# Chapter 10
# Agro-Silvopastoral Systems for the Andean-Amazonian Foothills of Colombia

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**Abstract** The Andean-Amazonian piedmont region of Colombia is recognized for its richness in terms of biodiversity and, at the same time, for the high deforestation that threatens it. This is the case of the Department of Caquetá, which has the highest rates of deforestation in the country. In this department, the colonization processes were developed mainly through extensive cattle ranching to occupy the territory and obtain economic benefits in the short term. This production system is continued until the present day. In this context, the document presents an intervention approach at the farm and landscape levels, to conserve and restore forests and wetlands, and promote the sustainable intensification of extensive cattle ranches. Different options of agro-silvopastoral systems are presented, including improved pasture management, live fences, scattered trees in pastures and mixed fodder banks for feed and food security.

**Keywords** Colombian Amazon · Livestock agroforestry · Sustainable cattle raising

## 10.1 Introduction

In Colombia, the transition between the Andes and the Amazon is widely recognized for its enormous richness and diversity of fauna and flora species, as well as its important role as a bridge to facilitate connectivity, migration, and diversification of species (Clerici et al. 2019). The Andean-Amazon piedmont is an important water pantry of the large Amazon River basin (Peña et al. 2016).

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J. Chará, S. Jose (eds.), *Silvopastoral Systems of Meso America and Northern South America*, https://doi.org/10.1007/978-3-031-43063-3_10

Throughout history, the settlement of the Amazon region in Colombia has been linked to the extractive economic dynamics of its natural resources; first gold in colonial times and later products such as cinchona (*Chinchona sp.*) and rubber (*Hevea brasiliensis*); in recent times, crops for illicit use such as coca (Arcila-Niño and Salazar-Cardona 2011).

Between 1950 and 1970, peasants from other regions of the country began to colonize the Andean-Amazon piedmont region (Salazar 2007). This colonization generated the greatest transformation and consolidation of anthropic activity and, at the same time, the greatest economic and social dynamics in the Colombian Amazon. These spatial dynamics of settlement continued with new vectors of occupation and colonization, from the periphery to the center in the Amazonian Forest (Salazar and Riaño 2016; Arcila-Niño and Salazar-Cardona 2011).

During the last decade, Caquetá has been the department with the largest deforested area at the national level, responsible for 22% of the total area in 2021 (IDEAM 2022b) concentrating deforestation in the municipalities of Cartagena del Chairá, San Vicente del Caguán and Solano. The change in land use is oriented towards land grabbing, conversion of forest to pasture, illicit crops, development of unplanned transportation infrastructure, illegal mineral extraction, and the expansion of the agricultural frontier in non-permitted areas (IDEAM 2022a, b).

According to a study developed by SINCHI on typologies of predominant productive systems in Caquetá, cattle ranching is the main activity in 68% of the farms studied (Jiménez et al. 2019). The department ranks fifth in cattle inventory and third in milk production at the national level, with 2,198,256 head of cattle (7.5%) (ICA 2022) and 1,948,167 liters of milk per day (8.9%) (DANE 2020), respectively.

According to the interventions carried out in the department through the different institutions present in the region, different designs of agro-silvopastoral systems have been promoted, with different levels of complexity in terms of implementation, management, labor availability, costs and acceptance by the producer.

The intervention model is based on three pillars: conservation and restoration, adaptation to climate change and sustainable intensification of livestock (Solarte et al. 2017), which is based on adequate planning, intelligent grassland management and increased tree cover in grazing areas in different agrosilvopastoral arrangements (Chará et al. 2019).

Agrosilvopastoral systems have a positive impact on the production and quality of forage, increase the carrying capacity and the production of meat and milk per hectare, while reducing the environmental damage caused by extensive livestock activity, providing a suitable environment to improve the edaphic biota and fauna associated with the system, making it a recommendable option for the producer (Gutiérrez and Mendieta 2022).

This chapter presents a description of the Andean-Amazonian piedmont and the experiences of agrosilvopastoral systems and their main limitations for adoption, as well as strategies for their scaling up.

## 10.2 The Context of the Andean-Amazon Piedmont Region

The eastern Andean Mountain range in Peru, Ecuador and Colombia that borders the Amazon basin is the region known as the Andean-Amazon piedmont (Hernandez and Naranjo 2007). In Colombia, it corresponds to the eastern slope of the eastern cordillera, a strip of territory that communicates the Andean and Amazonian biomes, corresponding to the western Amazonian or piedmont subregion, in a part of the departments of Cauca, Caquetá and Putumayo (Salazar and Riaño 2016) (Fig. 10.1).

