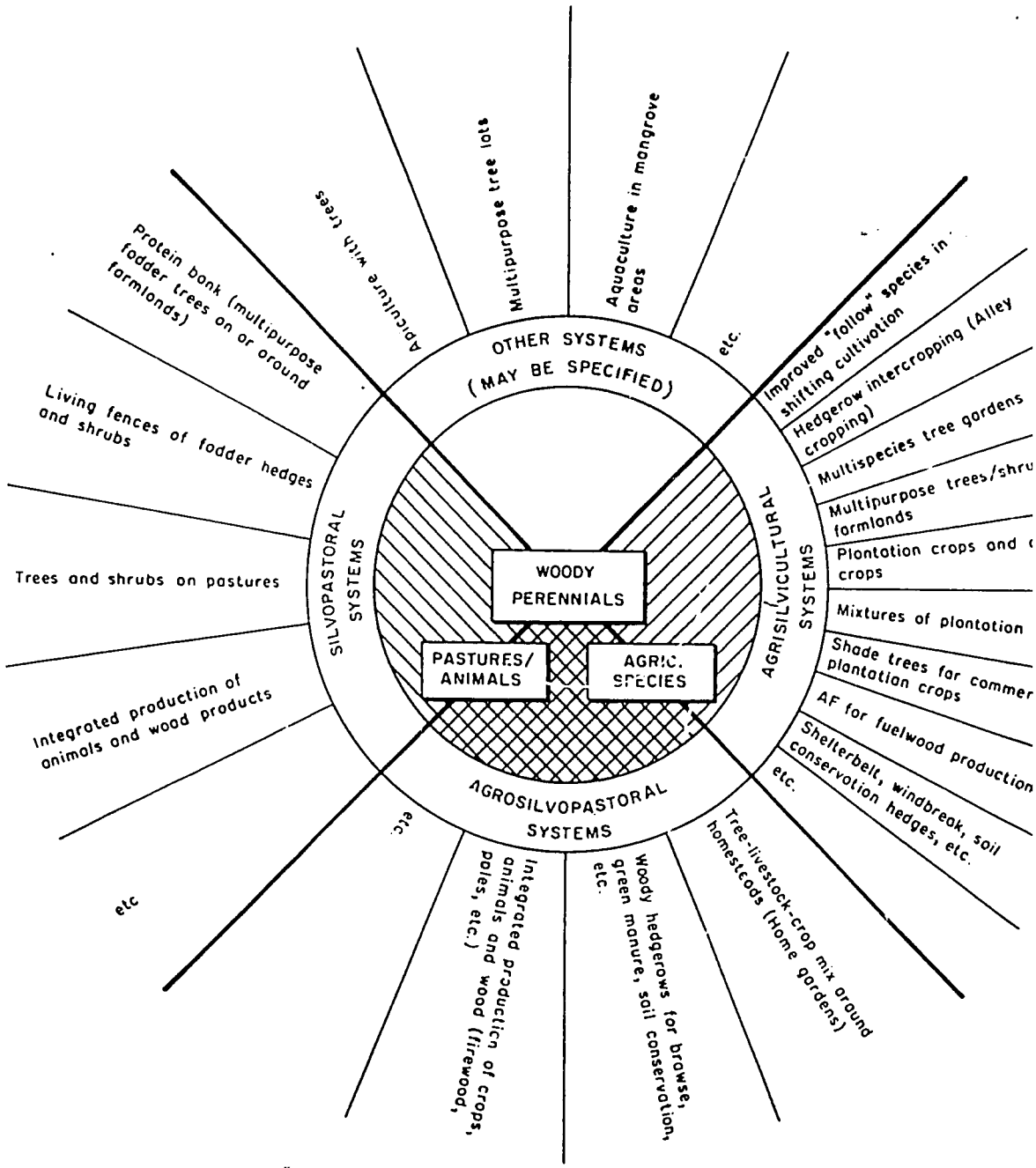


Fig. 1. Categorization of Agroforestry Systems based on the Nature of Components (with examples of common sub-systems/practices under each system).

Source: Nair, 1985

16'

