Chapter 12
Silvopastoral Systems with Native Tree Species in Venezuela

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Abstract This chapter describes the main silvopastoral developments in Venezuela with an emphasis on the use of native tree species in the states of Guarico, Cojedes, Barinas, Apure and Portuguesa in the Venezuelan Llanos and in the states of Lara, Falcon, Anzoategui, and Trujillo in the semi-arid life zones of the country. The main arrangements promoted are living fences, scattered trees in pastures, trees in rows, grazing in tree plantations and intensive silvopastoral systems. Cattle breeding is concentrated in the savanna zone (Llanos) an area with a well-defined dry season (mainly Tropical Dry Forest), in which scattered trees that supply fruits and legumes to livestock during the dry season predominate. The tree species with more consumption by cattle are legume trees such as *Samanea saman*, *Albizia guachapele*, *Enterolobium cyclocarpum*, *Cassia moschata*, *Prosopis juliflora*, *Acacia macracantha*, and *Gliricidia sepium*. On the other hand, in the arid and semi-arid zones of the country in the northern coastal region, there is a predominance of goat production. As in the plains, the presence of legume species, mostly of the Fabaceae family, play a significant role in the diet of animals. Other non-leguminous species that are also consumed by domestic animals are *Guazuma ulmifolia*, *Bulnesia arborea*, *Spondias mombin*, *Ceiba pentandra*, *Anacardium excelsum*, *Platymiscium pinnatum* and palms, such as *Attalea butyracea*, *Copernicia tectorum* and *Acrocomia aculeata*, and valuable wood species like *Cordia alliodora*, *Cordia thaisiana*, *Tabebuia rosea*, *Swietenia macrophylla* and *Tabebuia chrysantha*. Of the tree species whose foliage, pods and fruits are consumed by ruminants, *Samanea saman* is the most important as a scattered tree in the Tropical dry forest of Venezuelan Llanos. The chapter will analyze the growth rate and timber production of native species under silvopastoral arrays and the impact of the systems on economy, carbon sequestration, animal welfare and biodiversity.

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12.1 Introduction

For centuries, cattle raising has been an activity of extensive areas in Venezuelan savannas known locally as Los Llanos, an area mostly of Tropical Dry Forest, with total annual precipitation ranging from 1200–1800 mm year^{-1}, and average temperature of 25–27 °C. The Llanos are an extensive region of northern South America, which includes part of the territories of Colombia and Venezuela, with a total area of 355,112 km^2. The territory corresponding to Venezuela is 68% (241,000 km^2), generally characterized by a flat topography, an average altitude of 150 masl, and an average slope of 70 cm per km (Andressen and López 2015).

The Venezuelan Llanos are divided in two major landscapes: open habitats (savannas) and forest habitats (forests). Savannas cover approximately 75% of the surface of the Llanos; the rest is covered by semi-deciduous, deciduous and gallery forests (Utrera 2003). Geographically there are three types of savanna plains: Eastern plains, Central plains (high central plains and low central plains) and Western plains (high and low) (Andressen and López 2015).

According to Ramia (1967), savannas are classified into three main types: The Lowland-Bank savannas (Sabanas de banco-bajío y estero), savannas of *Paspalum fasciculatum* (Western savannas) and *Trachypogon* sp. savannas (Eastern savannas). The lowland-bank savannas are located mainly in the western plains of Venezuela. The *Paspalum fasciculatum* savannas include large open areas, with physiognomic and environmental characteristics similar to those described for the lagoons, estuaries and shallows in the south of the Apure river, and the *Trachypogon* savannas cover an extensive area in the Eastern Plains (35,000 km^2), with dominance of grasses of the genus *Trachypogon*, deep sandy soils, poor in nutrients and well drained, which are usually interspersed with scattered trees and shrubs, constituting the predominant vegetation formation in those landscapes.

12.2 Plants with Fodder Potential in Venezuela

12.2.1 Plants with Fodder Potential in the Venezuelan Central Llanos

The region of the Central High Plains is formed by the states Anzoategui, Guarico and Cojedes, and the southern areas of Aragua, and has an estimated surface of 28,700 km^2. According to Holdridge (1968) it is composed by three main ecosystems: Tropical Dry Forest, Premontane Dry Forest and Premontane Humid Forest.

Fig. 12.1 Pastures in the Tropical Dry Forest of Aragua state during the dry season with presence of Guacimo (*Guazuma ulmifolia*) providing shade and shelter. (Photo: E. Escalante)

The whole region is bi-seasonal with an intense period of rains between May and October (wet season) and a dry season from November to April, with a severe scarcity of forage during these months (Fig. 12.1).

The vegetation of the central plains has numerous plant species consumed by cattle, mostly legumes with high protein content and nutritional value. However, a significant number of tree species with forage potential have not yet been evaluated. In the south of Aragua state, including the Tropical dry forest, the Dense deciduous forest, the Espinal Llanero and the Chaparral, the natural shrub vegetation of the plant formations, constitutes a forage resource available for livestock feeding (Cecconello et al. 2003). In that area, 30% of the trees and shrubs species evaluated have fodder value and the forage offer for ruminants, ranges between 640 and 3997 kg DM ha^{-1} (Baldizán and Chacón 2007).