In Colombia, the transition between the Andes and the Amazon is a region of interest for biological conservation and research, widely recognized for its enormous richness and diversity of fauna and flora species, as well as for its important role as a bridge to facilitate connectivity, migration and diversification of species (Clerici et al. 2019). The region has about 29 ecosystems of terrestrial and aquatic environments, which are distributed in ecoregions of tropical rainforest, Andean forests and paramos (Barrera et al. 2007).

The Andean-Amazon piedmont is an important water pantry of the large Amazon basin (Peña et al. 2016). The high rainfall in the eastern Andes is the result of the aerial rivers formed by the interaction between evapotranspiration from the Amazon forests and the air currents that flow from the Atlantic Ocean to the Andean orographic barrier, which provide water to the Caquetá and Putumayo rivers, tributaries of the Amazon River, and supply water to communities and population centers located in the foothills and the Amazon plain (Poveda et al. 2006).

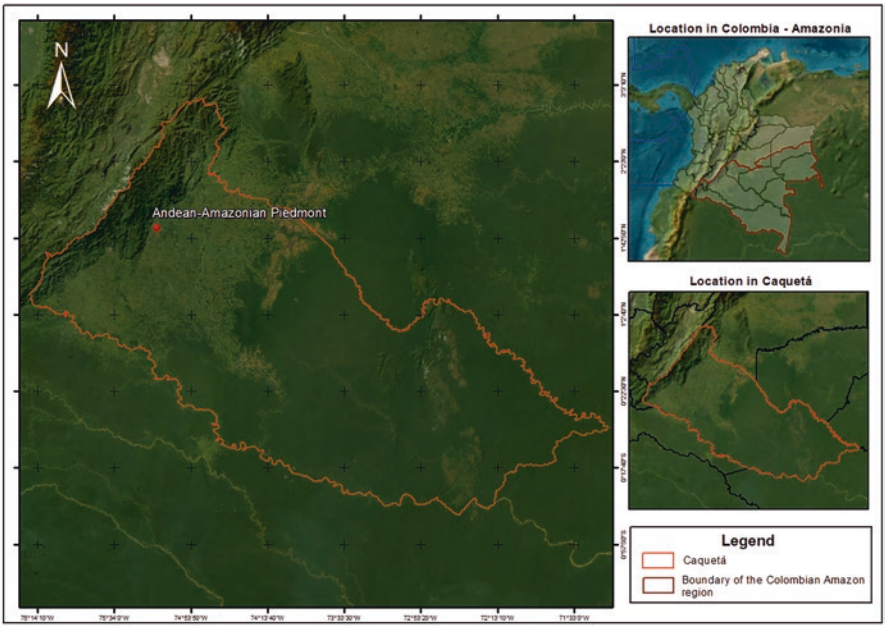


**Fig. 10.1** Map of the Andean-Amazonian piedmont in Colombia

The Andean Amazon piedmont has been inhabited for 3000 years by different indigenous peoples (Salazar 2007). Throughout history, the population of this region in Colombia has been linked to the extractive economic dynamics of its natural resources: first gold in colonial times and later products such as cinchona (*Chinchona sp.*) and rubber (*Hevea brasiliensis*), to supply markets in the United States and Europe. In recent times, illicit crops such as coca, timber extraction, illegal mining and hydrocarbon exploitation appeared (Arcila-Niño and Salazar-Cardona 2011).

Between 1950 and 1960, the Colombian government initiated a strategy to promote the colonization of the Andean-Amazon piedmont of Caquetá. Consequently, the department has the highest urban and rural population density rates in the entire Amazon region of Colombia (Salazar and Riaño 2016).

With the signing of the peace agreement between the government and the FARC-EP guerrillas in 2016, there was an increase in deforestation in the region as the control and pressure exerted by the guerrillas throughout the territory was reduced (Murillo et al. 2020; Prem et al. 2020; Rodriguez et al. 2017). Consequently, during the last 6 years the department of Caquetá has led the ranking of departments with the highest deforestation and in 2021 contributed 22% of the total deforested area in Colombia, particularly in the municipalities of Cartagena del Chairá, San Vicente del Caguán and Solano (IDEAM 2022b).