Fig. 2 Major ecological regions of the tropics and subtropics

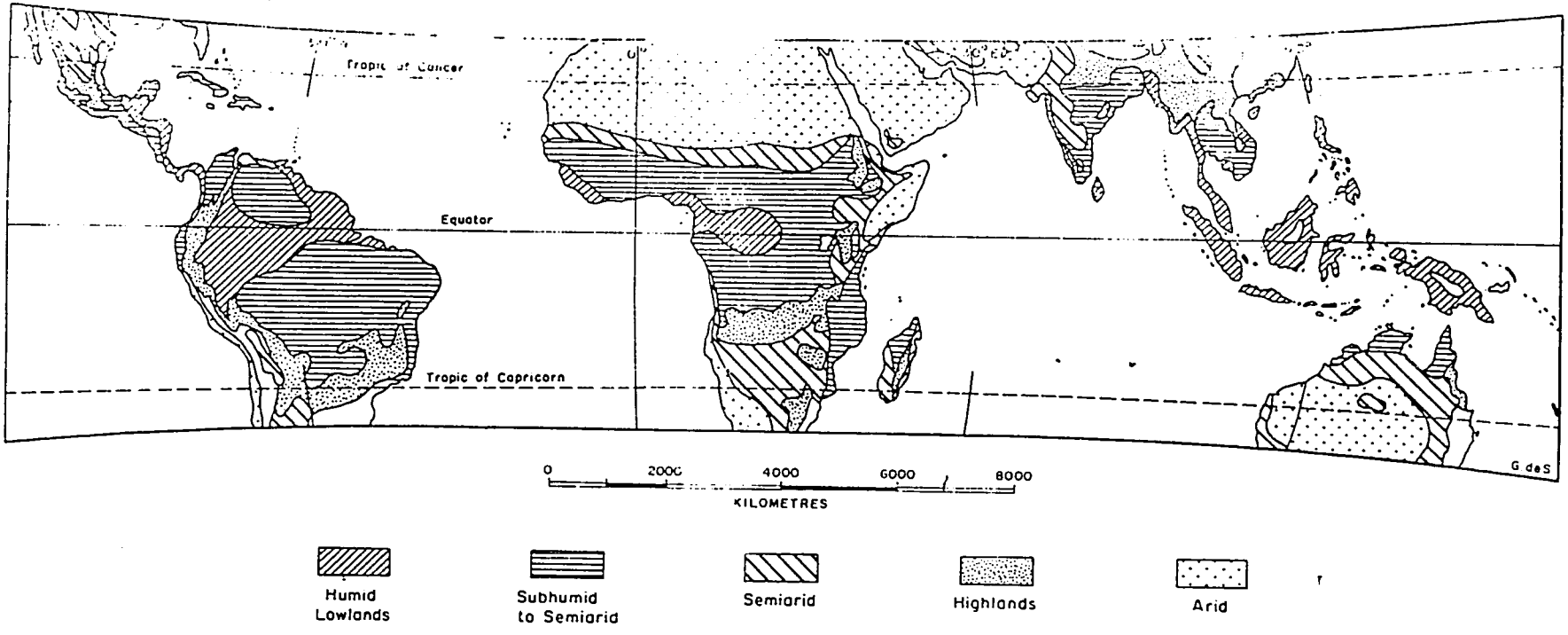
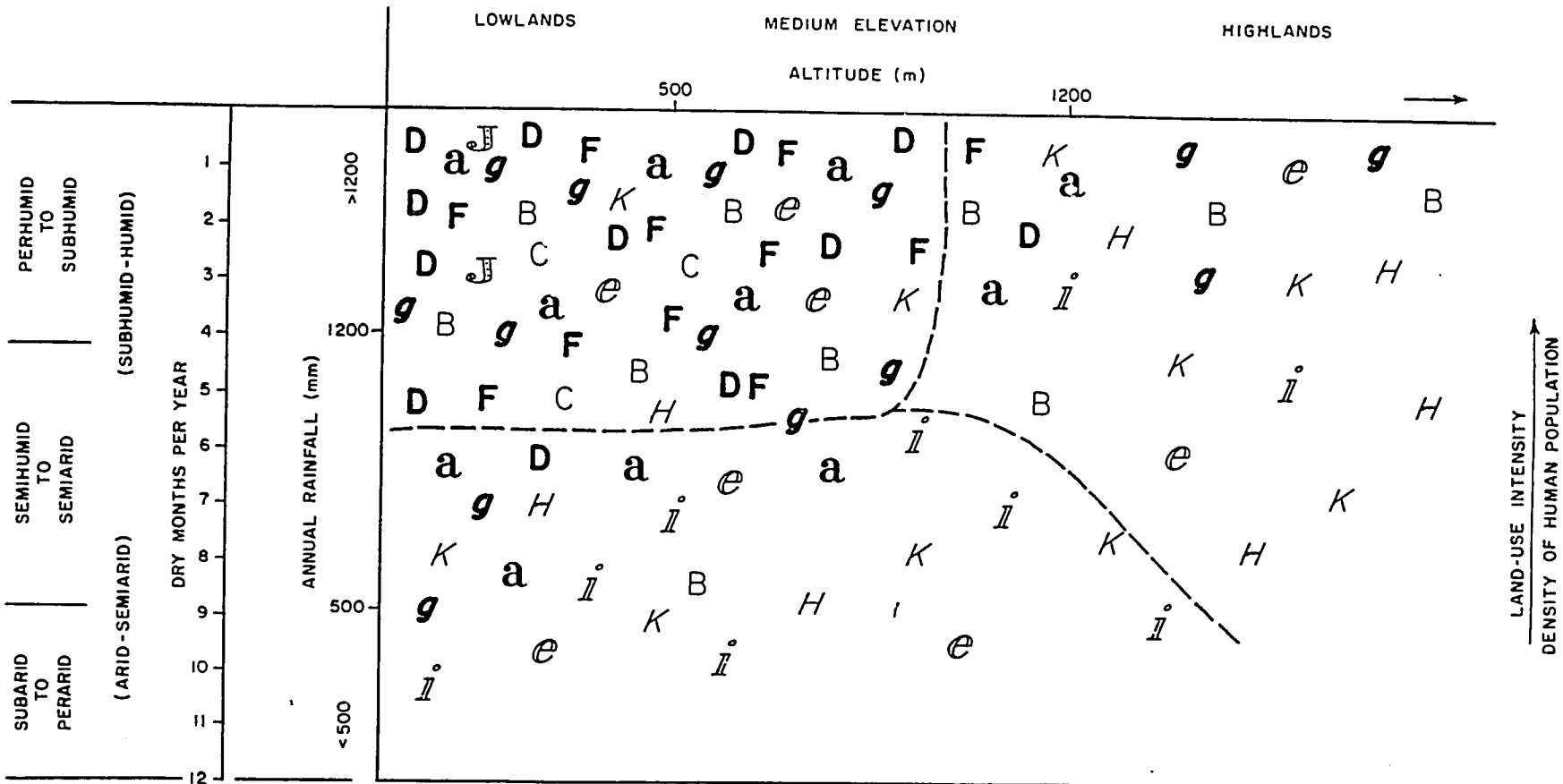


