CHAPTER 4

Distribution of agroforestry systems in the tropics

The geographical definition of the word "tropics" (that part of the world located between 23.5 degrees north and south of the Equator) is not of much value in a discussion on land use. For the purpose of this book, the word tropics is used in a general sense, and includes the subtropical developing countries that have agroecological and socioeconomic characteristics, and land-use problems, that are similar to those of the countries within the geographical limits of the tropics. In other words, the word is used, though erroneously, as a synonym for *developing countries*. This logic is also used later in the book when discussing agroforestry systems in the temperate zone (Chapter 25).

4.1. The tropical environment

Although it is important that readers of this book have a general understanding of the physical, biological, and socioeconomic characteristics of the tropics, detailed discussions on those topics are not included here. Some discussion on tropical soils is included in Chapter 14. For other details, readers may refer to other relevant books, several of which are available. For example, Sanchez (1976, Chapter 1), and Evans (1992, Chapter 1) give general accounts of the tropical environment, while annual publications such as *World Resources* (by the World Resources Institute, Washington, D.C.) give updated information on the current state of affairs regarding world environment and resources.

The major climatic parameters that determine the environment of a location in the tropics are rainfall (quantity and distribution) and temperature regimes. Altitude is important because of its influence not only on temperature, but also on land relief characteristics. From the agroforestry point of view, the major ecological regions recognized in the FAO State of Food and Agriculture Reports (SOFA) are relevant: these are temperate, mediterranean, arid and semiarid, subhumid tropical (lowland), humid tropical (lowland) and highland. These classes, excepting the first (and possibly the second), represent the tropical and subtropical lands where agroforestry systems exist or have a potential. The main characteristics of these ecological regions (humid and

Table 4.1. Main characteristics of the major ecological regions of agroforestry importance in the tropics and subtropics.

Characteristics	Humid/subhumid lowlands	Dry regions (semiarid 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; Koppen Af, Am and some Aw, esp. Aw"	Hot, one or two wet seasons and at least one long dry period; rainfall 1000 mm; Koppen Aw" (some), Aw', and B climates	Cool temperatures, subhumid or humid (arid highlands are of low AF potential); altitude over 1000 m; Koeppen Ca, Cw (agricultural growing period over 120 days)
Vegetation and 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 south-east 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
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 south and central America), shifting cultivation
Main land-use and ecological problems	Excessive deforestation (and consequent shortening of fallows, etc.) overgrazing, 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 woodland, 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

Source: Nair (1989).

subhumid lowlands, dry - semiarid and arid - regions, and highlands) are summarized in Table 4.1.

One of the special features of the tropics that is not a consequence of its climate and ecology is its poor economic, social, and developmental status. As mentioned earlier, the word tropics is used synonymously with developing countries. Most nations and people in the tropics are poor; gross domestic product per person is low (about $ 100-150 per year) in most of these countries. Economic growth seldom keeps pace with population increase. A vast majority of the people work and depend on the land for their livelihood; yet agricultural production per unit area is very low. The gravity of the situation is compounded by the unfortunate political instability and turmoil that are characteristic of many of these nations, which is a serious impediment to economic development.

4.2 Distribution of tropical agroforestry systems

The inventory of agroforestry systems (Chapter 3) resulted in several publications on indigenous agroforestry systems in the tropics and subtropics. This information was later compiled into a single volume *Agroforestry Systems in the Tropics* (Nair, 1989). Several other publications were published in the late 1980s to early 1990s that describe many such indigenous agroforestry systems. Notable among these are *Agroforestry in Dryland Africa* written by Rocheleau *et al*. (1988), *Agroforestry: Classification and Management* (MacDicken and Vergara, 1990), *Agroforesterie et Desertification* (Baumer, 1987), *Systemas Agroforestales* (Montagnini, 1986), and *Agroforestry Systems in China* (Zhaohua *et al*., 1991). Indeed, most if not all, proceedings of various conferences and meetings on agroforestry held during the 1980s contain descriptions of agroforestry systems. Thus, today there is a fairly vast literature of indigenous agroforestry systems.

