9 Silvopastoral Systems (SPS) in the Tropics and Subtropics

Contents

Abstract

Silvopasture is a broad term encompassing different forms of integrating trees, forage, and domesticated animals on the same unit of land. The practice ranges from the traditional, extensive animal grazing under woodlots and forests to modernized intensive forms of tree–animal integration. These can broadly be grouped under two categories: grazing system where cattle graze on pasture under scattered or systematically planted stands of trees; and the browsing (tree-fodder) systems, in which the animals are usually stall-fed with fodder from trees or shrubs grown on farms and farm boundaries. Most silvopasture systems (SPS) in Africa, South Asia, and other developing regions of the world involve extensive open grazing by free-roaming animals under natural stands of trees and shrubs. Major examples are found in the so-called Parklands of sub-Saharan Africa, the Brazilian *Cerrado* (wet savanna) and *Caatinga* (dry savanna) biomes, and the arid and semiarid lands of the Indian subcontinent. The browsing systems of small-

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scale dairy farming involving cut-and-carry fodder from fodder banks and boundary plantings are a popular and traditional means of livelihood strategy and income generation in rural households. The integrated crop-livestock-forestry system is a relatively new form of silvopastoral activity organized on a commercial scale in Brazil and some other parts of Latin America. Research on SPS in the tropics and subtropics has so far been more exploratory than experimental, with emphasis on understanding and documenting the existing situation. Thus, the literature on tropical SPS is dominated by conventional system descriptions, reports on species inventory and evaluations, nutritive values of indigenous tree fodder, and sociocultural narratives of the people and their traditions.

9.1 Introduction

Silvopasture is the agroforestry practice of integrating trees, forage, and livestock on the same land-management unit. The age-old practice of forest grazing (grazing under woodlots and forests by domestic animals) is considered the earliest example of the integration of trees and pasture for livestock production. Although the improvements in such traditional practices in the tropics over time have been relatively few, commercial silvopasture involving improved forage species (grasses and legumes) and tree-planting-and management operations based on research results has made impressive progress in several temperate countries and some tropical and subtropical regions during the past few decades. Thus, as in the case of most other types of land-use systems, silvopasture is practiced at varying levels of management intensity and technical input, ranging from extensive, often uncontrolled grazing systems in open lands and forests to high-intensity tree + animal management systems. Generally, the former type of low-input management and extensive grazing predominates in the resource-poor tropical and subtropical conditions, and the high-intensity management systems in the industrialized countries. Today, silvopasture is a broad term encompassing different variants of this traditional practice as well as vastly modernized forms of the tree–animal integration. Following a brief narrative of some general characteristics that are common to all forms of silvopastoral systems (SPS), this chapter will focus on tropical and subtropical SPS that are mostly noncommercial operations (except for the commercial SPS in Brazil and southern parts of South America). Salient aspects of commercial SPS in industrialized regions will be presented in Chapter 10 (Temperate Agroforestry Systems).

9.2 Tropical and Subtropical SPS: An Introduction

In many developing regions of Asia, Africa, and parts of Latin America, domestic animals that produce milk and meat and provide draft power for farm operations are an essential component of the farming system and livelihood strategy. In those conditions, a farm family's wealth is often expressed in terms of not only the area and productive capacity of the farmland but also the size and composition of its animal herd (Figure 9.1). Various types of trees and shrubs are a major source of animal feed in such situations. For example, India has a cattle population of 186 million, 12.65% of the world's total (FAO 2017), a vast majority of which depend on fodder from trees and shrubs grown mostly on farmlands and farm boundaries (Figure 9.2). It is also well recognized that uncontrolled grazing in forests and communal lands has caused severe soil erosion and ecosystem degradation around the world. On the other hand, the well-designed and properly executed commercial silvopasture operations of today provide enhanced soil protection and other forms of environmental benefits and increased long-term income from the simultaneous production of trees and animals. In such situations, the trees provide shelter for animals and can boost understory herbage production by adding nutrients – especially nitrogen – to the soil and enhance soil carbon storage; and typically,

Figure 9.1 Cattle are an essential component of farming systems and a symbol of wealth in many traditional societies. (Photo: PKR Nair 1997, Chhattisgarh, India)

Figure 9.2 Trees are a source of animal fodder in dry regions around the tropics: camels grazing on *Prosopis cineraria* trees in Rajasthan, India. (Photo: PKR Nair 1985).

the trees are selectively harvested for their wood or used to produce other products.

According to FAO statistics (FAO 2017), grasslands extend over about 3 billion hectares globally with roughly two-thirds in the tropics and one-third in the temperate regions; silvopasture is a major land-use system in about 450 million hectares and has the potential to be extended over larger areas. Besides the traditional forest grazing around the world, numerous forms of combined production of trees and animals from the same land management unit have been followed in many parts of the tropics for a long time. These include intimate integration of multipurpose trees and shrubs – some of which sprout back (coppice) vigorously after pruning – that produce nutrient-rich tree fodder with other production components of the complex farming system for feeding small herds of milk-producing farm animals reared in homegardens and other smallholder farms. Such integrated production systems are important components of livelihood strategies of countless numbers of resource-poor farmers but are seldom recognized, let alone appreciated, as SPS.

9.3 Common Forms and Terms of Silvopasture

Silvopasture being a traditional practice with a long history, it is only natural that various forms of the practice and location-specific terms and operations are prevalent in different places. Nevertheless, all forms of silvopasture can broadly be grouped under two categories: grazing systems and tree-fodder systems. In the grazing systems, cattle graze on pasture under scattered stands of trees or widely spaced – mostly planted – trees (Figures 9.3 and 9.4). In the tree-fodder systems, the animals are either stall-fed with fodder from trees or shrubs grown on farms and farm boundaries or are let to do controlled browsing of such trees (Nair 1993; Nair et al. 2008). The underlying principle and motivations of all such practices, however, are common. The principle is that multispecies combinations could result in better utilization of natural resources of solar energy, soil, and water. The motivations for adopting the practice are financial and opportunistic: more production leads to better economic

Figure 9.3 Livestock grazing under natural stands of trees is a common land-use system in many dry regions of the world especially in the tropics and subtropics. (Photo: ICRAF/World Agroforestry)

Figure 9.4 Livestock grazing under natural stands of trees, Niger. (Photo: ICRAF/World Agroforestry; http://blog.worldagroforestry.org/wp-content/uploads/2014/01/parklands-Niger-FAO.jpg)

returns, and it makes perfect sense to make use of the available opportunities.