Fig. 3. Ecological spread of major agroforestry systems (legend for system names attached)



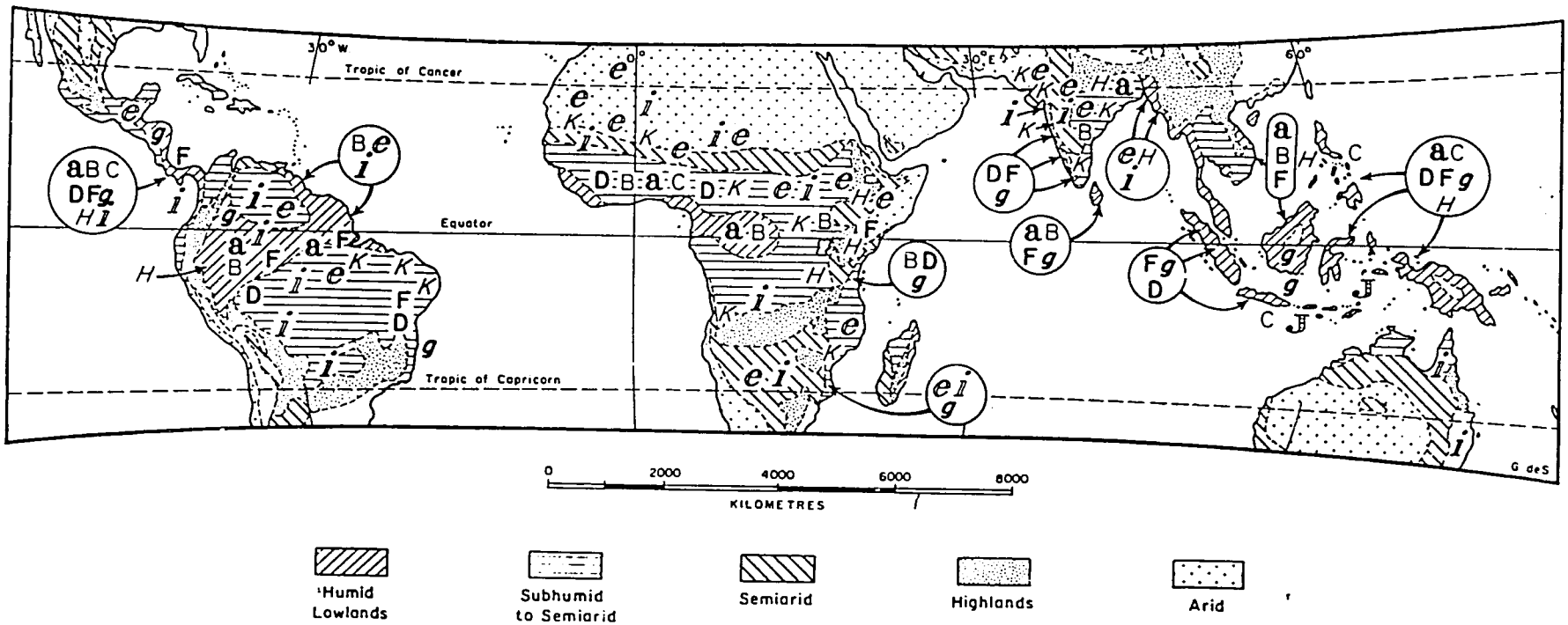
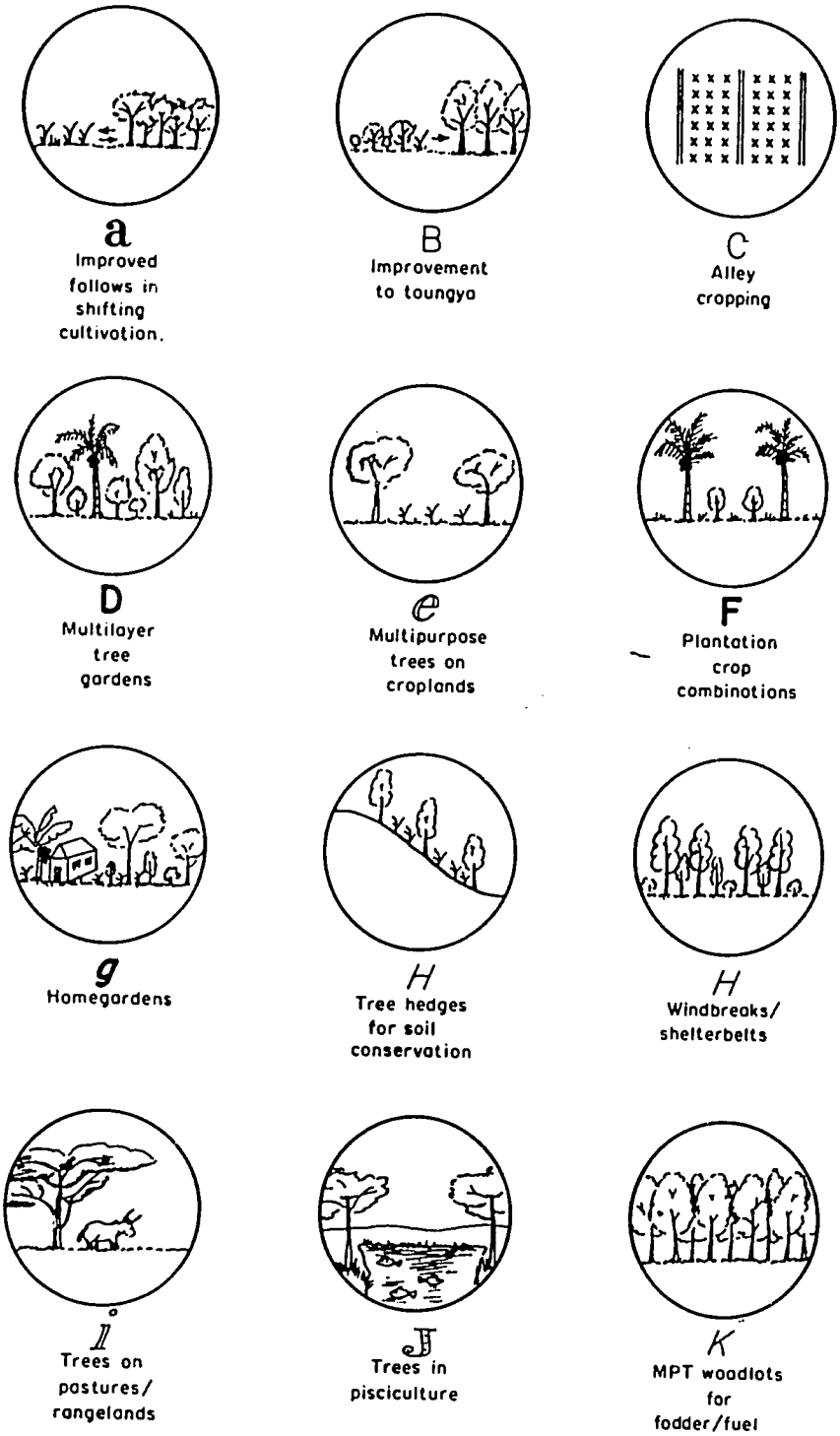