As mentioned earlier, fruits and pods from woody legumes provide an important resource during the dry season in the tropical dry forest. Crude protein (CP) of whole fruits in this region ranged from 4% to 22% (Cecconello et al. 2003). The fruits with highest protein content were those of *Chloroleucon mangense* with 22%, followed by those of *S. saman* with 14.04% and *Acacia macracantha* with 10.85%. The percentage of crude protein in seeds ranged between 16% and 21.26%, with the highest value in *C. mangense* with 21.16%. The ruminal degradability of DM was higher in whole fruits than in seedless fruits, with highest values in *S. saman* and *Enterolobium cyclocarpum* with 62% and 81% respectively. These species also had the highest degradability with a total index of approximately 90% (Cecconello et al. 2003).

Casado et al. (2001) studied the forage potential of a deciduous forest in the Guarico state. Plant species with the highest frequency index were *Acacia macracantha* with 30% followed by *Chloroleucon mangense* with 17%, and *Caesalpinia coriaria* with 13%, all of them of high acceptability of forage and fruits by the cattle. They also found that 81% of the identified species had a medium to high acceptability value (Casado et al. 2001). It was also estimated that the fruit production of *A. macracantha* was on average of 12.8 kg per tree.

According to Domínguez et al. (2007) the Fabacea family predominated in terms of the number of species and frequency of individuals. The most important were *Acacia macracantha, Calliandra affinis, Cassia moschata*, *Fissicalyx fendleri, Lonchocarpus sp*., *S. saman, Senna obtusifolia, Senna spectabilis* and some species of the genus *Inga*. Other species with forage value found in the same study were *Genipa americana, Spondias mombin, G. ulmifolia* and *Oyedaea verbesinoides*. Other species less frequent, but no less important because of their high acceptability by cattle in the region are *Acrocomia aculeata*, *Enterolobium cyclocarpum* and *Senna atomaria,* representing 16% of the total species found in the study (Casado et al. 2001). In other study in two forests in northeastern Guarico state Rengifo et al. (2008) identified also some species with forage potential such as *Acacia glomerosa*, *Pereskia guamacho*, *Caesalpinia granadillo*, *Pithecellobium unguis-cati*, and *Trichanthera gigantea*.

In Northeast Guárico state, Miliani et al. (2008a) evaluated the DM forage supply with three treatments: grazing in a pasture with *Cynodon nlemfuensis*, grazing with restricted access to the forest for 5 hours and grazing with free access to the forest. The total DM for *C. nlemfuensis* was 2227 and 2467 kg DM ha^{-1} for the dry and rainy season respectively. The supply of DM increased to 10,800 and 5926 kg DM ha^{-1}, in treatment with forest for the same previous seasons. The contribution of leaf litter, foliage and fruits of the forest species in the dry season contributed to a higher DM supply when compared to the rainy season. Therefore, the forest component grazing doubles DM in the rainy season and was five times greater in the dry season. It is concluded that through the use of the forest resource, animals tend to diversify their diet, improving their selection capacity (Miliani et al. 2008b).

12.2.2 Trees and Woody Shrubs with Potential as Fodder in the Forests of the Western High Plains

The forage potential of a tropical dry forest (deciduous forest), with acid soils and low fertility, in Mesa de Cavacas, Portuguesa state, was studied by Solórzano et al. (2004). The study conducted on ten farms allowed the identification of 89 plant species, of which 46 (53.7%) were arboreal, 25 (28%) shrubby, three palm species and the rest herbaceous.

In the study, producers identified the 30 species that were consumed by cattle, of which the most important were *Samanea saman*, *Cassia moschata*, and *Spondias* *mombin*, followed in order of preference by *Guazuma ulmifolia*, *Mangifera indica* and *Genipa americana*. Other species of importance and forage potential were *Cochlospermum vitifolium*, *Acrocomia aculeata*, *Anacardium excelsum*, *Attalea butyracea*, *Crescentia cujete*, *Cassia siamea*, *Gliricidia sepium*, *Inga spp.*, *Trichanthera gigantea* and *Enterolobium cyclocarpum*. Producers reported that cattle consumed only the fruits of 50% of the species and the leaves of 36% of species. Only in 14% of the species were both the fruits and foliage consumed, among them *C. moschata*, *G. ulmifolia*, *S. saman*, *S. mombin* and *M. indica* (Solórzano et al. 2004).

In the same state, Ojeda et al. (2012), determined the preference of woody plants by cattle in a silvopastoral system with access to a tropical semi-deciduous forest, evaluating the epidermal fragments in fecal samples. Twenty-two species of woody plants were identified in the area, grouped into 11 botanical families with 40.9% of the species within the family Fabaceae. The woody species of highest selectivity by cattle during the dry season were *Inga laurina, Machaerium humboldtianum, S. saman* and *Sida acuta* (Ivlev index = 0.60 ± 0.09) (Ojeda et al. 2012). Therefore, the design of silvopastoral systems in the tropical forest should consider the promotion of woody plants of forage value, without affecting the biodiversity of these ecosystems (Ojeda et al. 2012).

In another study Cardozo (2008) listed a group of plant species whose fruits had great potential as fodder in silvopastoral systems, most of them in the flooded savannas. The species identified were *Spondias mombin*, *Maclura tinctoria*, *Licania pyrifolia*, *Vitex orinocensis*, *Cordia tetrandra*, *Genipa americana*, *Attalea butyracea*, *Bactris balanophora*, *Crescentia cujete* and *Inga spp*.

Another important group of plants in silvopastoral systems are fodder species consumed directly by livestock in the field or under the cut and carry practice; the most used are *Leucaena leucocephala*, *Gliricidia sepium*, *Morus alba*, *Trichanthera gigantea*, *Tithonia diversifolia* and *Moringa oleifera*.