While the grazing system is practiced throughout the world, the browsing (tree-fodder) system is a common feature of the smallholder farming practice in the tropical regions as mentioned above, and virtually non-existent in the industrialized regions. Consequent to the realization in the 1970s and 1980s that the need for fodder (as well as fuelwood and small timber) was a major reason for tropical deforestation, the tree-fodder system received considerable scientific attention during the early stages of agroforestry development. That led to the recognition, for the first time, of the importance of fodder trees in animal agriculture and thus agroforestry. The grazing form of silvopasture, however, is the most common and widely practiced agroforestry system in the industrialized regions, and it has gained added prominence, thanks to the relatively higher research support, since the turn of the 1990s (see Chapter 10). Furthermore, with the recent emphasis on the environmental impact of land-use systems, the role of silvopasture and other agroforestry practices in mitigating climate change through carbon (C) sequestration has been a major area of research focus (see Chapter 20). Additional benefits of silvopasture include water quality improvement (Michel et al. 2007), soil conservation, aesthetics, and providing shade to cattle. Thus, silvopasture is considered highly compatible with traditional ranching and includes several elements of best management practices for ranchers in North America (Garrett 2009).

Most silvopasture systems in Africa, South Asia, and other developing regions of the world involve extensive open grazing by free-roaming animals under scattered natural stands of trees and shrubs mostly in semiarid to arid areas. A typical example is the so-called Parklands of sub-

Saharan Africa (Section 9.4.2). More intensive and controlled grazing systems of silvopasture are practiced in Latin America where animals are penned in parcels of land with barbed-wired living-fence, and grazing is regulated (Somarriba et al. 2012). Such organized SPS are popular in the extensive Cerrado region of Brazil, too (Nair et al. 2011). Open grazing by free-roaming animals, however, is still common in many arid and semiarid regions of the world, such as the Caatinga region of Brazil (Pinheiro and Nair 2018) and dry parts of India (Tejwani 1994). Cattle grazing under coconuts and other plantation crops is a traditional silvopastoral practice that is still followed in Asia and Oceania (Chapter 8, Section 8.6). The most labor-intensive SPS is the stall feeding of animals by fodder from trees grown elsewhere, which is a common practice in smallholder farming systems of South Asia and Africa (Kiptot and Franzel 2012); these are described in some detail in Section 9.5. Some of the common noncommercial SPS around the world are described briefly in the following sections.

9.4 Common Silvopastoral Grazing Systems in the Drylands

Drylands consisting of hyper-arid, arid, semiarid, and dry subhumid categories of the aridity index† classification, occupy about 60 million km^2 or more than 40% of the earth's land area [†Aridity index is a numerical indicator of the degree of dryness of the climate at a given location for characterizing regions that suffer from a deficit of available water for effective use of the land for agriculture (https://en.wikipedia.org/wiki/Aridity_index)]. Out of the 2 billion inhabitants of the drylands, about 90% live in developing countries and are relatively more dependent on natural resources than other groups of populations. Tropical drylands are more exposed than other ecological regions to the threat of environmental degradation, with vast areas, estimated as 6 million to 12 million km^2, affected by desertification, reducing their capacity to sustain human livelihoods (MEA 2005). Agrosilvopastoral systems consisting of intercropping under scattered trees with various food crops during the usually short rainy seasons and animal rearing through extensive, often free-roaming, grazing during long dry seasons are the most common land-use system in these areas. The types of systems and their species composition and management operations vary in different places according to local traditions and ecoclimatic conditions. General features of these dryland SPS in arid and semiarid parts of three major geographical regions (West Africa, Northeast Brazil, and Western and Central India) are presented here.

9.4.1 The Parkland System of West Africa

The Agroforestry Parklands, commonly known as the Parklands, constitute the predominant agroforestry system in semiarid West Africa and some other parts of sub-Saharan Africa. Included in the general category of "multipurpose trees on farmlands" in ICRAF's Agroforestry Systems Inventory (Nair 1985) and known by various names such as tree savanna, savanna parkland, and *parcs arborés*, the term refers to the traditional system where various multipurpose trees are planted or protected and nurtured on cropping and grazing lands (Boffa 1999). Parkland attributes include a regular distribution of relatively even-aged trees or shrubs and a low tree density with discontinuous tree cover (Figures 9.5, 9.6 and 9.7). The name Parkland is derived from the resemblance to urban or rural recreational parks with large scattered trees over expanses of grass. Although the system is prevalent predominantly in the vast semiarid regions of West Africa, it is also found in the Sudan zones as well as in southern Africa (Botswana, Malawi, and Zimbabwe). Several variants of the practice are found in different countries, but they all represent agrosilvopastoral intercropping systems under a stand of scattered trees. Except when the land is under food crops grown during the short rainy seasons (3–4 months a year), animal grazing – usually uncontrolled open grazing – is the practice during the ensuing long, hot, dry season.

Figure 9.5 Scattered stands of trees, called parklands, are a common feature of the drylands of sub-Saharan Africa, especially in West Africa (see Chapter 5). The photo, from Mali, shows a typical stand of *Faidherbia albida* trees in the dry season when the trees have green foliage when all the other vegetation is dry. (Photo: ICRAF/World Agroforestry)

Figure 9.6 West African parklands (see also Chapter 5). (Photo: ICRAF/World Agroforestry; http://old.worldagroforestry.org/wadrylands/images/sahelianParkland.jpg)

Figure 9.7. A stand of *Faidherbia albida* trees with new foliage that starts appearing at the beginning of the dry season. See also Figures 5.10 and 5.11

Depending on the seasons, the vast landscapes will look very different during the rainy (cropping) and dry (grazing) seasons: lush green foliage of crops under scattered stands of trees during the former and extremely dry scenes with very little vegetation during the latter. The contrast is more striking with the *Faidherbia albida* trees that have the remarkable phenology of the trees losing leaves in the rainy season (Figures 9.8 to 9.10) and being covered fully with a canopy of leaves during the dry season when everything else is dry and brown. The common trees in the parklands (Table 9.2) are included in the MPT species profiles of Chapter 13, Annexure 13-I). The trees are seldom planted but sustained by natural regeneration. The comprehensive account of the Parkland system by Boffa (1999) published as FAO Conservation Guide number 34 is still an authoritative and widely quoted reference manual.

Agroforestry parklands are also a major source of wood and nonwood products, which provide significant household income that is very important for the local economies. Shea butter from the nuts of the shea tree (*Vitellaria paradoxa*), a common tree in the parklands (Figure 9.11), for example, has gained considerable importance lately with excellent export earning potential for several nations in the Sahel. On the other hand, the decline in the trade of gum arabic produced from *Acacia senegal* (Figure 13.A.I.3: Chapter 13, Appendix I) a major component of the parklands in the Sudano-Sahelian zone, has seriously impacted the national economies of the countries of the region. In some places in West Africa, agroforestry parklands account for up to 75 percent of total harvests of wood and non-wood products (Boffa 1999). Parkland resources are of considerable social and cultural significance too. Specific social groups, including women and the poor, tend to be particularly involved in the gathering and sometimes the processing of parkland products.