Fig. 4 Major agroforestry systems in different ecological regions of the tropics and subtropics (see legend for system names attached).



Legend for system names (Fig. 3 and 4).

Table 1. MAJOR APPROACHES IN CLASSIFICATION OF AGROFORESTRY SYSTEMS (AND PRACTICES)

CATEGORIZATION OF SYSTEMS (BASED ON THEIR STRUCTURE AND FUNCTION)			GROUPING OF SYSTEMS (ACCORDING TO THEIR SPREAD AND MANAGEMENT)	
STRUCTURE (Nature and arrangement of components, especially woody ones)		FUNCTION (Role and/or output of components, especially woody ones)	AGRO-ECOLOGICAL/ ENVIRONMENTAL ADAPTABILITY	SOCIO-ECONOMIC AND MANAGEMENT LEVEL
Nature of components	Arrangement of components			
Agrisilviculture (crops and trees incl. shrubs/trees and trees)	In space (Spatial)	Productive Function	Systems in/for	Based on level of technology input
Silvopastoral (pasture/animals and trees)	Mixed dense (e.g.: Home garden)	Food	Lowland humid tropics	Low input (Marginal)
Agrosilvopastoral (crops, pasture/animals, and trees)	Mixed sparce (e.g.: Most systems of trees in pastures)	Fodder	Highland humid tropics (above 1,200 m a.s.l; e.g.: Andes, India, Malaysia)	Medium input
Others (multipurpose tree lots, apiculture with trees, aquaculture with trees, etc.)	Strip (width of strip to be more than one tree)	Fuelwood	Lowland subhumid tropics (e.g.: savanna zone of Africa, Cerrado of South America)	High input
	Boundary (trees on edges of plots/fields)	Other woods	Highland subhumid tropics (Tropical highlands) (e.g.: in Kenya, Ethiopia)	Based on cost/benefit relations
	In time (Temporal)	Other products		Commercial
	Coincident	Protective Function		Intermediate
	Concomitant	Windbreak		Subsistence
	Overlapping	Shelterbelt		
	Sequential (separate)	Soil conservation		
	Interpolated	Moisture conservation		
		Soil improvement		
		Shade (for crop, animal, and man)		

Source: Nair, 1985

Table 2: MAJOR AGROFORESTRY PRACTICES

Agroforestry practice	Brief description (of arrangement of components)	Major groups of components (w = woody h = herbaceous f = fodder for grazing a = animals)	*Main types of component interactions in space(s)/ time (t)	Primary role of woody component Prt = protective Prd = productive	Agroecological adaptability
A. AGRISILVICULTURAL SYSTEMS (Crops -- including shrub/vine/tree crops -- and trees)					
1. Improved fallow	Woody species planted and left to grow during the 'fallow phase'	w: fast-growing, preferably leguminous h: common agri. crops	t: sequantial (in rotational cycles)	Prt: soil fertility improvement Prd: wood products	in shifting cultivation areas
2. Taungya	combined stand of woody and agric. species during early stages of establishment of plantations	w: usually plantation forestry spp. h: common agric. crops	s: concomitant t: sequential (in rotational cycles)	Prd: addl. income from agric. crops; also management care for plantation species	in all ecol. regions (where taungya is practised); several improvements possible
3. Alley cropping (hedgerow intercropping)	woody species in hedges; agri. spp. in alleys in in between hedges; microzonal or strip arrangement	w: fast-growing, leguminous, that coppice vigorously h: common agric. crops	s: zonal (strip) t: concomitant to intermittent	Prt: soil improvement, and/or soil conservation Prd: addl. products from hedges	sub-humid to humid areas with high human population pressure and fragile (productive but easily degradable) soils.

