Global Distribution of Agroforestry Systems

4

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Abstract

In land-use parlance, the terms tropical and temperate are used loosely as approximate synonyms for *developing countries* and industrialized regions, respectively. From the agroforestry perspective, the arid and semiarid lands, and the subhumid and humid lowlands and highlands recognized in the FAO reports are considered as tropical developing regions and the temperate and Mediterranean regions as industrialized. The types of agroforestry systems (AFS) in these two major regions are different because of their climatic and socioeconomic characteristics. The common systems in the humid and subhumid tropics include forms of shifting cultivation and tree intercropping, homegardens, and shaded perennial associations, whereas various forms of silvopastoral systems, extensive tree intercropping, and windbreaks dominate the agroforestry scene in the semiarid and arid tropics. The major AF practices in the temperate regions include alley cropping, forest farming, silvopasture, riparian buffer, and windbreaks. While a substantial knowledge base and steady markets are available for tree species used in temperate agroforestry, most of the trees and other species used in tropical AFS are underexploited and of unknown nature. The global area under AFS is estimated

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as 1.6 billion hectares, with roughly 78% in the tropics and 22% in the temperate regions; but these are guestimates considering the lack of proper procedures for delineating the extent of areas under irregular stands of trees mixed with understory crops.

4.1 Introduction

Historically, agroforestry was popular in most parts of the tropics. More recently it has also become recognized as a sustainable and promising land-use strategy everywhere including the temperate regions of the world. Geographically, the tropics are located between 23.5 degrees north and south of the Equator, and the temperate region is between the Tropic of Capricorn and the Antarctic Circle in the Southern Hemisphere and between the Tropic of Cancer and the Arctic Circle in the Northern Hemisphere. These geographical definitions, however, are of limited value in discussions on land use; the terms tropical and temperate are used rather loosely and imprecisely while referring to vast areas between the two major zones extending over several degrees of latitude. In this book, the word tropics is used in a general sense to include not only countries and regions within the geographical limits of the tropics but also the subtropical developing countries that have agroecological and socioeconomic characteristics and land-use problems that are comparable to those of the countries within the tropical (geographic) limits. In other words, the word is used, even if erroneously, as a synonym for developing countries. This logic is also used when discussing agroforestry systems in the temperate zone in this chapter and elsewhere in this book (e.g., Chapter 10). The global distribution of the major ecosystems of the world is presented in Figure 12.4 (Chapter 12).

4.2 The Tropical Environment

Readers of this book are expected to 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 the soils, however, is included in Chapter 15. For other details, readers may refer to other relevant books and publications, several of which are available. The current situation on the world environment and resources is updated continuingly on online sources; for example, https://www.globalforestwatch.org/dashboards/global?category=forest-change&treeLossTsc=eyJoaWdobGlnaHRlZCI6ZmFsc2V9 is a website that gives updated information on the extent of deforestation in different regions of the world.

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. Wikipedia defines a tropical climate in the Köppen climate classification as a non-arid climate in which all twelve months have mean temperatures of warmer than 18 °C (64 °F). In tropical climates, there are often only two seasons: wet and dry. Tropical climates are frost-free, and changes in the solar angle are small; the temperature remains relatively constant (hot) throughout the year, and the sunlight is intense. From the agroforestry point of view, the major ecological regions recognized in the FAO State of Food and Agriculture Reports (SOFA: www.fao.org/publications/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 potential. The main characteristics of these ecological regions (humid and subhumid lowlands, dry – semiarid and arid – regions, and highlands) are summarized in Table 4.1.

A special feature of the tropics that is not necessarily a direct consequence of its climate and ecology is the relatively poor economic, social, and developmental status over most of the region. As mentioned earlier, the word tropics is used synonymously with developing

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 Ferrasols) 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 8" 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)

countries. Most nations in the tropics are poor according to the international criteria, with gross domestic product lower than the World Bank's definitions [For the 2019 fiscal year, low-income economies are defined as those with a gross national income (GNI) per capita of $995 or less in 2017; lower-middle-income economies are those with a GNI per capita between $996 and $3,895, and so on: https://blogs.worldbank.org/opendata/new-country-classifications-income-level-2019-2020]. 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. Although the number of people dependent on agriculture has been declining in countries such as India and China and agricultural productivity has shown remarkable increases in many parts of the world, extreme poverty and very low land-productivity levels are characteristic of several countries/regions of the tropics.