12.2.3 Plants with Fodder Potential in Northwestern Venezuela, Zulia and Trujillo States

According to Torres (2007), the nutritional advantages offered by the foliage of some perennial woody species for animal feed are known by the producers of the lowland area of Trujillo state. However, these species are not part of the strategy of bovine feeding as an essential source of nutrients and only constitutes another element of the livestock ecosystem. Considering this situation, in recent years several studies have been carried out to characterize representative forages of Trujillo state (García and Medina 2006), (García et al. 2008a, b, 2009a, b), the authors have carried out bromatological studies of species with greater forage potential for bovines, sheep and goats in the Tropical Dry Forest of the lower Andean foothills of Venezuela.

According to García et al. (2008a) the most consumed species by cattle, sheep and goats in Trujillo were *Chlorophora tinctoria, Pithecellobium pedicellare* and *Morus alba.* The sheep and cattle, eagerly consumed the biomass of *M. alba, C. tinctoria, G. ulmifolia, P. pedicellare* and *L. leucocephala*, while the most desired species by goats was *C. tinctoria*. Goats also preferred foliage with lower content of Neutral Detergent Fiber (NDF) and low concentrations of total polyphenols.

Also in Trujillo, through descriptive analysis (DA), principal components analysis (PCA) and linear correlations (CL) the nutritional composition of the foliage of 20 forage species was characterized, the legume species studied were: Hueso de pescado (*Pithecellobium pedicellare*), Matarratón (*Gliricidia sepium*), Leucaena (*Leucaena leucocephala*), Saman (*Samanea saman*), Cuji (*Acacia* spp.), Cadeno (*Bauhinia cumanensis*), Mucuteno (*Cassia alata*) and Burra (*Pentaclethra macroloba*); while the non-legumes were: Mora de palo (*Chlorophora tinctoria),* Morera *(Morus alba*), Guacimo (*Guazuma ulmifolia*), Caujaro (*Cordia alba*), Vero (*Bulnesia arborea*), Olivo (*Capparis odoratissim*a), Naranjillo (*Trichanthera gigantea*), Boton de Oro (*Tithonia diversifolia*), Moringa (*Moringa oleifera*), Neem (*Azadirachta indica*), Cayena (*Hibiscus rosa-sinensis*) and Flor amarilla (*Wedeliaaff caracasana*) (García et al. 2009a, b).

It was possible to verify that the legume species exhibited marked differences in the phytochemical pattern of the biomass, compared with the rest. The tannins precipitating the legumes affected the digestibility of the nutritive fractions, while the phenols and sterols present in the non-legumes exhibited greater antinutritional potential in this type of species (García et al. 2009a, b).

12.2.4 The Fodder Potential in Arid and Semi-arid Zones of Northern Venezuela

Plant biodiversity is also of major importance in the dry tropical forest in the arid and semiarid environments of Lara and Falcon states in Venezuela. Goat production in those areas greatly depend on fodder provided by small trees and shrubs whose leaves, flowers and fruits are the main diet of the goat livestock (Escalante et al. 2011).

Other arid zones of the country are located in Nueva Esparta, northern part of Anzoategui and Zulia states. The shrub desert ecosystems are the driest in the country with an average annual rainfall of 125–250 mm. Primary vegetation does not exist due to the exposure to overgrazing and the extremely low annual rainfall in those ecosystems.

The arid and semiarid ecosystems of Venezuela occupy 4.6% of the national territory, 41,023 km^2 (4,102,300 ha). The predominant soils are shallow, stony with little development (entisoles), and poor in organic matter. Shrubs and thorn scrub predominate in the vegetation, and herds are poor with low productivity and low profitability. This activity, together with the indiscriminate use of trees for the obtaining of firewood and poles, causes a constant loss of vegetation cover, favoring wind and water erosion and leading to desertification. Due to years of exhausting use, based on the breeding of goats without herd management and sanitary control, and the free grazing of the semi-natural vegetation, the desertification process has been intensified in the arid and semiarid environments, as well as the loss of biodiversity.

In the tropical dry forest of the semiarid of Lara, Falcon and Yaracuy states, 14 species of legumes native to the forest were evaluated (Nouel and Rincón 2004). These species were selected by direct observation of the consumption of grazing animals and by the traditional knowledge of producers in the study area. As a result of the selection, the following were identified: Chiquichiqui (*Cassia tora*), Sierra (*Acacia tamarindifolia*), Cujicillo (*Mimosa trianae*), Caudero (*Mimosa gritty* and *Mimosa caudero*), Brusca (*Cassia occidentalis*), Palo de arco (*Apoplanesias cryptopetala*), Carbonero or Tiamo (*Acacia polyphylla* or *Acacia glomerosa*), Tiamo blanco (*Piptadenia robusta*), Espinillo (*Parkinsonia aculeata*), Uveda or Cuji negro (*Acacia macracantha*), Platanico (*Cassia emarginata*), Uña de gato (*Pithecellobium dulce*), Bolsa de gato (*Diphysa carthagenensis*), Cuji (*Prosopis juliflora*) and *Haematoxylum brasiletto*; of the mentioned species, the nutritional Crude Protein value (CP) of plants of the genera Acacia, Mimosa and Prosopis was evaluated. The highest percentages of CP, corresponded to leaves of *A. macracantha* with 34.3% (pods 13.4%), and *A. tamarindifolia* with 35.1%; followed by *Mimosa arenosa* (21.9%), *A. glomerosa* (20.0%) and *P. dulce* (19.4%) (Nouel and Rincón 2004).

Goat diet depends on a few palatable plant species of each day most scarce flora. The most common species belong to the Acacia, Prosopis, Pithecellobium, Capparis and Cercidium genres, being the most important Cuji (*Prosopis juliflora*), Yacure (*Pithecellobium unguis-cati*) and Yabo (*Cercidium praecox*), whose flowers had a protein content of up to 27.6%.