Deforested areas are mainly used for land grabbing, extensive cattle ranching, illicit crops, illicit mineral extraction, illegal logging and the expansion of the agricultural frontier in non-permitted areas (IDEAM 2022a,b).

## 10.3 Cattle Ranching in the Andean-Amazon Piedmont in the Department of Caqueta

### *10.3.1 Evolution of Cattle Ranching in the Amazonian Foothills*

Since the mid-nineteenth century, cattle ranching has been associated with the transformation of the landscape in Latin America, intensifying its impact in the second half of the twentieth century. The introduction and wide acceptance of grass species of African origin mainly Brachiarias and the changes in the genetics of cattle through the introduction of crossbreeds and breeds have contributed to this fact. This process, which began in Brazil in the 1950s, was supported by governments and research and development institutions, then spread to other countries in the region (Van Ausdal and Wilcox 2013). In the case of Colombia, the main advance of cattle ranching in the Amazon region has occurred in the foothills of the department of Caquetá.

According to Michelsen (1990), the gradual growth of areas under extensive grazing in the department and the arrival of dairy processing companies led Caquetá to become important as a milk-producing region based on dual-purpose models in which part of the breeding cows in the cattle herds were destined for milking.

Since the early 1990s, research centers such as the International Center for Tropical Agriculture (CIAT), the Colombian Agricultural Institute (ICA), the Colombian Agricultural Research Corporation (Agrosavia), the University of the Amazon, and private enterprise initiatives, Nestlé and Fondos Ganaderos, began a process of identification, validation and incorporation of tropical pasture and legume resources to improve productivity and reorient livestock farming toward more intensive systems. According to Rivas and Hollmann (1999), during this period improved varieties of *Brachiaria sp*. and legumes such *as Arachis pintoi* were incorporated in partnership between CIAT and Nestlé.

Pioneering research led by Agrosavia proposed different tree and shrub species for arrangements such as protein and energy banks, forest or tree stands, live fences, strips of shrub and tree species, and herbaceous forage management (Cipagauta and Andrade 1997; Cipagauta et al. 2002; Escobar and Cipagauta 2005).

Beginning in 2000, organizations focused on the promotion of productive alternatives and rural development, such as research centers, academia, the cattle-raising association, the dairy sector and NGOs started the promotion and research on sustainable cattle-raising models. The Universidad de la Amazonia led the creation of a silvopastoral network of producers in three municipalities of the Colombian Amazon piedmont, with the purpose of adopting and validating sustainable production alternatives (Rodriguez et al. 2006).

Nestlé and the Center for Research on Sustainable Agricultural Production Systems (CIPAV) jointly developed the project Environmentally Sustainable Milk (LAS) between 2008 and 2011, which promoted the development of silvopastoral systems in several nuclei of farms in the department of Caquetá (Tafur et al. 2011, which allowed the scaling up of these initiatives in 2015 by Nestlé with support from the Inter-American Development Bank (IDB) to expand the silvopastoral systems to 100 farms (Nestlé 2011).

From 2010 to date, national and international cooperation projects related to climate change and biodiversity have prioritized the development of sustainable cattle ranching initiatives in the Colombian Amazon, with special attention to the departments where deforestation figures have increased, as is the case of Caquetá. Among the alternatives promoted, the component of innovation and pasture management and silvopastoral systems stand out.

### *10.3.2 Livestock Production in the Andean-Amazon Piedmont in Caqueta*

According to UPRA (2018), cattle ranching in the department of Caquetá occupies 1,628,761 ha. However, the area considered suitable for this activity is 1.3 million ha, as protection zones, riverbanks, slopes and wetland areas, among others, must be excluded.

According to ICA (2022), the department's cattle population reached 2,198,256 head of cattle in 2021, which places Caquetá fifth in the country with 7.5% of the national cattle herd. The department's cattle herd has grown steadily over the last decade, especially since 2016 (FEDEGÁN 2022), after the signing of the peace agreement between the national government and the FARC - EP guerrilla (*Fig. 10.2*).

Most of the cattle herd inventory at the regional level is concentrated in the municipalities of San Vicente del Caguán (41.4% of the herd), Cartagena del Chairá (17%) and Puerto Rico (9.3%). In terms of composition, the most representative age group is females over 3 years with 31.7% of the herd, followed by calves under 1 year with 23.7%, females and males between 1 and 2 years with 10.9% and females between 2 and 3 years with 10.7% (ICA 2022).