4. Multilayer tree gardens	multispecies, multilayer, dense plant associations with no organized planting arrangements	w: different woody components of varying form and growth habits h: usually absent; shade tolerant ones sometimes present	s: mixed dense t: coincident	Prd: various types of outputs Prt: soil conservation and protection; efficient nutrient cycling	areas with fertile soils, good availability of labour, and high human population pressure
5. Multipurpose trees on crop lands	Trees scattered haphazardly or or according to some systematic patterns on bunds terraces or plot/ field boundaries	w: multipurpose trees and other fruit trees h: common agri. crops	s: mixed sparce t: interpolated	Prd: prod. of various tree products Prt: fencing, social values, plot demarcation	in all ecol. regions esp. in subsistence farming; also commonly integrated with animals
6. Plantation crop combinations	1) Integrated multistorey (mixed, dense) mixture of plantation crops 2) Mixtures of plantation crops in alternate or other regular arrangement 3) Shade trees for plantation crops; shade trees scattered. 4) Intercropping with agric.	w: plantation crops like coffee, cacao, coconut, etc., fruit trees (esp. in 1); fuelwood/ fodder spp. esp. in 3. h: usually present in 4, and to some extent in 1; shade tolerant species	s: mixed dense (1, 2, 4) or mixed sparce (3) t: 1) interpolated 2) coincident or overlapping 3) coincident 4) intermittent or concomitant	Prd: prod. of a large number of produces Prt: soil surface protection; shade and windbreak	in humid lowlands or tropical humid/sub-humid highlands (depending on the adaptability of the plantation crops concerned); usually in small-holder subsistence system

Table 2 page 3

7.	Home gardens	Intimate, multi-storey combination of various trees and crops around homesteads.	w:	fruit trees predominate; also other woody spp; vines, etc.	s:	mixed dense	Prd:	prodn. of various products	in all ecol. regions esp. in areas with high population density
			h:	shade-tolerant crops	t:	coincident to inter-polated	Prt:	soil surface protection	
8.	Trees in soil conservation and reclamation	Trees on bunds, terraces, raisers, etc. with or with-out grass strips; trees for soil reclamation	w:	multipurpose and/or fruit trees	s:	zonal (strip)	Prt:	soil conservation	in slopping areas, esp. in highlands, reclamation of degraded, acid, alkali soils; and sand dune stabilization
			h:	common agri. species	t:	intermittent	Prd:	various tree products	
9.	Shelterbelts and windbreaks, live hedges	Trees around farm-lands/plots	w:	combination of tall-growing spreading types	s:	zonal (strip/ boundary)	Prt:	shelterbelts/ windbreak; fencing	in wind-prone areas
			h:	agri. crops of the locality	t:	coincident, interpolated	Prd:	usually firewood	
10.	Fuelwood production	Interplanting firewood species on or around agri. lands	w:	firewood species	s:	zonal (strip/ boundary)	Prd:	firewood	in all ecol. regions
			h:	agri. crops of of the locality	t:	coincident	Prt:	fencing; shelterbelts; boundary demarcation.	

Table 2 page 4

B. SILVOPASTORAL SYSTEMS (trees + pasture and/or animals)

11.	Trees on rangeland or pastures	Trees scattered irregularly or arranged according to some systematic pattern	w: multipurpose; usually of fodder value f: present a: present	s: mixed sparse t: coincident	Prd: trees as fodder Prt: shade; environmental protection	extensive grazing areas
12.	Protein banks	Production of protein rich tree fodder on farm/ range lands for cut-and-carry fodder production	w: leguminous fodder trees h: present f: present	s: zonal t: coincident or interpolated	Prd: fodder prodn. Prt: soil and environ. protection depending on arrangement	usually in areas with high man:land ratio.
13.	Plantation crops with pastures and animals	example: cattle under coconuts in southeast Asia and the south Pacific.	w: plantation crops f: present a: present	s: mixed sparse t: intermittent	Prt: shade and protection to fodder and animals Prd: (plantation crop products)	in areas with less human pressure on plantation crop lands

Table 2 page 5

C. AGROSILVOPASTORAL SYSTEMS (trees + crops + pasture/animals)

14.	Home gardens involving animals	Intimate, multi-storey combination of various trees and crops, and animals, around homesteads	w: fruit trees predominate; also other woody spp. a: present	s: mixed dense t: interpolated to coincident	Prd: various products Prt: soil surface protection; organic recycling	in all ecol. regions with high density of human population
15.	Multipurpose woody hedge-rows	woody hedges for browse, mulch, green manure, soil conservation, etc.	w: fast-growing and coppicing fodder shrubs and trees h: (similar to alley cropping and soil conservation)	s: zonal (strip or boundary) t: intermittent to coincident	Prt: soil conser-vation, Prd: various products, mainly fodder	humid to subhumid areas with hilly and slopping terrain.

D. OTHERS

16.	Apiculture with trees	Trees for honey production	w: honey producing trees (other components may be present)	s: boundary, mixed, sparse (or any other) t: (variable)	Prd: honey production Prt: location-specific	depending on the feasibility of apiculture
17.	Aquaforestry	Trees lining fish ponds, tree leaves being used as 'forage' for fish	w: trees and shrubs preferred by fish (other components may be present)	s: boundary planting t: coincident to intermittent	Prd: fish production Prt: bund stabilization around fish ponds	lowlands

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18.	Multipurpose woodlots	for various purposes, (wood, fodder, soil protection, soil reclamation, etc.)	w: multipurpose species; special location specific spp. (other components may be present)	s: zonal or mixed t: separate or overlapping	Prt: various protective Prd: various	various