4.3 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). Numerous other publications that describe indigenous agroforestry systems, as well as agroforestry applications for special situations, became available, especially during the early decades of the "agroforestry era" (the 1980s and 1990s), and the trend has continued since. Notable among these include *Systemas Agroforestales* (Montagnini 1986), *Agroforesterie et* Desertification (Baumer 1987), *Agroforestry in* Dryland Africa (Rocheleau et al. 1988), *Agroforestry: Classification and Management* (MacDicken and Vergara 1990), *Agroforestry Systems in* China (Zhaohua et al. 1991), *Agroforestry: Principles and Practices* (Jarvis 1991), *Agroforestry in* India (Tejwani 1994), *Agroforestry in Sustainable Agricultural Systems* (Buck et al. 1999), *Tropical Agroforestry* (Huxley 1999), *The Overstory Book* (Elevitch 2004), *Tropical Agroforestry* (Atangana et al. 2014), and *Agroforestry for the Management of* Waterlogged Saline Soils *and Poor-Quality Waters* (Dagar and Minhas 2016). Some of these authors have multiple books on the topic, but only one is listed here. Indeed, most proceedings of various conferences and meetings on agroforestry held since the beginning of the agroforestry era contain descriptions of agroforestry systems. A Google search on Best Books on Agroforestry lists more than 50 titles, not to mention the voluminous journal articles, reports, and so on. The bottom line is that a vast body of literature on tropical agroforestry systems and practices is available today.

A general overview 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.

4.3.1 Lowland Humid and Sub-humid Tropics

Characterized by hot, humid climate (average annual temperature of at least 24 °C 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 the rapid growth of numerous plants, various types of agroforestry plant associations can be found in areas with the high human population. As a result, various forms of homegardens, shaded-perennial crop combinations, and multilayer tree gardens abound 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 and Taungya
- Homegardens
- Shaded perennials
- Various forms of tree intercropping

The lowland humid tropics also include areas under natural rainforests. Historically, in such areas, the cutting of rainforests has exceeded the rates of natural or managed forest regeneration. A related problem was the shortening of fallow periods in the shifting cultivation cycles and the consequential soil productivity decline and accelerated soil erosion (see Chapter 5). The potential of appropriate agroforestry systems to combat these problems needs to be exploited in future land-use strategies in this zone.

Table 4.2 An overview of the common agroforestry systems in different parts of 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, 'Parc Arboreé'			e.g., Paraiso woodlots of Paraguay
Hedgerow intercropping (alley cropping)		Extensive use of *Sesbania grandiflora, Leucaena leucocephala* and *Calliandra calothyrsus*	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
Multipurpose trees and shrubs on farmlands	Mainly fruit or nut trees e.g., *Canarium, Pometia, Pandanus, Barringtonia, Artocarpus altilis*	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 arboreé'	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	Plantation crops and fruit trees; smallholder systems of crop combinations with plantation crops;	Integrated production systems in smallholdings; shade trees in plantations; other crop mixtures	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

(continued)

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
	Leucaena with cacao	plantation crops with spice trees	including various spice trees				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
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 e.g., used extensively	Sesbania, Euphorbia, Syzigium, etc., are 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
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)

4.3.2 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, and several other regions, the semiarid and arid tropics cover about 35% of the tropical and subtropical landscape that is characterized by one or two wet seasons (Köppen Aw or Aw', respectively) and at least one long dry season. Drought, which is a major hazard, and population pressure are the main factors that determine the type of agroforestry systems in this zone. Although homegardens and multilayer tree gardens are found in the wetter areas with high population pressure, the predominant agroforestry systems in this zone are:

- Various forms of silvopastoral systems
- Extensive tree intercropping (e.g., the Parklands of West Africa)
- Windbreaks and shelterbelts
- Multipurpose trees on croplands