A generalized overview[1] of the most common agroforestry systems in different parts of the tropics and subtropics is given in Table 4.2. A closer examination of the distribution of these systems in different ecological and geographical regions of the world reveals that there is a clear relationship between the ecological characteristics of a region and the nature of the current agroforestry systems there. The following sections examine this relationship for the three major ecological regions of the tropics.

[1] For more detailed information on the different types of agroforestry systems in the various ecological regions of the tropics and the common woody species involved in each, readers are advised to refer to: Nair, P. K. R. (ed.) 1989. *Agroforestry Systems in the Tropics,* pp. 74-84.

Table 4.2. An overview of agroforestry systems in the tropics.

Subsystems and practices	South Pacific	South-East Asia	South Asia	Middle East and Mediterranean	East and Central Africa	West Africa	American Tropics
			AGRISILVICULTURAL SYSTEMS				
Improved fallow (in shifting cultivation areas)		Forest villages of Thailand; various fruit trees and plantation crops used as fallow species in Indonesia	Improvements to shifting cultivation; several approaches e.g. in the north-eastern areas of India		Improvements to shifting cultivation e.g. gum gardens of the Sudan	*Acioa barterii, Anthonontha macrophyta, Gliricidia sepium* etc., tried as fallow species	Several forms
Taungya system	Taro with *Anthocephalus* and *Cedrella* trees, and other forms	Widely practiced; forest villages of Thailand an improved form	Several forms, several names		The Shamba system	Several forms	Several forms
Tree gardens	Involving fruit trees	Dominated by fruit trees	In all ecological regions	The Dehesa system, 'Pare Arboree'			e.g. Paraiso woodlots of Paraguay
Hedgerow intercropping (alley cropping)		Extensive use of *Sesbania grandiflora, Leucaena leucocephala and Calliandra calolhyrsus*	Several experimental approaches e.g. conservation farming in Sri Lanka		The corridor system of Zaire	Experimental systems on alley cropping with *Leucaena* and other woody perennial species	Experimental

Table 4.2. (continued)

Subsystems and practices	South Pacific	South-East Asia	South Asia	Middle East and Mediterranean	East and Central Africa	West Africa	American Tropics
Multipurpose trees and shrubs on farmlands	Mainly fruit or nut trees e.g. *Canarium, Pometia, Pandanus, Barringtonia, Artocarpus altilics*	Dominated by fruit trees: also *Acacia mearna* cropping system, Indonesia	Several forms in lowlands and highlands, e.g. *Khejri-based* system in dry parts of India hill farming in Nepal	The oasis system; crop combinations with carob trees; the Dehesa system; olive trees and cereals; irrigated systems	Various forms; the Chagga system of Tanzanian highlands; the Nyabisindu system of Rwanda	*Faidherbia (Acacia) albida*-based systems in dry areas; *Butyrospermum* and *Parkia* systems 'Parc arboree'	Various forms in all ecological regions
Plantation crop combinations	Plantation crops and multipurpose trees e.g. *Casuarina* with coffee in the Papua New Guinea highlands; also *Gliricidia* and *Leucaena* with cacao	Plantation crops and fruit trees; smallholder systems of crop combinations with plantation crops; plantation crops with spice trees	Integrated production systems in smallholdings; shade trees in plantations; other crop mixtures including various spice trees	Irrigated systems; olive trees and cereals	Intergrated production; shade trees in commercial plantations; mixed systems in the highlands	Plantation crop mixtures; smallholder production systems	Plantation crop mixtures; shade trees in commercial plantations; mixed systems in small-holdings; spice trees; babassu palm-based systems
Agroforestry fuelwood production	Multipurpose fuelwood trees around settlements	Several examples in different ecological regions	Various forms, including social forestry systems		Various forms	Common in the dry regions	Several forms in the dry regions

Table 4.2. (continued)