Cattle raising is mainly oriented towards dual-purpose production (Torrijos 2022), whose main characteristic is the milking of the cow and suckling of the calf to supply fresh milk to dairy companies and the sale of the calf 2 or 3 months after weaning, when it enters the rearing and fattening process (Cipagauta et al. 2002). This system has been consolidated since the late 1970s when the dairy sector began to develop a stable market with the presence of the multinational Nestlé, which provided financing to farmers for herd technification and improvement with dairy breeds (Nestlé 2011).

Caquetá produces 1,948,167 liters of milk per day, which is equivalent to 8.9% of national production and places it in third place as a dairy producer after the departments of Antioquia and Boyacá (DANE 2020). Livestock activity is carried out on 20,512 farms (FEDEGÁN 2022), of which 41.9% have between 1 and 50 animals, 26.2% have between 51 and 100 animals, and 29.8% have between 101 and 500 animals (ICA 2022). These data show that livestock activity in the region is mainly small and medium scale (Torrijos 2022).

Olarte-Hurtado et al. (2022) evaluated the effect of forage production of 13 types of pastures between native and introduced on milk production in the Colombian

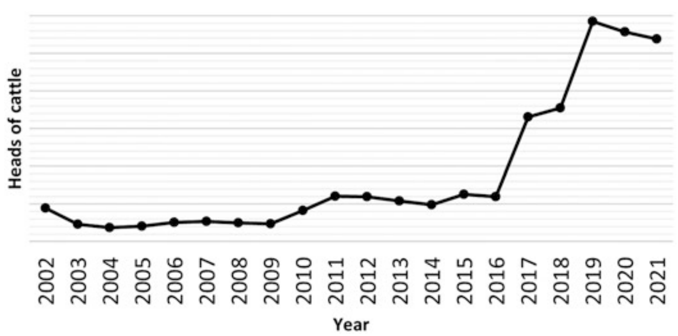


**Fig. 10.2** Total cattle and buffalo inventory for Caquetá over a 19-year period. (Source: Subdirección de Salud y Bienestar Animal – Fedegán (FEDEGAN 2022))

Amazon, finding the highest milk production associated with pastures in *Pennisetum purpureum cv* OM22 (6.77 kg milk cow/day), *Brachiaria ruziziensis* (5.72 kg milk cow/day), *Homolepsis aturiensis* (5.5 kg milk cow/day), *Homolepsis aturiensis* (5.5 kg milk cow/day); The lowest in *Andropogon gayanus* (3.36 kg cow milk/day) and *Brachiaria brizantha cv* Toledo (3.73 kg cow milk/day). Suárez et al. (2013), in a characterization of cattle farms under the dual-purpose system in the department of Caquetá, found milk yields ranging from 1.26 to 4.54 kg cow$^{-1}$ day$^{-1}$ in three types of farms (small, medium, large) that differed mainly in the availability of forage for animal feeding and pasture rotation. Table 10.1 shows the productive parameters of dual-purpose cattle raising in the Caquetá piedmont.

Different studies conducted in Caquetá, mention that the animal load in the region is between 0.73 and 0.8 UGG ha$^{-1}$ (Motta and Ocaña 2018; Pallares 2014) in

**Table 10.1** Productive and reproductive parameters of the dual-purpose system in the department of Caquetá

| Parameter | Unit | Authors | | | | | |
|---|---|---|---|---|---|---|---|
| | | Cipagauta et al. 2001[a] | Cipagauta and Orjuela 2003[b] | Santana et al. 2009[c] | Tafur et al. 2011[d] | Torrijos et al. 2015[e] | Motta and Ocaña 2018[f] |
| Mean age at first parturition | Months | 40.8 | | | | 42.1 | |
| Interval between deliveries | Days | 462.4 | | 401–700 | | 480 | |
| Lactation duration | Days | 224 | | | 280 | | |
| Milk pruduction cow/day | Kg | 4 | | | 4.8 | | 6.08 |
| Weaning age | Months | | | >10 | | | 9.15 |
| Weaning weight | Kg | 160 | | 151–180 | 160 | 159.3 | 168.5 |
| Daily weight gain | g/day | | 370–600 | | | 481 | |
| Birth rate | % | | | 56–65 | 60 | 72 | |