Colmenares et al. (2013) made a study with the aim to identify authoctonous species that strengthened the forage offer for goat herds. The identification was made from the knowledge dialogue, with conversations aimed at recognizing the species considered by the producers as preferred goat feed. There were 24 species recognized, 17% of them considered important. Of the plants considered beneficial, 100% of the herders considered Cuji (*Prosopis juliflora*) as a fundamental contribution to the diet, others of importance were *P. dulce* (60%), *Cordia dentata*, *B. cumanensis*, *C. biflora*, *C. flavens* and *L. noodosum*. Of the total number of species, 40% corresponded to trees, given the eating habit of the goats in semiarid environments (Colmenares et al. 2013).

12.3 Main Silvopastoral Systems of Venezuela

12.3.1 Scattered Trees in Pastures

Most of Venezuelan livestock areas and the "Llanos", are characterized by the presence of many plant species, mostly scattered trees or deciduous trees and shrubs in secondary forests, whose foliage, pods and fruits are consumed by cattle, being part of the diet of many ruminant species, especially during the dry season, when the forage supply from the grass is greatly reduced.

The plant species with highest consumption by cattle, are legume trees such as Saman (*Samanea saman*), Masaguaro (*Albizia guachapele*), Caro Caro (*Enterolobium cyclocarpum*), Cañafistola (*Cassia moschata*), Cuji (*Prosopis juliflora*), Cuji negro (*Acacia macracantha*) and Matarratón (*Gliricidia sepium*) (Escalante 1985, 2017). Other non-leguminous species that are also consumed by domestic animals are Guacimo (*Guazuma ulmifolia*), Vera (*Bulnesia arborea*), Jobo (*Spondias mombin*), Ceiba (*Ceiba pentandra*), Mijao (*Anacardium excelsum*), Roble (*Platymiscium pinnatum*) and palms, such as Palma de agua (*Attalea butyracea*), Palma Llanera (*Copernicia tectorum*) and Palma Corozo (*Acrocomia aculeata*). All these trees are combined in the Tropical Dry Forest with other valuable wood species such as Pardillo (*Cordia alliodora*), Pardillo Negro (*Cordia thaisiana*), Apamate (*Tabebuia rosea*), Caoba (*Swietenia macrophylla*) and Araguaney or Flor Amarillo (*Tabebuia chrysantha*) (Escalante 1985; Escalante et al. 2011).

Of the trees whose foliage, pods and fruits are consumed by ruminants, *Samanea saman*, formerly known as *Pithecellobium saman* and *Albizia saman* is the most important species in the Tropical dry forest of Venezuelan Llanos, providing numerous goods and services, such as the production of nutritive pods with 15–18% crude protein, shade, shelter and livestock protection, nitrogen fixation, and timber for ceilings and parquet floors. Also, as it is a deciduous tree, the litter contributes to the cycling of nutrients and the extended canopy modifies the microclimate giving comfort to the animals, by reducing the temperature during the hottest part of the day. This species has been widely studied in areas where it is a frequent and dominant species in silvopastoral systems (Escalante 1997). One of the least studied environmental services provided by *S. saman* is the provision of habitat for countless species of plants (Bromeliaceae, Orchideae, and some mosses, lichens, ferns and cacti), some of them parasites, and species of small animals, mainly insects (Morales 2005; Molina Prieto 2008) (Fig. 12.2). This characteristic has been seen and corroborated in populations of *S. saman* in Venezuela, Colombia, Ecuador, and Central America.

When eating the saman pod, the cattle perform a pre-germination treatment on the seed, so when it is expelled, it is accompanied by a nutritious material (excrement) and germinates easily (Lozada and Graterol 2003).

Saman is not only preferred by farmers because it provides shade and shelter to animals, but also for its valuable fruit called "Samana" consumed by animals during the dry season, for its wood quality and for the nitrogen fixation. In a study in the central savannas of Portuguesa state, it was reported that the content of nitrogen and organic matter (OM) in the soil was higher, and their concentration decreased from

Fig. 12.2 *Samanea saman* tree providing habitat for a high diversity of plant species. (Photo: E. Escalante)

the proximity of the tree trunk towards the open savanna grassland (Solórzano et al. 1998).

In Venezuela, saman wood production has major relevance in Zulia state. In the years between 1982 and 1998, saman sawmill wood represented 80% of the total wood production in the state, with the highest wood production in 1998 (10.641 m^3), 90% of the total (9430 m^3) in the Perijá Region of the Zulia state (Moreno and Daal 1998). For trees with diameter at breast height (DBH) in a range between 52 and 77 cm, the estimated volume was 1.0–1.2 m^3 per tree, with maximum values of up to 3 m^3 sawmill wood for old trees (Fernandez and Gutierrez 1985).

Also in Zulia, in the southern part of Maracaibo Lake, Fernández and Gutiérrez (1985) determined that a saman average canopy cover per hectare was 6.4% (640 m^2), with highest value of 63%. The study showed that the average number of saman trees per ha was five for highest canopy paddocks, with some trees shading more than 1100 m^2 of soil surface for trees with up to 29 m of canopy diameter and estimated age between 50 and 60 years.

12.3.2 Alternate Strips with Alleys

The System of Alternating Strips with Alleyways is the most complex of all, but it is also the one that provides more goods and services. Generally, the strips are formed by 3–5 rows of woody legume trees and/or species of high timber value, separated by alleyways of 12–24 m wide, depending on the preferences of the producer (Fig. 12.3).