*TEMPORAL ARRANGEMENTS OF COMPONENTS IN AGROFORESTRY SYSTEMS

COINCIDENT	CONCOMITANT
INTERMITTENT	OVERLAPPING
SEPARATE	INTERPOLATED

Woody species - non-woody component

Table 3. MAIN CHARACTERISTICS OF THE MAJOR ECOLOGICAL REGIONS OF AGROFORESTRY IMPORTANCE IN THE TROPICS AND SUBTROPICS*

Characteristics	Humid/Sub-humid Lowlands	Dry Region (Semi-arid and arid)	Highlands
Climate	Hot, humid for all or most of the year, rainfall >1000 mm; sometimes one or more extended dry periods per year; Koeppen Af, Am and some Aw, esp. Aw".	Hot, one or two wet seasons and at least one long dry period; rainfall < 1000 mm; Koeppen Aw" (some), Aw', and B climates.	Cool temperatures, sub-humid or humid (arid highlands are of low AF potential); altitude over 1000 m; Koeppen Ca, Cw (agricultural growing period over 120 days).
Vegetation & Soils	Evergreen or semi-evergreen vegetation; Ultisols (Acrisols) and Oxisols (Ferralsols) and other acid, low-base tropical soils.	Savannas with low or medium-high trees and bushes (Aw); thorn scrub and steppe grasslands (BS), Vertisols, Alfisols (Luvisols, Nitosols) and Entisols.	Evergreen to semi-evergreen vegetation depending on rainfall. Oxisols (Humic Ferralsols) and Ultisols (Humic Acrisols) Andosols (volcanic soils).
Major geographical spread (of areas with AF importance)	All tropical continents, especially Southeast and South Asia, West Africa and Central and South America; about 35% of tropical land.	Savanna and sub-Saharan zones of Africa, Cerrado of South America, semi-arid and arid parts of Indian subcontinent; approx. 45% of total tropical land.	Asia (Himalayan region, some parts of southern India and S.E. Asia), East and Central African highlands, Andes; about 20% of tropical land.

Table 3

Main land-use systems	Commercial forestry, agricultural tree crop plantations, rice paddies (esp. Asia), ranching S. America), shifting cultivation, arable cropping.	Arable farming, extensive ranching or nomadic pastoralism. perennial crop husbandry towards the more humid areas, forestry	Arable farming, plantation agriculture and forestry, ranching (in S. & C. America), shifting cultivation.
Main land-use and ecological problems	Excessive deforestation (and consequent shortening of fallows, etc.) over-grazing, soil acidity and consequent problems, low soil fertility, high rainfall erosivity.	Drought (in areas with less rainfall), soil fertility decline caused by over-cultivation, over-grazing, degradation of deciduous wood-land, fuelwood/fodder shortage.	Soil erosion; shortening of fallows; over-grazing, deforestation and ecosystem degradation; fodder/fuel shortage.
Major agroforestry emphasis	Improved fallows, soil fertility improvement and conservation, food production.	Fuelwood/fodder production, soil fertility improvement, windbreaks and shelterbelts, food production.	Soil conservation, fodder/fuel production, watershed management, ecosystem stabilization and protection of rare species.

* Adapted from Young (1986) in consultation with A. Young.

Table 4: MAJOR AGROFORESTRY SYSTEMS AND PRACTICES IN DIFFERENT ECOLOGICAL ZONES OF THE TROPICS AND SUBTROPICS*

System/Practice	Major output/ function	Country/Region	Socio-economic scale of production	Major woody species involved	Remarks
1. HUMID/SUB-HUMID LOWLANDS					
1.1. Agrisilvicultural Systems					
1. Improved 'Fallow' (in shifting cultivation areas)	Food and wood production; Soil fertility improvement	Indonesia	Subsistence	*Aleurites molucana* *Erythrina* spp. *Styrax* spp.	
		Nigeria	Subsistence	*Acioa barterii* *Anthonotha macrophylla* *Gliricidia sepium*	
		Also being tried in many other places		Various fruit trees also being tried	"Forest villages of Thailand"; Boonkird *et al.*, 1984; AFSD-2; Annex. I. Allen, 1985; AFSD-9; Annex. I.

(* Source: AFSI Database, ICRAF)

2.	Hedgerow inter-cropping (Alley cropping)	Production of food and firewood; Soil fertility improvement and soil conservation	S.E. Asia Nigeria Now being tried in very many places, mostly on experimental basis	Subsistence (Experimental)	Calliandra callothyrsus Leucaena leucocephala and several other species	
3.	Multispecies mixes (Tree gardens)	Production of food, fodder and wood products for home consumption and sale for cash	Nigeria	Subsistence	Daniellia oliveri Gliricidia sepium Parkia clappertoniana Pterocarpus africana	"Compound gardens of Nigeria" (Okafor and Fernandes, 1987; AFSD 24; Annex. I).
			Pacific Islands	Subsistence	Inocarpus edulis Morus nigra Spondias dulce	
			India Sri Lanka	Subsistence, Intermediate	Areca catechu Artocarpus spp. Cocos nucifera Mangifera indica Zyzygium aromaticum	"Homestead agroforestry in Kerala, India" (Nair and Sreedharan, 1986; AFSD-18; Annex. I).
			Paraguay	Subsistence, Intermediate	Melia azedarach Leucaena leucocephala	

			S.E. Asia	Subsistence Intermediate	Albizia falcataria Artocarpus spp. Bambusa spp. Cinnamomum aromaticum Durio zibethinus Nephelium lappacium	"Agroforestry garden system of Sumatra" (Michon et al., 1986; AFSD 21; Annex. I).
4.	Multipurpose trees/shrubs on farmlands	Production of food, fuelwood, other wood products; Sustainability of production; Soil conservation	Brazil	Intermediate Subsistence	Cassia excelsa L. leucocephala Mimosa scabrella	
			India	Subsistence Intermediate	Derris indica Emblica officinalis Moringa oleifera Tamarindus indica	Jambulingam and Fernandes, 1986; AFSD-15; Annex. I.
			Kenya	Subsistence	Anacardium occidentale Ceiba petandra Mangifera indica Manilkara achras	
			S.E. Asia	Subsistence Intermediate Commercial	Acacia mangium Artocarpus spp. Durio zibethinus Gliricidia sepium Sesbania grandiflora	Nair and Sreedharan, 1986; AFSD-18; Annex I.