[a]Productive behavior of *Bos Taurus x Bos indicus* crosses in a genetic improvement process with dual purpose cattle from the Piedemonte Caqueteño. EPP n = 111, IEP n = 284, DL = 475
[b]Use of agrosilvopastoral techniques to contribute to optimize land use in the intervened area of the Amazon
[c]Prospective research and technological development agenda for the cattle chain in Colombia
[d]Construction of a baseline with 13 cattle producers in the municipalities of Curillo, Albania, Belén de los Andaquíes, Morelia, El Doncello, La Montañita, Valparaíso, and Florencia
[e]Values presented according to the monitoring of the Departmental Livestock Committee of Caquetá in the region
[f]*Braquiarias sp.* pasture subsystems were characterized in humid tropical herds in the department of Caquetá, Colombia N = 20

traditional extensive systems, which is characterized by the incorporation of cultural management practices, both of the pasture and of the animals, aimed at preserving and, sometimes, enhancing the productive capacities of the livestock agroecosystem; the fundamental basis of production is the natural or introduced pasture of low productivity (Cajas et al. 2011), but with good practices of pasture rotation and implementation of agrosilvopastoral systems can reach from 1.43 UGG $ha^{-1}$ to 3.65 UGG $ha^{-1}$ (Lopera-Marín et al. 2019a; Rivera et al. 2015).

## 10.4 Approach to the Intervention of Alternatives for the Sustainability of Livestock Landscapes

The intervention model is based on three pillars: (i) conservation and restoration, (ii) adaptation to climate change and (iii) sustainable livestock intensification (Fig. 10.3). The approach must start with larger-scale environmental land-use planning processes that make it possible to reduce deforestation and zone the areas dedicated to livestock farming, through a combination of policies that include regulations, command and control mechanisms and incentives (Fig. 10.4).

Sustainable ecological intensification is proposed as an alternative close to agroecology, organic agriculture and agroforestry, which seek to take greater advantage of ecological processes for agricultural production (Tittonell 2014).

Along the same line of thought, one of the alternatives proposed for this productive reconversion of livestock production corresponds to reorienting extensive grazing systems towards systems capable of producing meat and/or milk, while at the