Although frequently dominated by just one or a few species, the parklands have contributed to the maintenance of numerous species. Scattered trees also fulfill fundamental ecological functions in soil and water conservation and environmental protection. Most of the agricultural production in the Sahel where there are settled populations occurs under the discontinuous cover of parkland trees. In several instances in arid and semiarid

Figure 9.8 The *Faidherbia albida* tree that is common in the West African Sahel has a unique phenology: it is leafless during the rainy season, which allows farmers to grow a variety of crops under or between the trees. The photo shows a leafless tree with a crop of cotton underneath in Mali. (Photo: PKR Nair)

Figure 9.9 Cattle seek shade and shelter under the canopy of *Faidherbia* (syn. *Acacia*) albida trees that have foliage during the extremely hot and dry season in the drylands of sub-Saharan Africa. (Photo: ICRAF/World Agroforestry)

regions, the *screen function* of trees is also evident. Human beings and livestock seek shade during mid-day when outside temperatures soar to more than 40 °C. In the degraded rangelands of the arid and semiarid regions, herbage yields under shade are usually much higher (up to twice or more) than that in the open, and the grass remains greener for 4 to 6 weeks more at the end of the rainy reason. The reason is that the intensity of solar radiation and wind speed is reduced in the tree+grass system compared to the open systems (sole grass), which in turn, reduces the potential evapotranspiration (PET) losses. Experimental studies in the semi-arid region of Botswana (southern Africa) showed that under the canopy of trees such as weeping wattle (*Peltophorum africana*), umbrella thorn acacia (*Acacia tortilis*), and raisin bush (*Grewia*

Figure 9.10 A "poster photo" of agroforestry showing maize under *Faidherbia albida* that is leafless during the rainy (crop-growing) season. (Photo: ICRAF/World Agroforestry)

Figure 9.11 *Vitellaria paradoxa*, the shea butter tree, is another common tree in the Agroforestry parklands of West Africa. (Photo: ICRAF/World Agroforestry)

flava), solar radiation and wind speed were reduced by about 50% and PET by about 70%, compared to the adjacent open area (Houerou 1987). Thus, the agroforestry parkland system is of considerable economic, ecological, and socio-cultural importance for the entire Sahelian region and the semi-arid southern Africa.

9.4.2 SPS in the Semiarid Brazilian Tropics

The Cerrado. Savannas are a major component of the world's vegetation, covering one-sixth of the land surface and accounting for 30% of the primary production of all terrestrial vegetation (Grace et al. 2006). The Brazilian savanna, known as the *Cerrado*, occurs mainly in the central Brazilian states and extends over 200 million ha (Batlle-Bayer et al. 2010). The Cerrado is a wet savanna consisting of a gradient of physiognomies from grassland (called "*campo limpo*") to a sclerophyllous (sclerophyll = a woody plant with hard evergreen leaves and short internodes) forest (*Cerradão*), with over 10,000 species of plants, of which 45% are unique. The region's typical climate is hot, semi-humid, with pronounced seasonality marked by a dry winter season from May through October. The annual rainfall ranging from 1200 to 2000 mm occurs during the summer (known, rightly, as the rainy) season between October and April, and the mean annual temperature varies from 22 °C in the south to 27 °C in the north. The Cerrado trees have characteristic twisted trunks covered by a thick bark and leaves that are usually broad and rigid.

The region has been the focus of intense agricultural expansion since the 1960s, and a large area of native vegetation has been replaced by agriculture, pastures, and planted forests (EMBRAPA CERRADO 1999; The Economist 2010 (http://www.economist.com/node/16886442). Cultivated pasture areas, estimated to range from 35 million to 50 million ha (Sano et al. 2000), account for the largest agricultural expansion, mostly with the introduction of the African grass of the genus *Brachiaria*. Most of these cultivated pastures have, however, experienced some degree of degradation; they have lost, to varying extents, their capacity to produce biomass due to deterioration of soil chemical, physical and biological conditions. Various types of landholdings and producers can be found in the Cerrado biome, ranging from large farms with areas of more than 20,000 ha and a variety of crop fields or cattle, to a large number of "small" farms with areas less than 100 ha. Large tracts of the Cerrado have also been planted to fast-growing trees, especially eucalyptus hybrids (*Eucalyptus* spp.) and pines (*Pinus* spp.), which account for roughly two-thirds and one-third, respectively, of the approximately 5.5 million ha of planted forests in Brazil (ABRAF 2008). Most of these plantations were established on small farmlands that used to raise cattle. This new development, motivated primarily by its monetary advantages, has brought up two major issues: the introduction of non-native tree species in the biome, and the decline – if not elimination – of the traditional activity of cattle raising. Integrating cattle and trees as in silvopastoral systems offers the advantages of monetary benefits from planted forests and supports traditional cattle rearing. Additionally, there are advantages via soil carbon sequestration (see Chapter 20).

Silvopastoral systems in the Cerrado are mostly of the commercial type. First established in the Minas Gerais State in the late 1900s, the area under the practice has been increasing steadily since and has extended to other areas of the Cerrado, mainly in the state of Mato Grosso do Sul. It is perceived (Dubé et al. 2000) that the establishment of silvopastoral systems can reduce the cost of establishment of the whole (beef + timber) system; furthermore, the additional income derived from the crops would be an economic incentive to tree-plantation owners during the early years of plantation establishment. The system is established by cultivating one or two annual crops in rows in between the widely-spaced tree rows Eucalyptus (hybrid), the most common tree used in the system, is planted at varying row spacings, the most common being 10 x 4 m or 8 x 4 m (Figures 9.12 and 9.13). Tree

Figure 9.12 Commercial silvopastoral systems, using *Eucalyptus* hybrids, have become popular in the semiarid Cerrado region of Brazil and elsewhere in Latin America. (Photo: PKR Nair 2008)