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Table 4

5.	Crop combinations with plantation crops				Plantation crops involved *Anacardium occidentale* *Camellia sinensis* *Cucus nucifera* *Coffea arabica* *Elaeis guineensis* *Havea brasiliensis* *Piper nigrum* *Theobroma cacao*	
(i)	Integrated production of plantation crops and other crops	Production of plantation crops) for sale (cash); Production of subsidiary (food) crops; Sustainability				
(ii)	Mixtures of plantation crops		Brazil	Commercial to subsistence	*Bertholletia excelsa* *Copernicia prunifera* *Cordia alliodora* *Inga* spp. *Orbignya* spp. *Samanea saman*	Alvim and Nair, 1986; AFSD-13; Annex. I. Johnson and Nair, 1984; AFSD-8, Annex. I. May *et al*., 1985; AFSD-11; Annex. I.

Table 4

iii)	Shade trees for commercial plantation crops		Costa Rica	Commercial to subsistence	*Cordia alliodora* *Erythrina poeppigiana* *Gliricidia sepium* *Inga* spp.	
			India, Sri Lanka	Subsistence to commercial	*Albizia* spp. *Cassia* spp. *Erythrina* spp. *Grevillea robusta*	Liyanage *et al.*, 1984; AFSD-7; Annex. I.
			S.E. Asia	Commercial to subsistence	Various fruit trees	
			West Indies	Subsistence Intermediate	*Inga vera* Various spice trees	
			Western Samoa	Subsistence	*Erythrina variegata* *Gliricidia sepium* *Leucaena leucocephala*	
6.	AF for fuelwood production (Interplanting firewood species on or around field/farms	Production of fuelwood; Production of other products like food, poles, fodder;	India	Subsistence	*Albizia* spp. *Cassia siamea* *Casuarina* spp. *Derris indica* *Emblica officinalis*	Nair (forthcoming) Jambulingam and Fernandes, 1986; AFSD-15; Annex. I.
		Fencing, shade, shelterbelts, etc.	Indonesia	Subsistence	*Albizia falcataria* *Calliandra callothyrsus* *Sesbania grandiflora* *Trema orientalis*	

7.	Shelterbelts, windbreaks, soil conservation hedges	Protective roles (shelterbelt windbreak, etc.) Soil conservation; Production of food, fuelwood	India	Subsistence Intermediate	Casuarina equisetifolia Syzygium cuminii	
			Indonesia and other parts of S.E. Asia.	Subsistence Intermediate	Gliricidia sepium Leucaena leucocephala Sesbania grandiflora	
1.2.	Silvopastoral Systems (Humid/sub-humid lowlands)					
1.	Protein bank Multipurpose trees on or around farmlands	Production of fodder/livestock and food crops	India Nepal, Sri Lanka	Mostly subsistence	Artocarpus spp. Anogeissus latifolia Bombax malabaricum Cordia dichotoma Dalbergia jambolana Samanea spp Zizyphus jujuba	
2.	Living fences of fodder trees and shrubs	Service function (fences); Production of tree products	Costa Rica		Diphysa robinoides Gliricidia sepium	
			Ethiopia	Subsistence	Erythrina abyssinica	
			S.E. Asia	Subsistence	Sesbania grandiflora	
3.	Trees and shrubs on pastures	Production of pasture/ livestock and wood	Brazil	Mostly subsistence	Acacia spp. Anacardium occidentale Cedrela odorata Cordia alliodora Various palms	Johnson and Nair, 1984; AFSD-8; Annex. 1.

Table 4

		Costa Rica	Subsistence	Enterolobium cyclocarpum Erythrina poeppigiana Samanea spp.	Escalante, 1985; AFSD-10; Annex. I.
		India	Subsistence to intermediate	Derris indica Emblica officinalis Psidium guajava Tamarindus indica	
1.3. Agrosilvopastoral Systems (Most Ecological Zones)					
1. Home Gardens Tree-crop-livestock mix around homestead (these dense associations are found in almost all ecological regions and countries; only some examples are given)	Production of food/fodder/ fuelwood, etc. for home consumption, and, sometimes, for sale (cash)	South and S.E. Asia	Subsistence to intermediate		"Kandyan gardens of Sri Lanka" (Jacob and Alles, 1987; AFSD-23; Annex. I).
		Nigeria	Mostly subsistence		
		Latin American countries	Mostly subsistence		
		Tanzania (Highlands)	Subsistence to intermediate		"Chagga homegardens" (Fernandes et al. 1984. AFSD-1; Annex. I).
2. Woody hedgerows for browse, mulch, green manure and soil conservation	Production of food/fodder/ fuelwood; Soil conservation	Indian sub-continent	Mostly subsistence	Erythrina spp. Leucaena leucocephala Sesbania spp.	"Homestead agroforestry in Bangladesh" (Leuschnerand Khalique, 1987; AFSD-25; Annex. I).
		S.E. Asia			

Table 4

2. (DRY) SEMI-ARID AND ARID REGIONS

2.1. Agrisilvicultural Systems

1. Multipurpose trees and shrubs on farmlands	(same as in lowlands)	Brazil	Subsistence	*Caesalpinia ferrea* *Prosopis juliflora* *Zizyphus joazeiro*	
In many places, strips of trees are planted along the edges of contour terraces		Central African Republic	Subsistence	*Adansonia digitata* *Balanites aegyptiaca* *Borassus aethiopium*	
		India	Subsistence	*Cajanus cajan* *Derris indica* *Prosopis cineraria* *Tamarindus indica*	Shankarnarayan and Harsh, 1987; AFSD-22; Annex. I.
		Kenya	Subsistence	*Acacia* spp. *Balanites aegyptiaca* *Cajanus cajan*	
		Sudan & Sahelian countries	Subsistence	*Acacia albida*	Poschen, 1986; AFSD-17, Annex. I. Miehe, 1986; AFSD, 1986; Annex. I.
		Tanzania	Subsistence	*Acacia* spp. *Combretum* spp.	