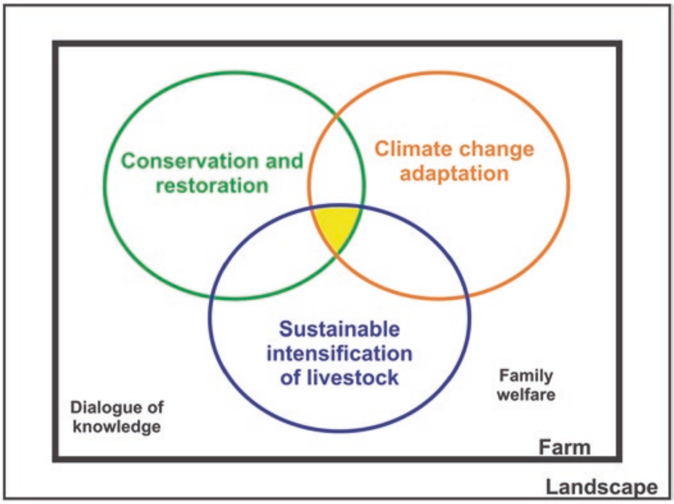


**Fig. 10.3** Approach for intervention in livestock production systems. (Adapted from Solarte et al. 2017)

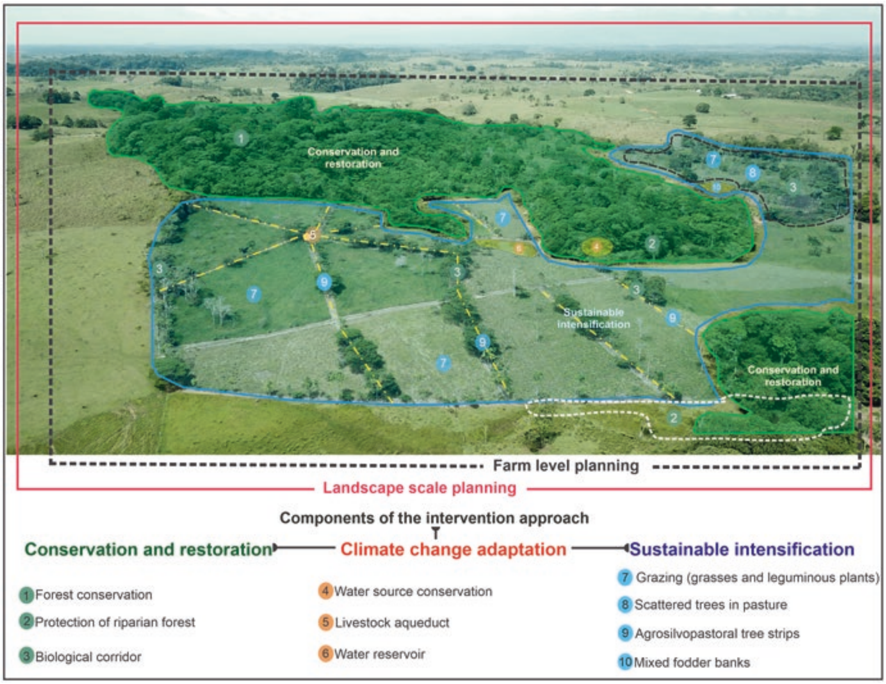


**Fig. 10.4** Approach to landscape scale planning in the Andean-Amazonian foothills

same time conserving ecosystems, based on the use of agroforestry as a means of production (Tittonell 2014).

Along the same line of thought, one of the alternatives proposed for this productive reconversion of livestock production is to reorient extensive grazing systems towards systems capable of producing meat and/or milk, and at the same time conserving ecosystems, based on alternatives generically known as agrosilvopastoral systems (SPS).

SPS are a form of livestock agroforestry, in which forage plants such as grasses and leguminous plants are combined in the same space with shrubs and trees for animal feed and other complementary uses (Murgueitio and Ibrahim 2001).

Within this same category, agrosilvopastoral systems are ecological intensification processes that seek to improve family welfare and build sustainable livestock farming adapted to climate variability (Solarte et al. 2017). A sustainable livestock intensification process at the farm and landscape scale must combine at least three elements (Chará et al. 2020):

(i) adequate planning, which allows the identification of areas dedicated to production and those dedicated to ecosystem conservation and restoration including the protection of springs, watercourses and wetlands;

(ii) a transition from traditional extensive management to intelligent grassland management, including rotational grazing with adequate stocking rates, division of paddocks, and provision of water through livestock aqueducts; and
(iii) an increase in tree cover in grazing areas through different agrosilvopastoral arrangements that contribute to improving productivity, animal welfare and the provision of environmental services, while contributing to the connectivity of protected areas.

Climate change scenarios for the department for the period 2011–2040 project an increase in temperature between 0.8 and 1 °C, an increase of up to 10% in precipitation in the highlands (mountain range), and a decrease of up to 19% in the foothills and the Amazon plain of Caquetá (IDEAM et al. 2017). In this sense, livestock farms should be prepared to face temperature increases and seasons of lower and higher precipitation with actions to adapt to climate change.

Solarte et al. (2022a) identified three climate signals (high precipitation and flooding; low precipitation and drought; and increased temperature) that affect livestock families in the Amazon piedmont and 13 adaptation measures for livestock activities related to efficient water managment, soil and pasture management, and animal welfare. The measures are listed below:

1. Conservation of water sources
2. Water harvesting
3. Livestock aqueduct
4. Vegetation cover
5. Tree cover in pastures
6. Adequate pasture management
7. Tracks for cattle transit
8. Transitory use of shade cloths
9. Crossbreeds and adapted breeds
10. Mixed Fodder Banks
11. Forage conservation
12. Improvement of buildings
13. Semi-confinement of livestock

### *10.4.1 Alternatives for the Sustainability of Livestock Landscapes*

According to the interventions carried out by different institutions in the department, nine agrosilvopastoral arrangements have been promoted, which vary in their level of complexity in terms of implementation, management, labor availability, costs and acceptance by the producer (Table 10.2). These include scattered trees in pastures, live fences, sustainable pasture division, tree strips, woodlots or stands, mixed fodder banks, forage hedges and intensive silvopastoral systems (Fig. 10.5).