Experience with tropical alley cropping that was a major agroforestry research theme during the 1980s and 1990s was not promising in the semiarid tropics (see Chapter 6). This has led to some serious but misconstrued criticisms being leveled against agroforestry in general for these regions. The criticisms were based on the classic "one-size-fits-all" misconception of equating alleycropping with agroforestry without recognizing that no single land-use practice (be it in the broad realm of agroforestry or agriculture) fits all ecological regions. Indeed, some of the best-known agroforestry systems are found in the semiarid tropics – for example, extensive intercropping of millets under *Faidherbia (Acacia) albida* trees in Africa (the Parklands system of West Africa: Boffa 1999), and under the "khejri" (*Prosopis cineraria*) trees in the dry areas of India (Shankarnarayan et al. 1987). Agroforestry systems are also commonly used for addressing other major land-use problems of the region such as fuelwood shortage and desertification.

4.3.3 Tropical Highlands

Approximately 20% of the tropical lands are at elevations from 900 – 1800 m. These areas include 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, Cameroon, the Deccan Plateau of India, and some parts of the southeast Asian mainland. The altitude exceeds 1800 m in about 3% of the tropical area in the Andes, the Ethiopian and Kenyan Highlands, northern Myanmar, 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 agricultural potential. Land-use problems in the highlands are comparable 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 shaded perennial (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.

The major types of agroforestry system subgroups are summarized in Table 4.3.

Table 4.3 Global distribution and area under different agroforestry system sub-groups†

AFS sub-group	Major AF Practices	Distribution (major agro-ecol./geographical regions) ‡		Approx. area (million ha) ‡	
		Tropical	Temperate	Tropical	Temperate
Multistrata systems	Homegardens	Humid: wet, moist, and montane (rainfall >1000 mm yr^{-1})		100	
	Shaded perennials		Forest farming		
Tree intercropping	Alley cropping	Rainfall > 800 mm yr^{-1}	N. America, Europe	50	50
	Trees on farmlands	Throughout tropics	N. America, Europe	550	50
Silvopasture	Cut-and –carry and browsing	Wet and moist; rainfall >1000 mm yr^{-1}		300	150
	Grazing under trees	Semiarid to arid	N. America, Europe, subtropical highlands		
Protective systems	Windbreaks, shelterbelts	Semiarid and arid lands; coastal areas	N. America, Europe, China	200	100
	Soil conservation hedges	Sloping lands in higher rainfall areas	N. America (Riparian buffer strips)		
	Boundary planting	Throughout	Windbreaks		
Agroforestry woodlots	Firewood and fodder	Drylands		50	
	Land reclamation	Degraded lands (eroded, salt-affected)			
TOTAL				1,250	350

†Estimates based on the reported values in literature
‡Including potential areas for adoption
Source: Nair (2012, 2014)

4.4 Agroecological Spread of Tropical Agroforestry Systems

The type of agroforestry system found in any location is determined to a major extent by agro-ecological factors. Socioeconomic factors such as human population pressure, availability of labor, and proximity to markets are also important determinants, such that considerable variations can be found among systems existing in similar or identical agroclimatic conditions. Sometimes socioeconomic factors take precedence over ecological factors in determining the appropriate type of agroforestry practices for a region. Even in the case of systems that are found in many ecological and geographical regions, numerous variants are specific to certain socioeconomic contexts. In general, it can be said that while ecological factors determine the major type of agroforestry system in a locality, 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). Fernandes and Nair (1986) found in an analysis of the structural and functional aspects of 10 homegarden systems in different ecological regions that although the average size of a homegarden unit is less than 0.5 ha, it generally consists of numerous woody and herbaceous species. The garden is carefully structured so that the canopies of the different species are oriented in three to five layers at varying heights, with each component having a specific place within the overall design.