Figure 9.13 The most common grass species used in commercial silvopastoral systems in Brazil, as shown in Figure 9.12 is *Brachiaria brizantha*. After establishing eucalyptus, crops such as rice (*Oryza sativa*) and soybean (*Glycine max*) are cultivated in the first and second year, respectively. In the third year, seeds of *B. brizantha* is sown to constitute the understory. Sixty days after sowing the grass seeds, beef cattle are stocked in the area for grazing. (Photo: PKR Nair 2008)

rows are usually aligned in the east-west orientation to allow the highest extent of light availability to the understory grass between trees. Most planters limit the soil preparation for the silvopastoral establishment to the minimum, mainly spot application of herbicides to kill weeds in the rows where the trees would be planted. This minimum soil preparation is important to avoid soil disturbance and oxidation of soil organic matter. Soil moisture availability and mild temperature under trees create better conditions for mineralization of nitrogen which contributes to improving and extending the forage quality in the dry season. Crops such as rice (*Oryza sativa*) and soybean (*Glycine max*) are cultivated in the first and second year, respectively, after establishing eucalyptus. In the third year, seeds of the grass *Brachiaria brizantha* is sown to constitute the understory. Sixty days after sowing the grass seeds, beef cattle are stocked in the area for grazing. Several research studies on management aspects of the system such as planting configuration and stand density of trees and the use of forage legumes as a means to reducing nitrogen fertilizer application have been reported (Silva 2008; Nair et al. 2010; Tonucci et al. 2011).

The Caatinga Biome of Northeast Brazil. Extending over about 850,000 km^2 in ten states and located between 3° to 17° S, and 35° to 45° W (IBGE 2004), the Caatinga has some of the most complex bio-climatological features. The rainfall is highly erratic varying in the range of 260–800 mm per year; the rainy season lasts 3 to 5 months, and severe droughts lasting 3 to 5 years occur every three or four decades (Fernandes 2003). For the inhabitants of the region (more than 25 million), the main livelihood options are livestock and crop production. The most common vegetation includes trees and shrubs belonging to the botanical families Cactaceae, Caesalpinaceae, Mimosaceae, Euphorbiaceae, and Fabaceae, the major genera being *Senna*, *Mimosa,* and *Pithecellobium*. The most common woody species are *Amburana cearensis*, *Anadenanthera colubrina*, *Aspidosperma pyrifolium*, *Caesalpinia pyramidalis*, *Croton* spp., *Commiphora leptophloeos*, and *Mimosa* spp. Examples of fodder trees retained by farmers in the Caatinga include: *Bauhinia forficata, Caesalpinia ferrea*, and *Mimosa caesalpiniaefolia* (Prado 2003). Overgrazing and intense firewood gathering account for about 45% of deforestation and desertification in many parts of the region (MMA 2007, 2011). Pinheiro and Nair (2018) suggested opening up the overstory canopy, coppicing to facilitate the production of fresh and abundant forage for animals, enrichment planting with desirable tree and understory species, and introduction of unconventional feed sources such as cactus (*Opuntia ficus-indica)* as the opportunities for enhancing the low carrying capacity of the Caatinga region.

9.4.3 SPS in the Arid and Semiarid Parts of India

As mentioned in the introductory paragraph of this chapter, India has a large cattle population, estimated as 186 million or 12.65% of the world total according to FAO Statistics 2018 (Section 9.2 of this chapter). The Government of India statistics (BAHS 2017) estimate the total livestock (cattle, buffalo, goats, etc.) population of the country as 512 million including 190 million cattle. Estimates about the area under silvopasture in India also vary, because different forms of SPS are practiced on lands categorized as under agriculture, forestry, range management, etc. The vast majority of the animals are maintained in subsistence, low-input grazing systems on permanent pastures and other grazing lands, mostly under scattered trees. Although climatically the country is predominantly tropical and subtropical, some temperate meadows and pastures occur at elevations above 2000 m in the eastern and western Himalayan regions.

Trees and shrubs are an integral part of most grazing lands in India, and they support animal production both directly through the provision of fodder and shade and indirectly through maintenance of soil quality and protection. Thus, most grazing systems in India are examples of silvopastoralism. Several variants of the practice exist;

Tejwani (1994) classified them into two broad categories: Pastoral silviculture and Silvopastoral practices. The former includes grazing lands with scattered trees with animal grazing as the principal activity; the types of grasses and trees vary with regional agroecological conditions. Some of the well-known examples are the grassland and tree management systems in the arid region in and adjoining the state of Rajasthan (Figure 9.14) and the Deccan plateau (Figure 9.15). The other category, silvopastoral practices, involves lopping of trees and feeding the foliage to animals as well as grazing on the understory grasses and bushes in forestlands or plantations across the country. Nomadic pastoralism, a traditional form of human-livestock-grassland interaction, is also practiced in the drylands of western India, the Deccan Plateau, and in the mountainous reaches of the Himalayas (Roy and Singh 2013). Grazing or harvesting of forage crops grown in association with planted trees constitutes another subset of silvopastoralism. The differences between the two categories (Pastoral silviculture and Silvopastoral practices), however, are not rigid and the terms are often used synonymously. Considering the geographical diversity and vastness of India, it is only natural that numerous types of tree- and grass species occur in different agroecological regions of the country. The Indian agroforestry literature is also replete with details of the production potentials of a wide array of tree+grass combinations under varying ecoclimatic conditions (Figure 9.16).

In the arid rangelands in the western part of the country in and adjoining Rajasthan, farmers have been practicing traditional farming systems in which domesticated livestock are integrated with