Table 4

2. AF Fuelwood production	Fuelwood	Chile	Subsistence	Prosopis tamarugo	
		India	Subsistence	Albizia lebbek Cassia siamea Prosopis spp.	
		Sahel	Subsistence	Acacia albida A. senegal A. tortilis	
3. Shelterbelts and Wind-breaks	Protection of agri. fields fields from winds; Production of fuelwood	India Pakistan	Subsistence, Intermediate	Azadirachta indica Cajanus cajan Cassia siamea Eucalyptus spp. Pithecellobium dulce Populus spp.	Shankarnarayan and Harsh, 1987; AFSD-22; Annex. I.
2.2. Silvopastoral Systems (Dry Regions)					
1. Protein bank	Same as in other regions	India	Subsistence	Acacia nilotica Ailanthus excelsa Opuntia ficus Prosopis spp. Rhus sinuata	Jambulingam and Fernandes, 1986; AFSD-15; Annex. I.
2. Living fences	Same as in other regions	East Africa	Subsistence	Acacia spp. Commiphora africana Euphorbia tirucalli Zizyphus mucronata	

3. Trees and shrubs on pastures	Same as in other regions	India	Subsistence	Acacia spp. Prosopis spp. Tamarindus indica	
		Middle East and Mediterranean	Commercial	Acacia spp. Ceratonia siliqua Haloxylon spp. Prosopis cineraria Tamarix aphylla	

3. TROPICAL HIGHLANDS

3.1. Agrisilvicultural Systems

1. Multipurpose trees and shrubs on farmlands	Food production; Soil conservation	India	Subsistence	Albizia spp. Bauhinia variegata Dalbergia sissoo	"Hill farming in Nepal" (Fonzen and Oberholzer, 1984; AFSD 4; Annex. I).
		Kenya	Subsistence	Ceiba petandra Eriobotrya japonica Grevillea robusta	
		Nepal	Subsistence	Bauhinia spp. Erythrina spp. Ficus spp. Litsea polyntha	
		Paraguay	Subsistence /	Melia azedarach	"Gigante woodlots" (Evans and Rombold, 1984; AFSD-5; Annex. I).

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		Tanzania	Subsistence	Albizia spp. Cordia africana Croton macrostachys Trema guineensis	
2. Crop combinations with plantation crops		Brazil	Subsistence, Intermediate	Alnus acuminata Enterolobium contorsiliquum Erythrina velutina	
		Costa Rica	Subsistence, Intermediate	Alnus acuminata Erythrina poeppigiana Inga spp.	
		India Sri Lanka Kenya Papua New Guinea	Subsistence Subsistence Subsistence, Intermediate	Albizia spp. Grevillea robusta Grevillea robusta Casuarina olygodon	Bourke, 1984; AFSD-6; Annex. I.
		Rwanda	Subsistence	Albizia spp.	
		Tanzania	Subsistence	Cordia africana Grevillea robusta Trema guineensis	
3. AF Fuelwood production	(same as lowlands)	India Nepal	Subsistence	Albizia stipulata Bauhinia spp. Grewia spp.	

4.	Shelterbelts, Windbreaks, Soil conservation Hedges			(same as in lowlands)	
3.2.	Silvopastoral Systems (Tropical Highlands)				
	Protein Bank	Production of fodder/animals and fuelwood; Soil conservation	Indian sub-continent	Mostly Subsistence	Albizia stipulata Bauhinia spp. Ficus spp. Grewia oppositifolia Morus alba
2.	Living fences	Service roles	Costa Rica	Commercial to subsistence	Gliricidia sepium
			Ethiopia	Commercial to subsistence	Erythrina abyssinica
			East Africa	Commercial to subsistence	Dovyalis caffra Euphorbia tirucalli Iboza multiflora
3.	Trees and shrubs on pastures	Fodder/animal production; food production	Brazil	Mostly subsistence	Desmanthus varigatus Desmodium discolor
			Costa Rica	Mostly subsistence	Alnus acuminata
			Indian sub-continent	Mostly subsistence	Albizia stipulata Alnus nepalensis Grewia spp. Robinia pseudoacacia

PUBLICATIONS FROM THE AGROFORESTRY SYSTEMS INVENTORY PROJECT

I. AGROFORESTRY SYSTEM DESCRIPTIONS

January 1987

This series of Agroforestry System Descriptions is edited by Dr. P.K.R. Nair and published by Martinus Nijhoff/Dr. W. Junk Publishers in the journal Agroforestry Systems.

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B. Papers

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2. Nair, P.K.R., E.C.M. Fernandes and P.N. Wambugu. 1984 Multipurpose leguminous trees and shrubs for agroforestry. Agroforestry Systems 2: 145-163. (Also published in Pesquisa Agropecuaria Brasileira, Vol. 19 S/N - Junho 1984, pp. 295-313).

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