Subsystems and practices	South Pacific	South-East Asia	South Asia	Middle East and Mediterranean	East and Central Africa	West Africa	American Tropics
Shelterbelts, windbreaks, soil conservation hedges	*Casuarina oligodon* in the highlands as shelterbelts and to improve soils	Terrace stabilization on steep slopes	Use of *Casuarina* spp. as shelterbelts; several windbreaks	Tree species for erosion control	The Nyabisindu system of Rwanda	Various forms	Live-fences, windbreaks, especially in highlands
			SILVOPASTORAL SYSTEMS				
Protein bank (cut-and-carry) fodder production	Rare	Very common, especially in highlands	Multipurpose fodder trees on or around farmlands, especially in highlands		Very common	Very common	Very common
Live-fences of fodder trees and hedges	Occasional	*Leucaena, Calliandra* etc. used extensively	*Sesbania, Euphorbia, Syzigium,* etc. common		Very common in all ecological regions		Very common in highlands
Trees and shrubs on pasture	Cattle under coconut, pine and *Eucalyptus deglupta*	Grazing under coconut and other plantation crops	Several tree species being used very widely	Very common in dry regions; the Dehesa system	The *Acacia*-dominated system in the arid parts of Kenya, Somalia and Ethiopia	*Cattle* under oilpalm; cattle and sheep under coconut	Common in humid as well as dry regions e.g. grazing under plantation crops in Brazil

Table 4.2. (continued)

Subsystems and practices	South Pacific	South-East Asia	South Asia	Middle East and Mediterranean	East and Central Africa	West Africa	American Tropics
			AGROSILVOPASTORAL SYSTEMS				
Woody hedges for browse, mulch, green manure, soil conservation etc.	Various forms; *Casuarina oligodon* widely used to provide mulch and compost	Various forms	Various forms, especially in lowlands		Common; variants of the Shamba system	Very common	Especially in hilly regions
Homegardens (involving a large number of herbaceous and woody plants and/or livestock)	Several types of homegardens and kitchen gardens	Very common; Java homegardens often quoted as good examples; involving several fruit trees	Common in all ecological regions; usually involving fruit trees	The oasis system	Various forms; the Chagga homegardens; the Nyabisindu system	Compounds farms in humid lowlands	Very common in thickly populated areas
			OTHER SYSTEMS				
Agrosilvo fishery (aquaforestry)		Silviculture in mangrove areas; trees on bunds of fish-breeding ponds	Occasional				
Various forms of shifting cultivation	Common	Swidden farming and other forms	Very common; various names		Very common	Very common in the lowlands	Very common in all ecological regions
Apiculture with trees	Common	Common	Common	Common	Common	Common	

Source: Nair(1989).

4.2.1. Lowland humid and subhumid tropics

Characterized by hot, humid climate for all or most of the year, and an evergreen or semi-evergreen vegetation, the lowland humid and subhumid tropics (hereafter referred to as humid tropics) is by far the most important ecological region in terms of the total human population it supports, extent, and diversity of agroforestry and other land-use systems. Because of the climatic conditions that favor 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, improved fallow in shifting cultivation areas, and multipurpose tree woodlots, are the major agroforestry systems. Thus, the common agroforestry systems in this zone are:

- shifting cultivation,
- taungya,
- homegardens,
- plantation-crop combination, and
- various intercropping systems.

The lowland humid tropics also include areas under natural rainforests. In such areas, the cutting of rainforests at rates exceeding natural or managed regeneration is a common problem. This causes shortening of fallow periods in shifting cultivation cycles and results in declining 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.

4.2.2. Semiarid 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 semiarid and arid tropics are characterized 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 are also influenced by population pressure; homegardens and multilayer tree gardens are found in the wetter areas with high population pressure. But generally speaking, the predominant agroforestry systems in this zone are:

- various forms of silvopastoral systems,
- windbreaks and shelterbelts, and
- multipurpose trees on crop lands, notably *Faidherbia (Acacia) albida-based* systems in Africa and *Prosopis-based* agrisilvicultural systems in the Indian subcontinent.

Alley cropping as it is known today is unlikely to be widely adopted in the

semiarid tropics (see Chapter 9). This does not imply that agroforestry in general is unsuitable for these regions. Indeed, some of the best-known agroforestry systems are found in the semiarid tropics - for example, the system based on *Faidherbia (Acacia) albida,* found in the dry areas of Africa (Felker, 1978; Miehe, 1986; Vandenbeldt, 1992), and the system based on *Prosopis cineraria,* found in the dry areas of India (Mann and Saxena, 1980; Shankarnarayan *et ah,* 1987).