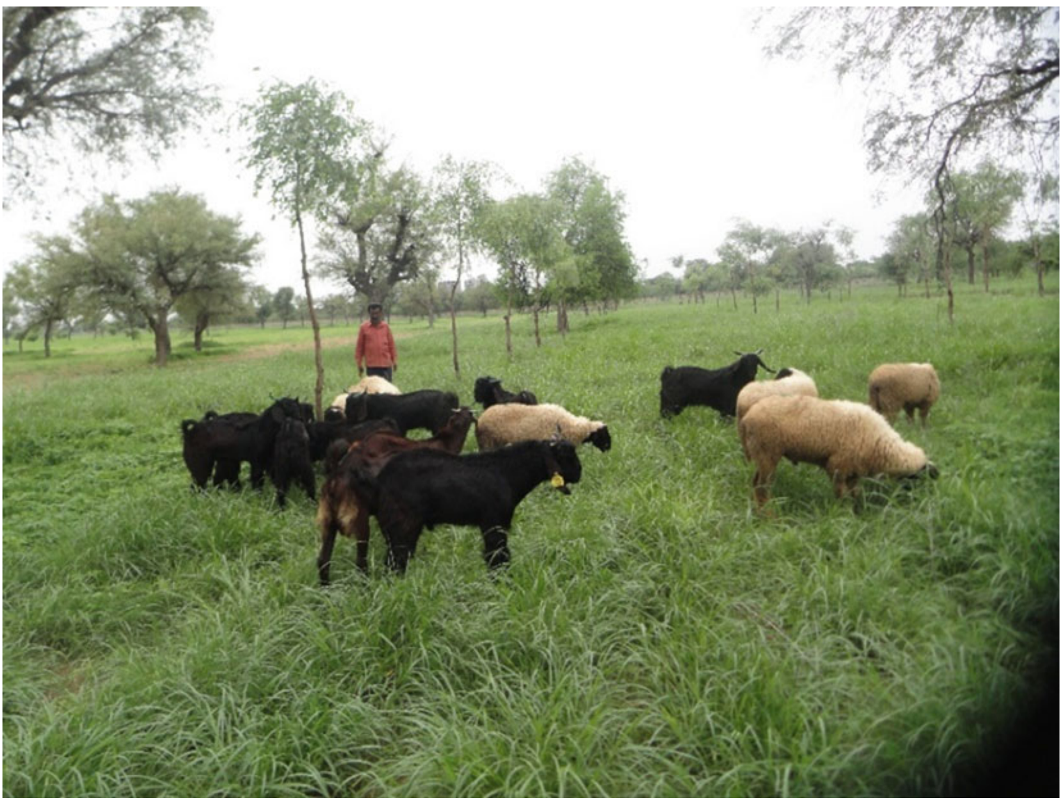

Figure 9.14 Animal grazing on the grass under natural (scattered) or planted stands of trees is a common form of silvopasture in the dry (arid and semiarid) regions of the Indian subcontinent. The photo shows sheep grazing on the grass *Cenchrus ciliaris* under a stand of *Hardwickia binata* trees in Rajasthan in northwestern India. (Photo: M. Patidar, CAZRI, ICAR, India)

Figure 9.15 The *Kangayam* system, a silvopastoral system similar as in Figure 9.12: Mecheri sheep grazing on *Cenchrus ciliaris* under *Acacia leucophloea* trees in Tamil Nadu, India. (Photo: N. Biradar, ICAR-IGFRI, India)

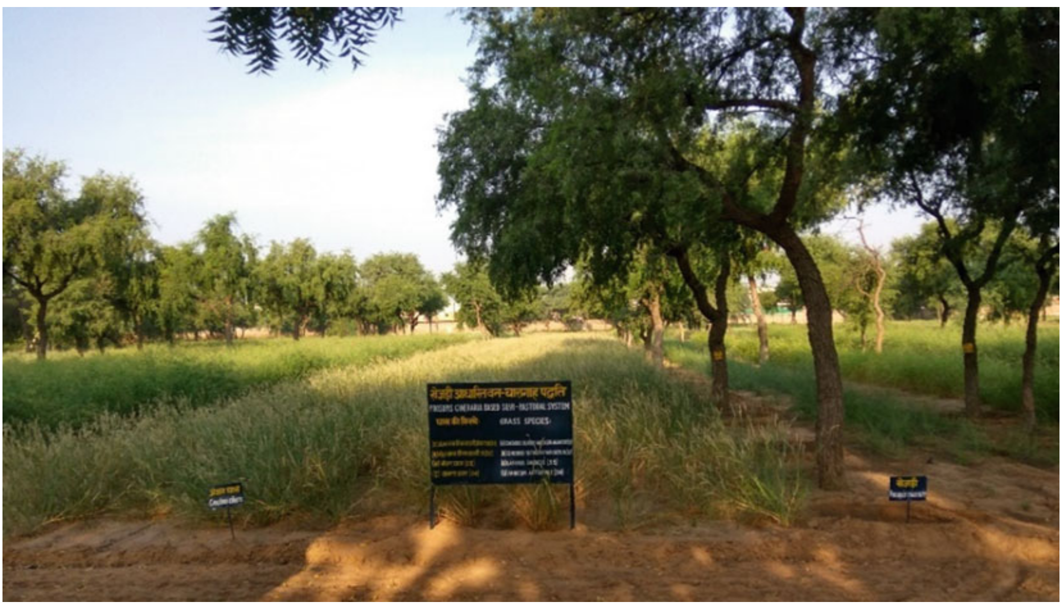

Figure 9.16 The Central Arid Zone Research Institute (CAZRI: www.cazri.res.in), Jodhpur, Rajasthan is a leading Indian government research institution with a long record of productive research in silvopastoral and other agroforestry practices in the drylands. The photo shows a field experiment of *Prosopis cineraria* (the "*khejri*") trees and various understory forage species. (Photo: Archana Verma, CAZRI)

natural ecosystems (Tewari and Arya 2005). Free grazing in the common pasturelands has been a dominant survival strategy for the landless farmers in this region for a long period (Roy and Singh 2013), which makes the system similar to the Parkland system of West Africa described in Section 9.4.1. Overgrazing by small ruminants like goats and sheep, however, is a major problem of the grazing systems in these economically poor and climatically hostile regions.

Khejri, a well-known term in land-use of the drylands of Rajasthan, is used to refer to both the tree (*Prosospis cineraria)* and the wide-spread land-use system where the trees are deliberately nurtured and interplanted with millets and legumes on farmlands, and the trees are lopped and fed to farm animals (Mann and Saxena 1980; Tejwani 1994). Known as the "king of the desert," *P. cineraria* is a sacred tree for a large number of people in Rajasthan, and every part of the tree from foliage to pods and wood is utilized. Various aspects of the *khejri* system have been investigated and reported in numerous studies since the 1970s (Mann and Saxena 1980). Wild jujube (*Zyziphus nummularia*) (Figure 13.A.I.22) is another important tree species in the pastoral-silvicultural system of this region; other similar examples include *Acacia nilotica, A. tortilis,* and *Ailanthus excelsa,* known as the Indian tree of heaven (Shankarnarayan et al. 1987).

Kancha is another traditional, low-input, grassland- and tree management system practiced widely in the semiarid tropics in the Deccan plateau of southern and south-central parts of India. The region has an elevation of 300 to 1000 m and a mean annual rainfall of 500 to 1300 mm (Tejwani 1987). The *kancha* is a controlled grazing system, in which the land is left fallow for periods of 1–3 years. During this phase, the existing trees are protected from biotic pressures, which results in the development of natural succession of grasses in the *Sehima-Dichanthium* grassland type, attaining maturity in 4–10 years depending on the location and site conditions. Several tree species are retained in the kanchas, including *Eucalyptus tereticornis*, *Casuarina equisetifolia*, *Borassssus flabellifer*, neem (*Azadirachta indica,* and *mahua* (*Madhuca longifolia*) (Tejwani 1987). Fruit trees such as custard apple (*Annona reticulata*), mango (*Mangifera indica*), ber (*Ziziphus mauritiana*), and tamarind (*Tamarindus indica*) are also common, their fruits being collected for home consumption; fruits of neem and *mahua* are collected for sale and *mahua* fruits are used for extracting the edible oil and its flowers used to brew an alcoholic drink.