Fig. 12.3 Silvopastoral system with tree alleys of *Samanea saman*, *Cordia thaisiana* and *Tabebuia rosea* in La Esmeralda Farm, Tachira state, Venezuela. (Photo: E. Escalante)

The system could be planted with one species or with a combination of two to four species to reduce its vulnerability. The combination could be made by planting each row with a single species or by alternating tree species in the same row. The latter option is desirable to increase the resilience and adaptability of the system in the face of climate change, and to enhance the biodiversity of the area. The distance between trees in each row ranges from 3 to 10 m depending on the characteristics of each species in terms of canopy conformation, and on the management of the trees during the growing stage that includes periodic pruning and thinning to improve timber production and reduce the competence between species and with the grass.

The strips are made up of rows of woody species to provide shade, protection and comfort to the animals, along with other multiple benefits, including nitrogen fixation (for leguminous species) and wood production, rods and fence poles, as well as the supply of a friendly and appropriate habitat for epiphyte plants, insects, birds and small mammals and reptiles, thus favoring biodiversity, in addition to contributing to the mitigation of extreme temperatures.

12.3.3 Cattle Grazing in Forestry Plantations

Extensive pasture grazing has been done in commercial plantations of Pino Caribe (*Pinus caribaea*), Melina (*Gmelina arborea*), Teca (*Tectona grandis*) and *Acacia mangium* in the eastern and western savannas of Venezuela.

In the highlands of the Venezuelan Andes, it is common to see silvopastoral systems of Aliso or Jaul (*Alnus sp*.) with Kikuyo grass (*Cenchrus clandestinus*) or with Capin Melao grass (*Melinis minutiflora*). In these systems the Aliso, in spite of not being a legume species, fixes nitrogen and protects livestock from low temperatures, either as a live fence or windbreaker, in addition to providing wood for construction, crafts and other uses (Escalante 1985).

In the last 30 years, there has been a notorious increase in the practice of silvopasture and intercropping in commercial forest plantations in Venezuela (Escalante et al. 2011). DEFORSA, a recognized company in the paper industry in Venezuela, intercropped in eight-meter alleys, coffee, rice, maize and black beans in between tree rows of eucalyptus (*Eucalyptus urophylla*) plantations, and also established extensive grassland areas (3000 ha) in the field within the eucalyptus rows, for beef and dairy production, with white Brahman cattle and buffaloes (Fig. 12.4).

12.3.4 Living Fences

Living fences are recognized as the most ancient and widespread agroforestry practice in Venezuela. Almost in every life zone, linear plantations are found, dividing grazing plots or established as perimeter fences between farms or along road borders. *Gliricidia sepium* is by far the most used species, together with some valuable timber trees such as *Cordia alliodora, C. Thaisiana*, *Cedrela odorata*, *Tabebuia rosea*, *Tabebuia chrysantha*, *Swietenia macrophylla*, *Gmelina arborea*, and *Tectona grandis*. Lozada and Graterol (2003) reported the presence of living fences of

Fig. 12.4 Brahman cattle grazing in a silvopastoral system with *Eucalyptus urophylla* in DEFORSA, Cojedes state, Venezuela. (Photo: E. Escalante)

Cedrela odorata in Rosario de Perija municipality in Zulia state with a growth a rate of 8.2 m^3 km^{-1} $year^{-1}$.

In the coffee production areas, it is common to find living fences with *Erythrina spp.* and *Bursera simaruba*, and in the Andes *Alnus acuminata* is also used (Escalante 1985).

Currently, living fences have gained recognition as a connectivity element in the landscape that has been fragmented by intense deforestation. Those long linear plantations help birds, small mammals, and insects in their dispersion and movement in the ecosystem giving them greater chances of survival (Escalante 2017). Table 12.1 presents some of the most important arboreal and shrub species identified and studied in silvopastoral systems in Venezuela (Fig. 12.5).

12.4 The Silvopastoral Experience at Fundacion Empresas Polar and Fundacion Danac

The Sustainable Tropical Agriculture Program, currently known as the Centro Nacional de Capacitación para Pequeños Productores Agropecuarios (CNCPPA), emerged in 1996 as a result of an alliance between Fundación Empresas Polar, Fundación Danac and the Faculty of Agronomy of the Central University of Venezuela (FAGRO-UCV), in San Javier, Yaracuy state; proposed as an initiative to have a permanent offer of technological innovations in sustainable agriculture and to contribute to the formation and training of talents (farmers, professionals and students) in the knowledge and application of the principles and practices of sustainable agriculture in Venezuela (Escalante & Guerra 2015; Escobar et al. 2000).

12.4.1 Silvopastoral Systems of the Integral Farm of Sustainable Tropical Agriculture

1. Pasture System in Alleys of Matarratón (*Gliricidia sepium*) and Leucaena (*Leucaena leucocephala*).

The pasture system in alleys of *L. leucocephala* and *G. sepium* covers a total area of 10 ha. The paddocks were divided with electrified fences into 0.25 ha modules for a total of 40 modules. *G. sepium* and *L. leucocephala* were established in double rows separated at 5 m and with a distance between rows and between plants of 1 m (1 m × 1 m × 5 m) for an initial planting density of 3333 plants per ha. The predominant grasses are Estrella (*Cynodon nlemfuensis)*, Guinea (*Megathyrsus maximus*), *Brachiaria mutica* and Caribe (*Eriochloa polystachya*) (Messa-Arboleda et al. 2009).