Agroecological factors have a considerable bearing on the functional dynamics 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 to 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, 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). Caution must be exercised, however, 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. Innumerable location-specific agroforestry systems exist 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 are 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 the design of agroforestry systems, the underlying concept being that areas with similar ecological conditions can have structurally similar agroforestry systems. This strategy is used by development agencies for designing various agroforestry research networks on a national/regional basis (see, for example, Nair 1992). Such matrices of agroecological conditions versus agroforestry practices could be developed for any region, although 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 into simple models. Knowledge-engineering applications such as Decision Support Systems have been attempted (e.g., Warkentin et al. 1990; Ellis et al. 2004; Moser and Bentrup 2017), but do not seem to have made any significant progress in tropical applications.

4.5 The Temperate Environment and Land Use Systems

Areas with temperate climate have large temperature extremes during the year; they have cold winters and warm rainy seasons. While the northern portions of the temperate region feature Boreal, Continental, and Oceanic climates, the lower latitudes have Mediterranean and subtropical climates. A basic definition encompassing all these different climates is that the temperate zone has a mean temperature in the range of −3 °C to 18 °C in the coldest month. The winter temperatures will be milder in lower latitudes in both northern and southern hemispheres (nearer the equator) and colder in the higher latitudes.

From the agroforestry – and agricultural – standpoint, the distinction between tropical and temperate zones, especially in the borderline areas in both hemispheres is based not strictly on climatic or geographical factors, but a combination of factors including socioeconomic conditions and developmental status of the regions. As mentioned in Section 4.2, tropical regions are generally in the lower strata of economic development and industrialization, and most countries of the tropics are the so-called developing nations, as opposed to industrialized

North America, Europe, and the other so-called developed nations. Temperatures and vegetation in most subtropical zones can be somewhat comparable to those of the tropics for much of the year, and the practice of agroforestry in the subtropical parts of developing countries (e.g., of the Indian subcontinent) are comparable to that of the tropical than the temperate regions. For these reasons, temperate agroforestry refers to agroforestry practiced in the temperate regions of the world generally between latitudes 30° and 60°. The USA and Canada, Europe, southern Australia, and New Zealand constitute the main temperate countries/regions from the agroforestry perspective.

4.6 Temperate Agroforestry Practices

Developments in agroforestry applications have taken place in a rather simultaneous and parallel manner in both the major temperate-zone continents of North America (the USA and Canada) and Europe since around the 1990s. Europe, with its long history of land use practices and traditions, had some agroforestry-like practices right from the Roman times until the onset of industrial agriculture during the post-World War II (Eichhorn et al. 2006). In the USA and Canada, however, there was no such historic precedent, and agroforestry is considered a new science and set of practices tailored to address numerous sustainability issues associated with production agriculture (Gold and Garrett 2009).

According to the agroforestry system classification based on nature and arrangement of components explained in Chapter 3, the two most common types of temperate-zone systems have been the agrisilvicultural use of windbreaks and riparian buffers for soil protection and environmental amelioration, and silvopastoral practices with livestock in different woodland and range ecosystems. Agrisilvicultural combinations of nut- or fruit trees and herbaceous crops are also common. Agroforestry systems in the temperate zones, however, are not classified according to component-based classification scheme; instead, the practices are grouped under a few distinct categories as mentioned in Chapter 3 (Tables 3.3 and 3.4). Although there are remarkable similarities between the North American and European agroforestry practices of the same names (such as alleycropping, silvopasture, windbreaks, etc.), some minor differences exist, which arise primarily from the location specificity of the practices. There is also one practice in the list of European agroforestry practices called kitchen garden or homegarden, an equivalent for which does not exist in the US and Canada literature.

4.7 Temperate vs. Tropical Agroforestry

The seasonality of climate in the temperate regions that includes distinct warm and cold seasons engenders some unique agroforestry qualities. In the tropics, the same crops may be produced throughout the year, whereas individual crops in the temperate zone are generally restricted to one or rarely two seasons a year and fewer crops are grown each year. Therefore, unlike the great variety of systems and practices in the tropics, only a few agroforestry systems are practiced in the temperate region. Socioeconomic conditions in the developed countries of the temperate zone have strongly influenced land-use practices such that the production objectives and outlook of temperate agroforestry practitioners are quite different from those of the tropics. Although small farms were historically dominant in the temperate zone, and still are in many regions, there has been a significant trend in the 20th century towards large, family, corporate, or communal farms where production is largely concentrated on a few crops for local and distant markets. Agroforestry applications on such farms have often focused on one or two high-value crops and include high levels of mechanization. Combinations of trees and agriculture are opportunistically perceived as a strategy for improving economic profitability. This is in sharp contrast to the tropical practices that are