Fuelwood shortage is a major problem in most parts of the semiarid and arid tropics; agroforestry potentials in fuelwood production are well documented (e.g., Nair, 1987). Similarly, desertification and fodder shortage, which are the other major land-use problems in this zone, could be addressed to some extent through the agroforestry approach (Rocheleau *et at.,* 1988) (see also Chapter 10).

4.2.3 Tropical highlands

Approximately 20% of the tropical lands are at elevations from 900-1800 m. These areas include approximately 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 Cameroon, the Deccan Plateau of India and some parts of the southeast Asia mainland. The altitude exceeds 1800 m in about 3% of the tropical areas in the Andes, the Ethiopian and Kenyan Highlands, northern Myanmar (Burma) and parts of Papua New Guinea. In the subtropical regions, the most important highlands are in the Himalayan region.

The highland tropics with significant agroforestry potential are humid or subhumid, while areas with dry climates are 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); this affects the growth of certain lowland tropical species.

The main agroforestry systems in tropical highlands are:

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

In summary, the major types of agroforestry systems in the tropics are as listed in Table 4.3.

Table 4.3. Major types of agroforestry systems in the tropics.

Humid Lowlands

Shifting cultivation
Taungya
Plantation-crop combinations
Multilayer tree gardens
Intercropping systems

Semiarid Lowlands

Silvopastoral systems
Windbreaks and shelterbelts
Multipurpose trees for fuel and fodder
Mutlipurpose trees on farmlands

Highlands

Soil conservation hedges
Silvopastoral combinations
Plantation-crop combinations

4.3. Agroecological spread of tropical agroforestry systems

The type of agroforestry system found in a particular area is determined to some extent by agroecological factors. However, several socioeconomic factors, such as human population pressure, availability of labor and proximity to markets, are also important determinants, so that considerable variations can be found among systems existing in similar or identical agro-climatic conditions. Sometimes, socioeconomic factors take precedence over ecological considerations. Even in the case of systems that are found in most ecological and geographical regions, such as shifting cultivation and taungya, there are numerous variants that are specific to certain socioeconomic contexts. As a general rule, it can be said that while ecological factors determine the major type of agroforestry system in a given area, the complexity of the system and the intensity with which it is managed increase in direct proportion to the population intensity and land productivity of the area.

The multispecies, multistoried homegarden systems serve to illustrate some of these points. Although these systems are found mainly in humid lowlands, they are also common in pockets of high population density in other ecological regions (see Chapter 7). In their analysis of the structural and functional aspects of 10 homegarden systems in different ecological regions, Fernandes and Nair (1986) found that although the average size of a homegarden unit is less than 0.5 ha, it generally consists of a large number of woody and herbaceous species. The garden is carefully structured so that the species form three to five canopies

at varying heights, with each component having a specific place and function within the overall design.

Agroecological factors have a considerable bearing on the functional emphasis of agroforestry practices. For example, the primary function of agroforestry practices in sloping lands is erosion control and soil conservation; in wind-prone areas, the emphasis is on windbreaks and shelterbelts; and, in areas with a fuelwood shortage, the emphasis is on fuelwood production. There are also specific agroforestry approaches for the reclamation of degraded lands or wastelands (for example, land that has been badly eroded or overgrazed, or is highly saline or alkaline). The preponderance of homegardens and other multispecies systems in fertile lowlands and areas with high agricultural potential at one end of the ecological scale, and extensive silvopastoral practices at the other end, with various systems in between, indicates that the ecological potential of an area is the prime factor that determines the distribution and extent of adoption of specific agroforestry systems.

The ecological and geographical distribution of the major agroforestry systems in the world has been schematically presented by Nair (1989) (Figure 4.1). However, caution must be exercised in producing and interpreting such "agroforestry maps" because they aim to show general distribution patterns and thus include only those areas in which specified agroforestry systems are abundant. There are innumerable location-specific agroforestry practices in the tropics which, although important in certain respects, are not significant enough in terms of the overall economy and land-use pattern of the area in which they operate to warrant inclusion on a global map. Conversely, some practices, such as multipurpose trees on farmlands, are found in almost all ecological and geographical regions, but only a few of them - for example, the arid zone systems involving *Faidherbia (Acacia) albida* and *Prosopis* (Shankarnarayan *et ah,* 1987) - can be classified as distinct agroforestry systems and included on an agroforestry map.