The herd is managed under rotational grazing, with an occupation time of 2 days and 74 days of rest, and an average stocking rate of 2.2–2.5 AU ha^{-1} (1 AU equals 450 kg LW). However, in the dry season and due to the lower availability of fodder,

Table 12.1 Arboreal and shrub species important in silvopastoral systems in Venezuela

Family	Species	Common name	Main use, function and services							Cited by
			F	Fr	NF	Sh	T	FW	She	
Acanthaceae	*Trichanthera gigantea*	Naranjillo, Yatago, Nacedero	X			X			X	Solórzano et al. (2004), García et al. (2008a), Rengifo et al. (2008), Messa-Arboleda et al. (2009), Camacaro et al. (2013), Farreras and Schargel (2015)
Anacardiaceae	*Anacardium excelsum*	Mijao		X		X		X	X	Escalante (1985), Solórzano et al. (2004), Domínguez et al. (2007), Camacaro et al. (2013)
Anacardiaceae	*Spondias mombin*	Jobo		X		X	X		X	Solórzano et al. (2004), Domínguez et al. (2007), Cardozo (2008), Camacaro et al. (2013)
Anacardiaceae	*Mangifera indica*	Mango		X						Solórzano et al. (2004)
Arecaceae	*Attalea butyracea*	Palma de agua				X				Escalante (1985), Solórzano et al. (2004), Cardozo (2008), Farreras and Schargel (2015)
Arecaceae	*Copernicia tectorum*	Palma llanera				X				Escalante (1985)
Arecaceae	*Acrocomia aculeata*	Corozo		X		X				Escalante (1985), Casado et al. (2001), Solórzano et al. (2004), Messa-Arboleda et al. (2009)
Asteraceae	*Tithonia diversifolia*	Botón de oro	X	X					X	García et al. (2008a)
Betulaceae	*Alnus acuminata*	Aliso			X	X	X	X	X	Escalante (1985)

(continued)

Table 12.1 (continued)

Family	Species	Common name	Main use, function and services							Cited by
			F	Fr	NF	Sh	T	FW	She	
Bignoniaceae	Crescentia *cujete*	Totumo, Taparo	X	X		X				Solórzano et al. (2004), Cardozo (2008), Messa-Arboleda et al. (2009)
Bignoniaceae	*Tabebuia chrysantha*	Araguaney				X			X	Escalante (1985)
Bignoniaceae	*Tabebuia rosea*	Apamate					X			Escalante (1985), Camacaro et al. (2013)
Bombacaceae	*Ceiba pentandra*	Ceiba				X	X		X	Farreras and Schargel (2015)
Boraginaceae	*Cordia alliodora*	Pardillo				X	X			Escalante (1985), Camacaro et al. (2013)
Boraginaceae	*Cordia thaisiana*	Pardillo negro				X	X			Escalante (1985), García et al. (2008a), Rengifo et al. (2008)
Burseraceae	*Bursera simaruba*	Indio desnudo				X			X	Escalante (1985)
Cactaceae	*Pereskia guamacho*	Guamacho	X			X		X		Rengifo et al. (2008)
Fabaceae	*Inga interrupta*	Guamo	X	X	X	X				Camacaro et al. (2013)
Fabaceae	*Inga* spp.	Guamo	X	X	X	X				Domínguez et al. (2007), Cardozo (2008), Farreras and Schargel (2015)
Fabaceae	*Albizia guachapele*	Masaguaro	X	X	X	X	X		X	Camacaro et al. (2013)
Fabaceae	*Cassia moschata*	Cañafistola		X	X	X		X	X	Escalante (1985), Solórzano et al. (2004), Domínguez et al. (2007), Camacaro et al. (2013)
Fabaceae	*Cassia siamea*	Acacia		X	X	X				García et al. (2009a, b)

(continued)

Table 12.1 (continued)

Family	Species	Common name	Main use, function and services							Cited by
			F	Fr	NF	Sh	T	FW	She	
Fabaceae	*Chloroleucon mangense*	Palo fierro	X		X		X		X	Casado et al. (2001), Cecconello et al. (2003)
Fabaceae	*Enterolobium cyclocarpum*	Caro caro		X		X	X		X	Escalante (1985), Casado et al. (2001), Cecconello et al. (2003), Solórzano et al. (2004)
Fabaceae	*Pithecellobium dulce*	Uña de gato	X	X	X	X			X	Nouel and Rincón (2004), Camacaro et al. (2013)
Fabaceae	*Gliricidia sepium*	Matarratón	X		X	X	X	X		Escalante (1985), Solórzano et al. (2004), García and Medina (2006), Messa-Arboleda et al. (2009)
Fabaceae	*Leucaena leucocephala*	Leucaena	X		X	X		X		García et al. (2008a), Messa-Arboleda et al. (2009)
Fabaceae	*Samanea saman*	Saman, Lara	X	X	X	X	X		X	Escalante (1985, 2017), Moreno and Daal (1998), Solórzano et al. (1998), Cecconello et al. (2003), Morales (2005), Domínguez et al. (2007), Molina Prieto (2008)
Fabaceae	*Erythrina fusca*	Bucare	X		X	X			X	Camacaro et al. (2013)
Fabaceae	*Acacia macracantha*	Cují negro	X	X	X	X		X		Escalante (1985), Casado et al. (2001), Domínguez et al. (2007), Rengifo et al. (2008)

(continued)

Table 12.1 (continued)