A remarkable example of silvopastoralism is practiced by the nomadic communities in the western and central Himalayas (including the cold desert areas). Animals graze in the alpine pastures during the summer and are then moved down to the temperate forests with the onset of cold weather and eventually into the subtropical forests situated in the lower reaches (Tejwani 1994). The dominant grass species found in the alpine meadows is oat grass (*Danthonia cachemyriana*); other grasses of the genera *Agrostis, Bromus, Briza, Calamagrostis, Festuca,* and *Poa* are also common (Chandran 2015). The temperate zone supports forests of deodar (*Cedrus deodara*), and Himalayan cultivars of the genera *Abies* (fir), *Acer* (maple), *Betula* (birch), *Picea* (spruce), *Pinus* (pine), and *Quercus* (oak).

As in the case of dryland silvopastoral systems in other tropical regions of Africa and Latin America, the silvopastoral systems in the drylands of India, too, represent a low-input, traditional land-use system that has been practiced for long by the local inhabitants, who are generally poor and have little or no social or political power. No wonder, then, that practically no organized efforts have been made to study and improve the systems. The Green Revolution and such other technological advancements have had no impact on these forgotten and ignored systems and their practitioners. The information base on the system is patchy and limited to some descriptions with listings of common species. Given the large areas that are covered by these systems, it is not unlikely that the systems, hopefully, will one day attract deserving attention for improvement.

9.4.4 Other SPS in the Semiarid Regions Worldwide

In the Middle East and the Mediterranean, the most widespread SPS is the Dehesa system in the oak woodlands of Spain and Portugal, estimated to cover more than 3 million ha (Mosquera-Losada et al. 2012; Moreno and Pulido 2009 (see Chapter 10, Section 10.4.1 for details of this system). Open woodlands in other Mediterranean countries are also used as SPS, with either oaks or carob trees (*Ceratonia siliqua*). Various intercropping systems, including silvopasture with olive trees (*Olea europeaea*), are also very common in the Mediterranean, especially Greece (Papanastasis et al. 2009) and Portugal (Castro 2009). In Chile, silvopasture system management practices include fodder banks, grazing in croplands, family gardens; but due to the high aridity in many regions, only a few forage/food-producing tree species survive, *Acacia saligna, Prosopis tamarugo*, and *P. chilensis* being the most common (Rojas et al. 2016). These species are also common in the salt-affected soils and severely degraded arid regions in Peru, Bolivia, and Argentina. Throughout the arid and semiarid regions of these countries, these tree species are used in reforestation projects as well as a variety of other land-use systems, including degraded-land reclamation, soil-erosion control, and supplemental human food items so that the system may not strictly be SPS (Rojas et al. 2016; Peri et al. 2016).

In East and Central Africa, the silvopastoral systems are dominated by different species of the genus *Acacia* in the arid parts of Kenya, Somalia, and Ethiopia; protein bank (cut-and-carry) and fodder production are also very common. Numerous reports are available on this and similar extensive SPS in the region (Garrity et al. 2010). Overall, the general socioeconomic conditions of the regions and the countries concerned are the main factors that influence the nature of system management. Thus, in Africa and the Indian subcontinent, the SPS systems are more subsistence-oriented and labor-intensive than in the Mediterranean and southern regions of South America, where the system management is more capital-intensive and less labor-intensive.

9.5 The Browsing Systems: Tree Fodder and Fodder Trees

Small-scale dairy farming has been a popular and traditional means of livelihood strategy and income generation in many rural households throughout the tropics. Numerous reports are available on the extent and importance of the practice as well as the various types of practices in different parts of the world. All of them involve using foliage of forage species to feed the animals by either letting them browse the plants or transporting the fodder to the animals in their sheds or stalls. Several trees and shrubs are valuable sources of animal feed, and tree fodder (a common name for forage obtained from fodder trees and shrubs) is a major component of animal feed in such smallholder animal production systems. Fodder trees and shrubs are a basic component in almost all such practices. A significant addition to this information base is provided in a new publication "*Alternative animal feeds from agroforestry plants,*" a special issue of the journal *Agroforestry Systems*, volume 94, issue 4, August 2020. It contains 50 articles that report a variety of information on the role, nutritive value, chemical composition, management, etc. of several plants (trees, shrubs, and herbs), some well-known and others little-known in agroforestry and SPS, from different parts of the tropics. Profiles of the major fodder trees and shrubs that are used widely in tropical SPS are included in the multipurpose (MPT) Species Profiles in Chapter 13 (Annexure 13-I), and various terms used to denote the tree-management practices for fodder production in SPS are presented in Tables 9.1 and 9.2.

Table 9.1 Some Common Terms Used in Silvopastoral Literature

Boundary Planting: Refers to planting trees as a boundary demarcation between two farms (or fields on the same farm), as a **buffer** between roads and farms. Trees in the boundary provide fodder, fuelwood, poles and timber, and services like windbreaks and soil erosion control in addition to protection and privacy to the farm/plot.
Cut-and-Carry System: Also known as zero-grazing, cut-and-carry is an animal feeding practice followed by smallholder dairy farmers, in which the fodder (leaves and small branches) obtained by pruning the trees and shrubs is carried and fed to animals kept in sheds or stalls. It is called cut and carry because the fodder is brought to the animal, not the animal to the fodder.
Fodder Bank: An assemblage of tree and shrub species that are predominantly fodder species, but are multipurpose in nature, providing multiple products and services such as forage, fruits, soil fertility improvement, and biodiversity habitats. They can be assembled as woodlots, live fences, windbreaks, soil conservation barriers, and for similar other purposes. Usually, the fodder is cut and carried to stall-feed the animals, but sometimes are allowed to graze on the fodder bank in a controlled manner for defined periods.
Hedgerows: Trees and shrubs that can withstand repeated pruning planted close together to form long vegetative barriers of varying thickness and height. Hedgerows that used to be a common feature of agricultural lands as boundary markers have gradually been removed to allow the use of farm machinery. Depending on the tree or shrub species used, traditional hedgerows provide many benefits including forage and browse for livestock or for soil fertility improvement in tropical alley cropping (Chapter 6), and food and medicinal plants for rural populations.
Live (Living) fence: Live fences consist of trees planted on property lines that serve as poles for establishing barbed-wire fence-lines. They are common as boundary markers between paddocks in silvopastoral systems, especially in Central American countries.
Open grazing**:** Uncontrolled grazing by free-roaming anmals.
Pannage: A practice dating from Roman times, in which pigs are released into beech and oak woodlands to feed on the acorn and beech mast, and into fruit orchards to eat fallen fruit. The term is not used much in current literature.
Pollards/Pollarding: The practice of cutting branches from trees two to three meters above ground level to obtain leaf fodder for feeding livestock and/or wood for fuel or other uses; a common practice in both temperate and tropical forestry and agroforestry. See Figure 14.3 for the explanation of common tree management terms.
Shelterwoods (Temperate Regions): Mature woodlands providing shelter to cattle and sheep during winter months
Stall feeding: Feeding animals retained in sheds or pens with fodder cut and carried from nearby stands of trees and shrubs.
Wood-pasture (Mostly in Temperate Regions): Remnants of old woodlands with a widely scattered stand of trees and associated biodiversity in the temperate regions especially in Europe and the UK, some of them with historical and cultural values, e.g., the New Forest in southern England.