most frequently found on small individual farms or sharecropped and community lands where production is often for subsistence consumption or local markets and a large variety of crops are both available and necessary in most family settings. The major motivation for adopting agroforestry in the temperate zone is the increasing realization of the environmental benefits offered by the presence of trees on agricultural lands such as protection of soil- and water quality, climate change mitigation, and biodiversity conservation. In the tropical settings where food security is the primary concern, such environmental benefits, although appreciated, are seldom the top priority for the smallholder farmers. These contrasts between the tropical and temperate agroforestry systems in terms of their focus on addressing the "top ten" land-use challenges are presented in Figure 4.1.

Another significant attribute of temperate-zone agroforestry is that a substantial knowledge base is available and market values have been established for the components used (trees, crops, animals) especially for trees. Research in the region over more than a century has provided information on genetic variability, physiological characteristics, and cultural requirements for a wide variety of species, many of which have also been important in wood products markets. Thus, the detailed information base and dependable markets are strong incentives for incorporating many temperate species in agroforestry systems, as opposed to the underexploited and unknown nature of species and lack of market and other support services that are so characteristic of tropical agroforestry systems.

4.8 Geographical Distribution and Area Under Agroforestry Systems

Estimating the area under agroforestry on a farm is a challenge because of the lack of clarity and proper procedures for delineating the area influenced by trees in a mixed stand of trees and crops (Nair et al. 2009). In simultaneous systems, the entire area occupied by multistrata systems such as homegardens and shaded perennial systems and intensive tree-intercropping situations can be listed as agroforestry. However, many agroforestry systems are rather extensive where the components, especially trees, are not planted at regular spacing or density; for example, the parkland system and extensive silvopasture. Such situations exist also in Europe and other temperate regions where mosaics of intensive field systems, with hedgerows and patches of woodland, are common features of agricultural landscapes. The problem of estimating the area under agroforestry is more difficult in the case of practices such as windbreaks and boundary planting where the trees are planted at wide distances between rows (windbreaks) or around agricultural or pastoral parcels (boundary planting), and the influence of trees both above and below ground

Figure 4.1 Agroforestry and the top ten land-use challenges

extends beyond the visible area of influence of the trees. For windbreaks, the rule of thumb is that the area protected from wind erosion extends laterally to 10 times the height (H) of trees in the central core of windbreaks (see Chapter 18). The problem has a different dimension when it comes to sequential tropical systems such as improved fallows and shifting cultivation. In such situations, the beneficial effect of trees and other woody vegetation (in the fallow phase) on the crops that follow them (in the cropping phase) is believed to last for a variable length of time (years). Despite these temporal and spatial issues, an ICRAF survey using high-resolution remote-sensing quantified the areas of agricultural landscapes with at least 10% tree cover worldwide as nearly a billion hectares in the tropics (Zomer et al. 2009). Zomer et al. (2016) estimated that the area of agricultural land with at least 10% tree cover – currently 43% of all agricultural land – had increased by 2% during the previous 10 years globally. The area under agroforestry in Europe is currently estimated at about 20 million ha (Mosquero-Losada et al. 2012; AGFORWARD 2017). The potential area available for agroforestry in the United States is estimated as 143.7 million ha (Jose et al. 2012); although such area estimates are not available for Canada, windbreaks and shelterbelts are reported as the most widespread agroforestry practice extending over 200,000 km in the Prairie Region and 10,000 km in Quebec Region (Thevathasan et al. 2012). Based on these estimates and considering the prevalence of agroforestry practices in non-agricultural lands, Nair (2012, 2014) estimated the global area under agroforestry as 1.6 billion ha. This is, however, an estimate; no matter how experience-based, it is still a guesstimate!

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