Family	Species	Common name	Main use, function and services							Cited by
			F	Fr	NF	Sh	T	FW	She	
Fabaceae	*Caesalpinia coriaria*	Dividive	X	X	X	X		X	X	Casado et al. (2001), Camacaro et al. (2013)
Fabaceae	*Prosopis juliflora*	Cují	X	X	X	X		X	X	Escalante (1985), García et al. (2009a, b), Messa-Arboleda et al. (2009)
Fabaceae	*Mimosa trianae*	Cujicillo			X	X		X	X	Nouel and Rincón (2004)
Fabaceae	*Cassia occidentalis*	Brusca	X		X	X				Nouel and Rincón (2004)
Fabaceae	*Acacia polyphylla*	Carbonero			X	X			X	Nouel and Rincón (2004)
Fabaceae	*Acacia macracantha*	Uveda, Cuji negro	X		X	X			X	Nouel and Rincón (2004)
Fabaceae	*Platymiscium pinnatum*	Roble	X		X	X	X		X	Escalante (1985, 2017)
Fabaceae	*Pithecellobium unguis-cati*	Yacure, Taguapire	X		X	X			X	Rengifo et al. (2008)
Fabaceae	*Cercidium* praecox	Yabo	X		X	X			X	–
Meliaceae	*Cedrela odorata*	Cedro				X	X			Escalante (1985), Lozada and Graterol (2003), Farreras and Schargel (2015)
Meliaceae	*Swietenia macrophylla*	Caoba					X			Escalante (1985), Camacaro et al. (2013), Farreras and Schargel (2015)
Moraceae	*Maclura tinctoria*	Mora	X			X	X	X		Cardozo (2008)
Moraceae	*Morus* spp	Morera	X							García et al. (2008a), Messa-Arboleda et al. (2009)
Myrtaceae	*Eucalyptus urophylla*	Eucalipto				X	X			Escalante & Guerra (2015)
Pinaceae	*Pinus caribaea*	Pino caribe					X		X	Escalante (1985), Escalante et al. (2011)

(continued)

Table 12.1 (continued)

Family	Species	Common name	Main use, function and services							Cited by
			F	Fr	NF	Sh	T	FW	She	
Rubiaceae	*Genipa americana*	Caruto		X		X	X			Domínguez et al. (2007), Cardozo (2008), Camacaro et al. (2013)
Sterculiaceae	*Guazuma ulmifolia*	Guácimo	X	X		X		X	X	Escalante (1985), Casado et al. (2001), Solórzano et al. (2004), Domínguez et al. (2007), García et al. (2008b), Rengifo et al. (2008), Camacaro et al. (2013)
Verbenaceae	*Tectona grandis*	Teca					X			Escalante (1985), Escalante & Guerra (2015)
Zygophyllaceae	*Bulnesia arborea*	Vera	X	X		X			X	Escalante (1985), García et al. (2009a, b)

F forage, *FR* fruits, *NF* nitrogen fixation, *SH* shade, *T* timber, *FW* firewood, *She* shelter

Fig. 12.5 Linear plantation of Teca (*Tectona grandis*) alongside perimeters of a silvopastoral system in a tropical dry forest at Danac Foundation, Yaracuy state, Venezuela. (Photo: E. Escalante)

the occupation time is reduced to one day and consequently, the rest time decreases to 37 days. *G. sepium* and *L. leucocephala* are periodically pruned to keep it accessible to the cattle (Messa-Arboleda et al. 2009).

2. Enhanced pasture with high density scattered trees

The improved pasture with scattered trees is located on a low terrace with flat to undulating relief, covers a total area of 3.3 ha and is divided into two plots of 1.68 ha each. The predominant grass is *M. maximus* combined with the following trees: *Samanea saman*, *Guazuma ulmifolia*, *Enterolobium cyclocarpum* and *Pterocarpus officinalis*; established by natural regeneration at a density of 120 trees ha^{-1} (Messa-Arboleda 2009). This system is used for grazing growing animals, mainly replacement females, with a stocking rate of 1.0–1.5 AU ha^{-1} (Messa-Arboleda 2009).

3. Mixed fodder bank of Matarratón (*Gliricidia sepium*), Naranjillo (*Trichanthera gigantea*) and Morera (*Morus spp.*).

As of the year 1997, the establishment of a mixed fodder bank began, by planting in alleys *G. sepium*, *T. gigantea* and *Morus spp.*, and covers an area of 1.1 ha. The mixed bank is a multilayer system, consisting of *G. sepium* in rows spaced 5 m × 0.6 m between plants, with *T. gigantea* and *Morus spp.* established at 1 m × 0.6 m in the alleys. The plants of *G. sepium* were established with sexual seed collected in the area and the plants of *T. gigantea* and *Morus* spp., by vegetative seed. The species were established in a nursery and after three to four months of age were transplanted at the beginning of the rainy season. The system is managed under cutting and hauling, for the supplementation of cows in production and calves, through fresh consumption, silage, and for the elaboration of multi-nutritional blocks with flours obtained from sun-dried foliage. The plants are pruned every 3–4 months, at an approximate height of 1.0–1.5 m and the stems are distributed between the rows of the legume; providing soil coverage, barriers for erosion control and organic matter (Messa-Arboleda 2009).

4. The Multilayer Silvopastoral System

The multilayer silvopastoral system covers an area of 4.4 ha and has been jointly developed by Fundación Danac and the CNCPPA since 2002 (Messa-Arboleda et al. 2009). The system consists of three plant layers, whose components fulfill different functions and services, and *Megathyrsus maximus* grass.