A significant feature that emerges from this analysis is that, irrespective of the sociocultural differences in different geographical regions, the major types of agroforestry systems are structurally similar in areas with similar ecological conditions. Thus, agroecological zones can be taken as a basis for design of agroforestry systems. The underlying concept is that areas with similar ecological conditions can have structurally similar agroforestry systems. ICRAF used this strategy in designing its Agroforestry Research Networks for Africa (AFRENAs) (ICRAF, 1987). The idea was further developed by Nair (1992), who proposed a generalized matrix of the most common types of land-use constraints or problems in the three major agroecological zones in the tropics, and the broad types of agroforestry interventions that could be developed to address these problems. This is presented in Figure 4.2. Such matrices of agroecological conditions versus agroforestry practices could be developed for any given region. However, the agroecological conditions and the biological and socioeconomic characteristics of agroforestry systems are so complex and varied that it would be difficult to integrate all this information

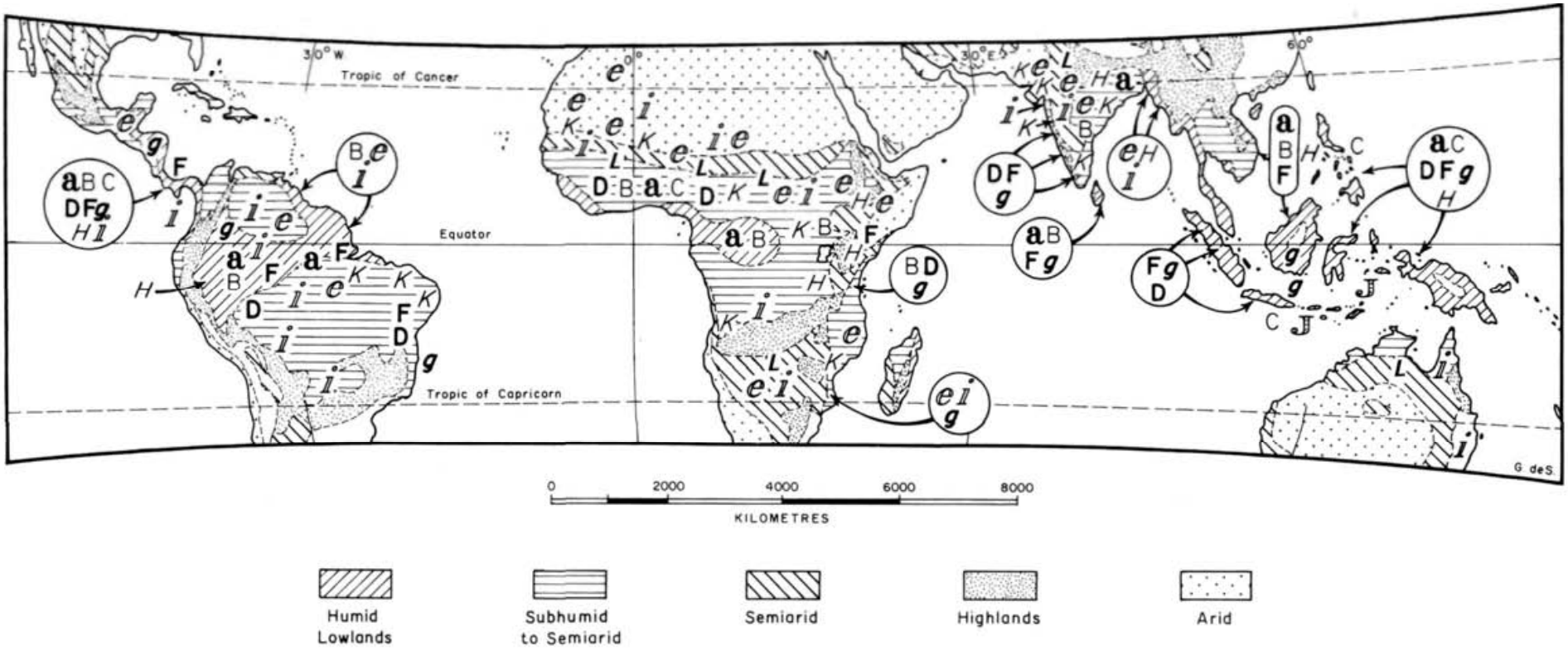

Figure 4.1. Major agroforestry systems in different ecological regions of the tropics and subtropics (*see* legend for systems on page 51). Source: Nair (1989).