9.5.1 The Cut-and-Carry System

It is called the cut-and-carry system because the fodder is brought to the animal, not the animal to the fodder (Figure 9.17). Along with Fodder Banks (Section 9.5.2), cut and carry is a common aspect of traditional, smallholder farming systems (Figures 9.18 and 9.19). Unlike in drylands, extensive grazing is not an option in smallholder farms in humid and subhumid tropics, where most family-farms are small (less than 2 ha), and managed communal grazing lands are almost non-existent anymore. The successful eradication of the tsetse fly (a collective name for 23 species of the fly of the genus *Glossina* that are biological vectors of trypanosomes, which cause human sleeping sickness and animal trypanosomiasis) in the late 1990s provided an incentive to adopt cut-and-carry fodder production for enhanced animal-farming opportunities in smallholder production systems in Africa. More farmers established small dairy units in their backyards and began cultivating grass-legume plots to feed their dairy cows. For example, in Zanzibar islands of Tanzania the number of households that kept improved dairy cows increased steadily from 2.4% of the total livestock keepers' pre-tsetse eradication to 23.5% in 2002, whereas the proportion of crossbred cows also increased from 2% of the total cattle population in 1993 to 5% in 2003. On average, 52% of the typical small-scale dairy households in Zanzibar, each with seven to eight family members, kept four to five head of cattle and described livestock keeping as their

Table 9.2 Common trees in the West African Parklands[a]

Scientific name	English name	French name
Acacia senegal	Gum arabic	Gommier
Adansonia digitata	Baobab	Baobab
Anogeissus leiocarpus		Bouleau d'Afrique
Balanites aegyptiaca	Desert date	Dattier du désert
Bombax costatum	Red flowered silk cotton	Kapokier rouge
Borassus aethiopum	Fan palm	Rônier
Ceiba pentandra	Silk cotton	Fromager
Diospyros mespiliformis	Ebony	Faux ébenier
Elaeis guineensis	Oil palm	Palmier à huile
Faidherbia albida (syn. *Acacia albida)*	Winterthorn	Kad, Faidherbia
Hyphaene thebaica	Dum palm	Palmier doum
Lannea microcarpa		Raisinier
Parkia biglobosa	African locust bean	Néré
Sclerocarya birrea	Marula	Prunier
Tamarindus indica	Tamarind	Tamarinier
Vitellaria paradoxa (syn. *Butyrospermum paradoxum*)	Shea nut tree	Karité, arbre à beurre
Vitex doniana	Black plum	Prunier noir
Ziziphus mauritiana	Jujube	Jujubier

[a]See Annexure 13-I, Chapter. 13, for short species profiles of selected species

Figure 9.17 Stall-feeding of animals penned in sheds with grasses and tree fodder cut from trees or shrubs grown on farms and farm boundaries (the "cut-and-carry" type of silvopastoral practice) is common in many smallholder farming systems around the tropics and subtropics. (Photo: ICRAF/World Agroforestry)

Figure 9.18 *Calliandra calothyrsus,* a fast-growing leguminous shrub/small tree that resprouts vigorously after pruning, is a preferred fodder species for the cut-and-carry system of silvopasture to support of animal production in smallholder farming systems. The photo shows a smallholder farmer in Kenya tending her small farm that has calliandra and other cut-and-carry fodder species planted along the farm boundary. (Photo: ICRAF/World Agroforestry)

Figure 9.19 Napier grass (*Pennisetum purpureum* syn. *Cenchrus purpureum*) behind on the right side of the stand of coconut palms as one of the components, as a cut-and-carry fodder for animals, in a coconut-based agroforestry system in Karnataka, India. (Photo: ICRAF/World Agroforestry)

major source of family income (http://www-naweb.iaea.org/nafa/news/2006-zanzibar-1.html). Similar cut-and-carry type of smallholder fodder production for stall feeding of domestic animals penned closer to the farmer's dwellings are common throughout East and Southern Africa.

9.5.2 Fodder Banks

The term refers to designated, often enclosed, areas where fodder trees and shrubs – especially leguminous ones – are grown intensively for a steady supply of fodder, especially during the dry season. The fodder available in the "banks" may be "withdrawn" and fed to cattle by cut-and-carry or by letting the animals in for controlled browsing. The main objective of fodder banks is to overcome the protein deficiency of grass that usually has low and seasonally fluctuating protein content (often going below 6%). Fodder banks should be managed to ensure high productivity and dominance of the legume as well as its persistence at the end of the growing season.

9.5.3 Boundary Planting

Boundary planting refers to planting trees as a boundary demarcation between two farms (or fields on the same farm), as a buffer between roads and farms. Live fences that are common as boundary markers between paddocks in silvopastoral systems, especially in Central American countries, consist of trees planted on property lines that serve as poles for establishing barbed-wire fence-lines. Such trees in boundary planting and live fences provide fodder, fuelwood, poles, and timber, and services like windbreaks and soil erosion control in addition to protection and privacy to the farm/plot. Moreover, by including soil-fertility-enhancing trees on boundary lines, the overall productive capacity of the soil could be improved by augmenting soil carbon input. Additional benefits will include enhanced biodiversity through various flora and fauna that the trees' environment might attract and support. This system may also be suitable for use along roadsides, watercourses, and other community amenities.