(a) Tree Layer: made up of leguminous species that produce fruits, wood and firewood, such as *S. saman*, *P. juliflora* and *C. moschata* mixed with Corozo palm (*Acrocomia aculeata*). In this stratum, timber species of high commercial value such as *Tectona* grandis, *Cordia thaisiana*, *Swietenia macrophylla* and *Tabebuia rosea* are also included for timber production.
(b) Shrub layer: constituted by *L. leucocephala*, established at high density in quadruple strips and pruned at 1 m height to facilitate accessibility (browsing) of forage by cattle.
(c) Herbaceous stratum: conformed by *Megathyrsus maximus*, provides fodder for animals, in addition to soil cover and organic matter.

The multilayer system, was divided into modules or paddocks of 0.2 ha, by electrified fences and managed under rotational grazing. The incorporation of cattle into the system began in 2007 with heifers, with a low stocking rate (1 AU ha^{-1}) to avoid damaging the developing trees. As of 2008, adult bovine animals were introduced, and the animal load in the system was progressively increased (Messa-Arboleda et al. 2009; Escalante 2017) (Fig. 12.6).

5. Live fences of *Gliricidia sepium*, Linear Plantation with oil and timber palms and Biological Corridors

The integral farm has some segments of live fences, composed mainly by *Gliricidia sepium* to provide shade and forage for the animals. Also, there are linear plantations and scattered of oil palms, such as *Elaeis guineensis, Acrocomia aculeata and Bactris gasipaes*. The fruits of these palms are used as a source of energy for lactating cows (fresh and ground and silaged with lime) and for poultry (the whole fruit is offered). A part of the oil palm plants (*Acrocomia aculeata*) is associated with a productive decontamination system that is integrated into the pig production of the farm.

As an alternative for the use of space, the conservation of wildlife habitats and the expansion of small-scale timber production on the farm, among others; since 2002, the species *T. grandis, C. thaisiana, S. macrophylla and T. roseae*, located 4 m apart between trees, were established on the perimeter of the area (700 m) of the improved pasture with scattered trees. The farm also has a collection of Totumo (*Crescentia cujete*) of 0.1 ha whose fruits were used to feed lactating cows and poultry.

Fig. 12.6 Multilayer silvopastoral system in the integral farm of sustainable tropical agriculture. Danac Foundation. (Photo: E. Escalante)

12.4.2 Cattle Production

The dual-purpose cattle herd of the integral farm is made up of *Bos taurus* x *Bos indicus,* with a predominance of the *Holstein* x *Cebu* and *Swiss Brown* x *Cebu* crosses. Cows are managed under rotational grazing in silvopastoral systems, with an average stocking rate ranging from 2.2 to 2.5 AU ha^{-1}. The animals are supplemented according to their physiological state and in pre-established amounts according to the management of the farm. For this, forage of *G. sepium*, *T. gigantea* and *Morus spp*., silages made with Cassava (*Manihot esculenta)* (root + foliage), *Sorghum vulgare* and/or *S. officinarum* (sugarcane) and *Canavalia ensiformis*; ground fruits and silage of Oil palm (*Elaeis guineensis*) (partially saponified with calcium) and multi-nutritional blocks *ad libitum.* Growing females (post-weaning) graze in an improved pasture with scattered trees with average animal load of 1.5 AU ha^{-1} (Messa-Arboleda et al. 2009).

The total availability of plant biomass in the pasture in alleys showed average values of 3.31 and 3.87 t DM ha^{-1} $cycle^{-1}$ during the dry and rainy periods respectively. Of the total available biomass per year (40.65 t DM ha^{-1}), about 92% is contributed by grasses (*Cynodon nlemfuensis, M. maximus, Brachiaria mutica* and *Echinochloa polystachya*) and the remaining 8% by shrub legumes (*G. sepium* and *L. leucocephala)* (Messa-Arboleda et al. 2009).

12.4.3 Environmental Benefits

From the environmental point of view, there is evidence that demonstrates that the establishment and management of the different productive components of the integral farm have contributed to the conservation and improvement of the soils, increased the vegetal cover, animal welfare, the protection of water sources, carbon sequestration in the soil and in the aboveground biomass. They have also contributed to the compensation of greenhouse gas emissions and increased biodiversity associated with the production system (birds, mammals, reptiles, insects and plants), it has also favored connectivity between forested patches surrounding the farm and contributed to the beauty and aesthetics of the landscape (Messa-Arboleda et al. 2009).

Regarding the carbon storage in the system, different land uses linked to the bovine subsystem of the integral farm and a fragment of primary forest (control) adjoining the farm were evaluated (Messa-Arboleda 2009). The total carbon in the system (organic soil carbon + total carbon above ground) in the primary forest was 3.2 times higher than the average value of the systems intervened (73.88 Mg ha^{-1}). The systems with anthropic intervention presented total carbon storage values in a range of 63.79–100.69 Mg ha^{-1}, for the sugarcane and the improved pasture with scattered trees, respectively.

Evaluations made in the tree component in multilayer silvopastoral systems determined that among the legume trees *S. saman* was the species with the best growth and development, while in terms of timber trees, *T. grandis* presented the largest Annual Average Increase for diameter at breast height, (DBH), Total Height (TH), and Fuste Height (FH), with values of 1.75 cm year^{-1}, 1.09 m year^{-1} and 0.51 m year^{-1} respectively; followed by *Cordia thaisiana* (Messa-Arboleda et al. 2009).

12.4.4 Biological Corridors

Motivated by the presence of a fragment of primary forest and a gallery forest surrounding the Quebrada Naranjal, apparently separated by anthropic intervention, on the integral farm from 1997–1998, the area was reforested and manages natural regeneration in a strip of approximately 300 m of length and 15–20 m wide, with what is currently achieved connectivity between both natural formations, providing spaces for the protection and mobility of different wildlife species present in these forests (Messa-Arboleda et al. 2009).

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