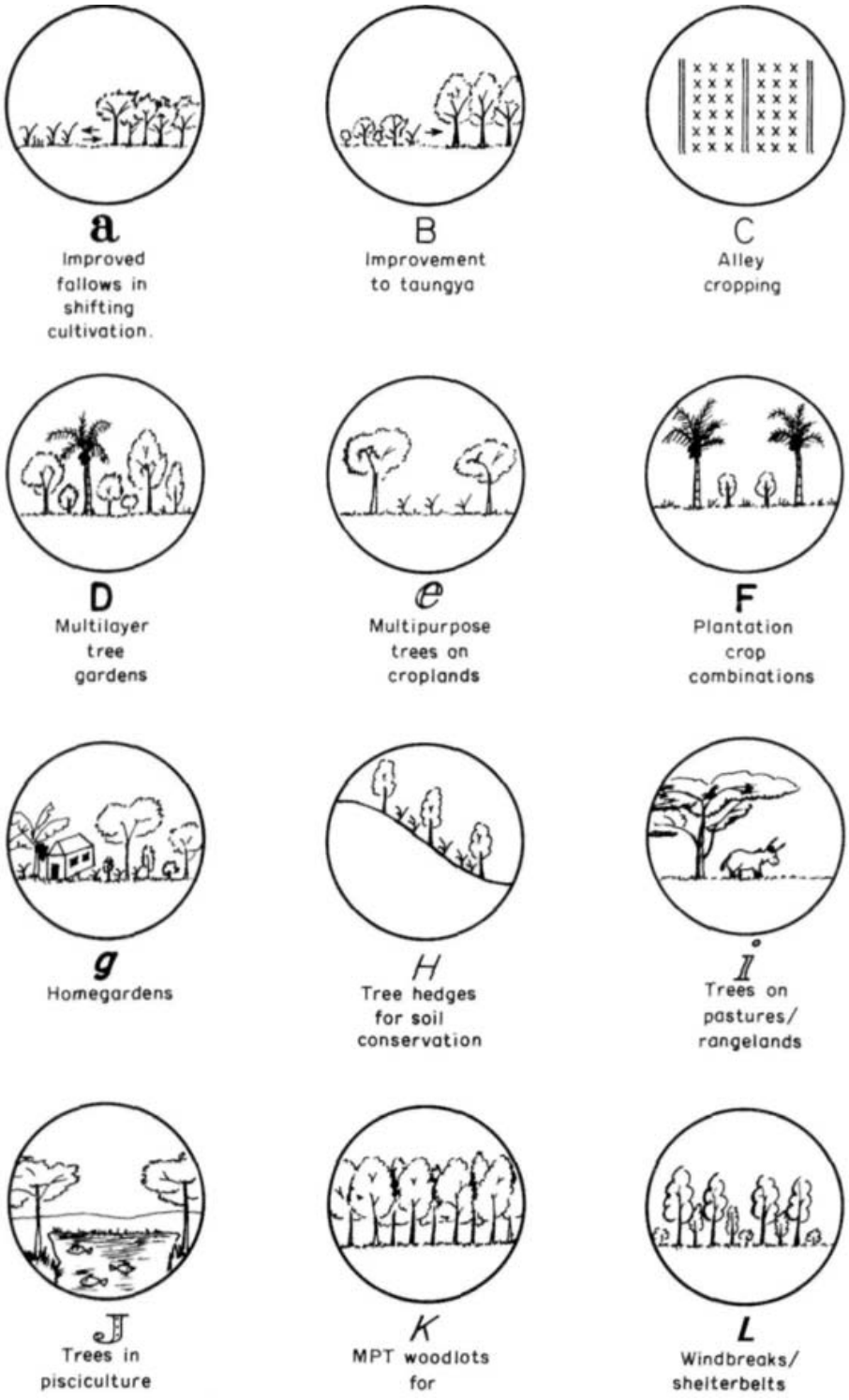

Figure 4.1 A.

into simple models. Computer-aided, knowledge-engineering applications such as Expert Systems would perhaps be a feasible approach to address this problem. A Knowledge-Based Expert System developed by Warkentin *et al.* (1990) for design of alley cropping illustrates the opportunities and possibilities in applying this technique in agroforestry systems design.