9.6 Research in Tropical Silvopastoral Systems

Research in tropical and subtropical SPS has so far been more exploratory than experimental in nature and scope. The emphasis has been on understanding and documenting the existing situation, which is the essential first step in developing research programs on any new land-use activity. The outputs of such activities are descriptions and catalogs of the systems, their characteristics, structure (nature and arrangement of components), nutritive values of the fodder from various trees and shrubs, and performance of the components and systems expressed as yield or outputs in the short term and system behavior (sustainability) in longer-terms (George et al. 1996; Mathew et al. 1992). These efforts related to tropical SPS have yielded substantial information on the nature and distribution of different types of SPS in various ecological regions, and the major tree components of each as summarized in the previous sections of this chapter. Numerous reports are available on various fodder trees that have been traditionally used, as well on relatively "new" or underexploited species (Chapter 13: Tables 13.1 and 13.2, Annexure 13-I). It was based on these efforts that certain "new" species, the potential of which had not been recognized – at least not at the current level – as fodder trees became prominent. Notable among such genera are *Leucaena, Calliandra, Gliricidia*, and *Sesbania*. Another major research accomplishment was in understanding the nutritive value of tree fodder (Chapter 11, Table 13.2). As mentioned at the beginning of Section 9.5, a new publication (August 2020) "*Alternative animal feeds from agroforestry plants,*" a special issue of the journal *Agroforestry Systems*, volume 94, issue 4 is a significant new addition to the information base on this topic.

While such efforts that focused on identifying, evaluating, and improving the fodder trees despite being resource-constrained and limited in scope have yielded some valuable information, comparable efforts on scientific approaches to improving the performance and management of these trees as components of SPS seem to have been lacking. Practically very few silvicultural or tree-improvement studies on these trees and the design of improved SPS involving them have been reported. In this context, the phenomenal success of an innovative farmer-initiated effort on rehabilitating degraded pastures in the semi-arid Caatinga region of Brazil is worth mentioning. The study evaluated the changes in the ecological (vegetation and soil) characteristics of a 24-ha smallholder farm in Barreiros, Riachão do Jacuípe (11°36' S, 39°31' W) in the semiarid (annual rainfall about 600 mm during 3–4 months) Caatinga region of Brazil (Pinheiro et al. 2019). The farmer's efforts started with controlling uncontrolled grazing by free-roaming animals and then introducing several management measures including high-density planting of cactus (*Opuntia ficus-indica*), broadcasting seeds of native fodder trees, planting and nurturing tree seedlings, and managing the buffelgrass (*Pennisetum ciliare*) covers. On-farm data collected included the biomass production and water storage: stand density and species composition of shrubs/trees, soil organic carbon up to 30 cm soil depth, and percentage of soil cover on parcels of the farm that had been under 17, 10, and 3-years under SPS, as well as a degraded pasture (DP) that had been left under free-roaming grazing. Remarkable increases were recorded in the annual dry matter production (cactus+grass+trees), shrub/tree density, soil organic carbon stock, and the soil cover under the SPS systems. The interviews with the farmer indicated a possible rapid (one year) return on the investment for the SPS implementation. The study shows the enormous scope for reversing the on-going ecosystem degradation in the Caatinga, and is indicative of the high potential of such low-cost land-management interventions in the vast areas of degraded pastures in the semi-arid tropics through such innovative, farmer-designed SPS. The rapid increase in soil carbon stock makes the effort a noteworthy initiative under the concept of "4 per mille Soils for Food Security and Climate" (see Chapter 20).

9.7 Integrated Crop Livestock Forestry Systems: *New Wine in Old Bottles*?

During the past few years (since around 2010), there has been a "movement," primarily in Brazil, to promote silvopastoral systems under a new banner "Integrated Crop Livestock Forestry Systems (ICLF)." Proposed and promoted by EMBRAPA (*Empresa Brasileira de Pesquisa Agropecuária* = Brazilian Agricultural Research Enterprise), the massive Brazilian government organization for agricultural research and development, https://www.embrapa.br, the term is different from the "Integrated Crop-Livestock Systems (ICLS)" of FAO (www.fao.org/.../spi/scpi-home/managing-ecosystems/integrated-crop-livestock-systems/) and the "good-old" agroforestry. The Embrapa website in English (https://www.embrapa.br/web/rede-ilpf/emglish) defines the term as: "Integrated crop-livestock-forest (ICLF) is an agricultural production strategy that integrates different production systems — agricultural, livestock and forestry — within the same area. It can be implemented using mixed, rotating, or succession crops, so that there is an interaction between each component, thus generating mutual benefits." Another website, also in English states "ICLF systems are a feasible production alternative to recover altered or degraded areas. The integration of trees with pastures and/or crops is described as a system integrating the crop, livestock, and forest components, in rotation, combination, or succession, in the same area. It allows the soil to be economically exploited all year round, favoring an increase in grain, meat, and milk yield at lower costs due to the synergy created between crop and pasture." It continues "... The above mentioned systems include the agroforestry systems (AFS), which are classified as agroforestry, forest-pasture, and agroforestry-pasture. ICLF is, therefore, the strategy with the broadest scope."

Impressive photographs of commercial land-use systems of tree plantations in zonal arrangement with crops (maize, soybean), and pasture and cattle are included on the websites; various displays and presentations on ICLF have become a feature at the international congresses and other platforms in the past few years. A book on the topic (Bungenstab and Gigolo de Almeida 2014); an international Congress in Brasilia, 2016; and publications based on ICLF in peer-reviewed research journals (e.g., Alves et al. 2017) are also available suggesting that the momentum on promoting the concept and term is on the rise. The concept is only a rehash of agroforestry. So far (January 2020) the enthusiasm in the new term seems to have been limited to some professionals in some parts of Brazil. It is too early to say if this activity is going to develop into a significant silvopastoral management option.

9.8 Outlook on Tropical Silvopastoral Systems

Silvopastoral systems in the tropics and subtropics are among the land-use activities that are at the low end of the management spectrum. These systems have received little or no attention for improvement, unlike commercial SPS in the industrialized nations. Whatever little that has been done so far has included conventional system descriptions, species inventory, and sociocultural narratives of the people and their traditions. It may sound paradoxical that despite the vast extent of areas under these systems and the large numbers of human and animal populations involved, these systems have not attracted the research and development attention they richly deserve. It is of little solace that this sort of sad state of affairs is true of all traditional low-input land-use systems.

The problems and challenges facing such systems are too many and all too familiar. Conventional, fragmented, discipline-oriented, and uncoordinated research efforts are of little relevance in tackling the issue. Strong commitment and determination, appropriate policy, and adequate resources are needed to initiate programs that cut through disciplinary barriers and perceptions, and institutional hierarchies. These may sound like lofty ideas and idealistic rantings. We can only wish that some earnest efforts are initiated at least on a pilot scale to improve these systems and demonstrate the extent of benefits that can be reaped from modest investments. After all, the land areas involved are so large, the number of hapless people who stand to benefit, and the extent of environmental and ecosystem benefits that can be reaped are so enormous that these forgotten land-use systems that offer tremendous benefits deserve the needed attention sooner than later.

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