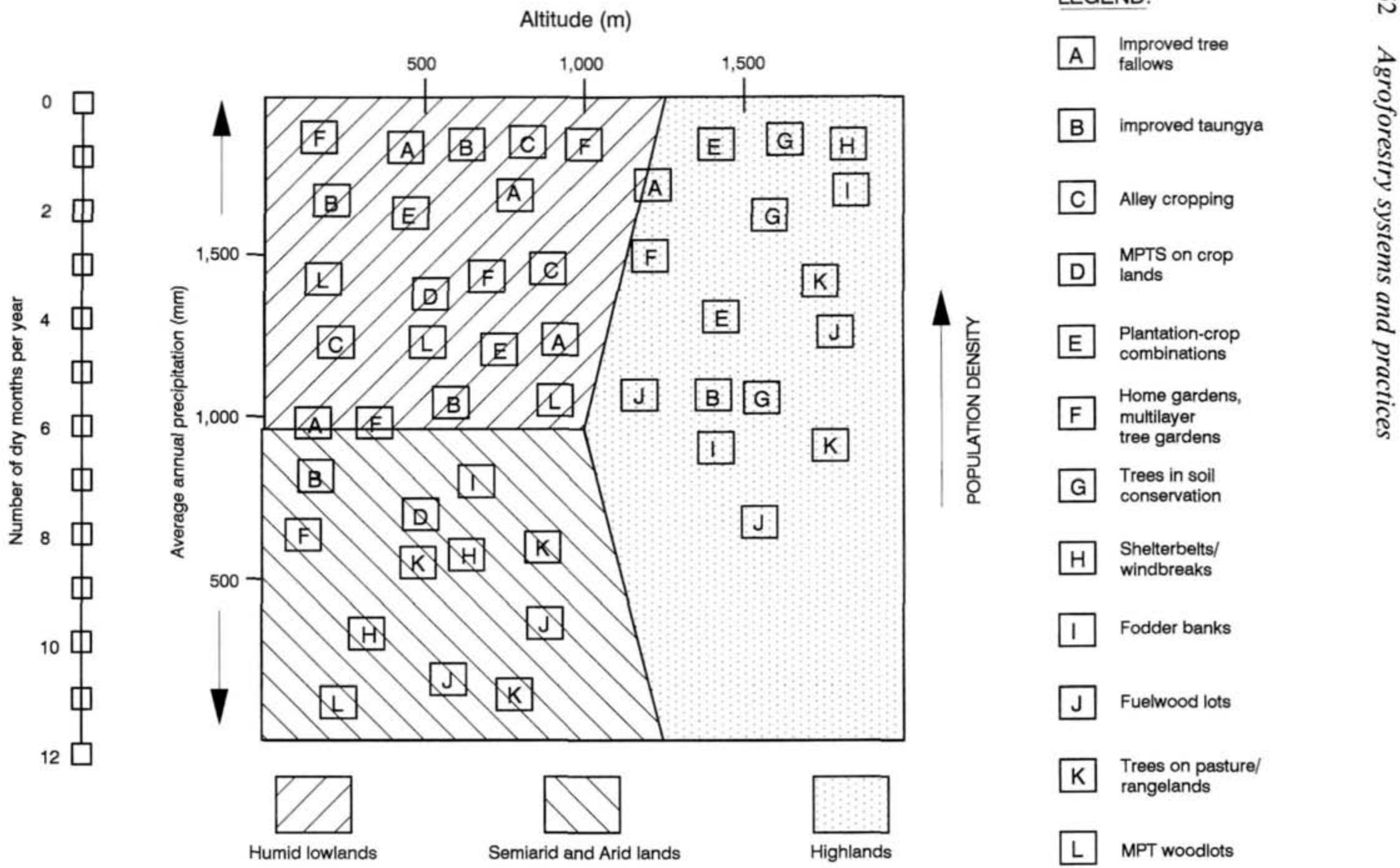

Figure 4.2. An agriforestry/agroecological matrix for the tropics and subtropics.
Source: Nair (1992).

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