**Table 10.2** Level of requirements for the establishment and management of each system according to its complexity

| System | Level of requirements per system | | | | |
|---|---|---|---|---|---|
| | **Investment** | **Labor** | **Management** | **Knowledge** | **Technical assistence** |
| Scattered Trees in Pasture | Low | Low | Low | Medium | Low |
| Live Fences | Low | Low | Medium | Medium | Medium |
| Sustainable Pasture Division | Medium | Medium | Medium | Medium | Medium |
| Pastures division with tree strips | Medium | Medium | Medium | Medium | Medium |
| Pasture division with agrosilvopastoral strips | High | High | Medium | Medium | Medium |
| Woodlots or stands | High | High | Medium | Medium | Medium |
| Mixed Fodder Banks | High | High | High | High | High |
| Forage Hedges | High | High | High | High | High |
| Intensive Silvopastoril Systems | High | High | High | High | High |

High Medium Low

These systems are designed to produce beef and milk, and also allow the generation of wood, firewood, fruits and other associated goods, where one or more species from different strata interact in the same space and time (Murgueitio et al. 2016). These strata usually associate pastures of the genus *Brachiaria sp.* and *Urochloa sp.*; herbaceous legumes (*Arachis pintoi, Pueraria phaseoloides),* shrubs, and multipurpose trees (*Cratylia argentea, Tithonia diversifolia (Hemsl.) A.Gray, Trichanthera gigantea, Leucaena sp., Mimosa trianae, Gmelina arborea, Cariniana pyriformis*) and/or by plant succession management (*Inga sp., Bellucia pentámera, Psidium guajava, Zygia longifolia, Vismia baccifera, Piptocoma discolor*, among others (Annex 1).

- ***Scattered trees in pastures (STP)***

As its name indicates, this arrangement refers to natural or improved pastures in which trees or palms are incorporated in densities greater than 25 individuals per hectare in linear or random arrangements. This system can be established by planting and protecting the trees in the pastures in formation or already established. However, the most effective and least costly way to establish this arrangement in the region is through the management of plant succession in which trees and shrubs that grow spontaneously in the paddocks are managed (Tafur et al. 2011). This requires thinning and pruning the existing vegetation in the paddock, to achieve the desired

**Fig. 10.5** Main silvopastoral models promoted in Caqueta department, Colombia. (1) Scattered trees in pastures, (2) Pasture division with tree strips, (3) Pasture division with agrosilvopastoral tree strips. (4) Mixed fodder banks, (5) Live fences, (6) Intensive silvopastoral system with *T. diversifolia*

density of trees and shrubs, and to allow optimal development of pastures, avoiding competition for light. Likewise, it should be considered that not all plant species are desired in a paddock, so it is necessary to select the trees/shrubs that are of interest in the system and in the pasture (Sotelo et al. 2017).

This plant succession management is a valuable tool and the most economical for the recovery of the tree cover of the pastures, as it does not require the removal of animals from the pastures, or the construction of protective fences for the trees and the labor needed is low (Zapata and Silva 2020).

Another alternative for the successional management of vegetation in the region proposed by Cipagauta & Orjuela (2003), is to form small circular or square areas in the center or corners of the pastures to provide shade and protection to livestock during the hottest hours of the day through the generation of microclimates generated by the associated species, to improve the well-being of the animals and the biological activity of the soils.

- ***Live fences (LF)***

Live fences are lines of trees on the main divisions and boundaries of pastures that are used to replace wooden posts or other materials traditionally used to support barbed or electrified wire on cattle ranches. It consists of the establishment of trees or shrubs of different strata to delimit paddocks, crops, and boundaries, as protection to prevent the passage of animals and generate a comfortable and favorable microclimate for animal production (Arango et al. 2016), forming a live fence in dense rows or hedge style, at a distance of approximately two to three meters between trees (Cipagauta and Orjuela 2003). Over time, live fences can become biological corridors that contribute to wildlife conservation (Sotelo et al. 2017).

Another type of implementation of live fences is the so-called sustainable division of pastures (SDP), proposed by Torrijos et al. (2016) for the region, a linear arrangement of trees protected by an electric fence; these divisions improve the forage supply in the paddocks, also allowing the adjustment of the carrying capacity and the occupation and rest times.

These systems with multipurpose tree arrangements can have benefits such as: the production of firewood, stakes for other live fences, fodder production, green manure, posts and wood for other uses and other products, the greatest advantage is that the tree can last 30 years or more.

- ***Pasture division with tree strips (PDTS) and agrosilvopastoral tree strips (PDAS).***

Tree strips contemplate two types of designs. The first design consists of trees in strips and establishes a matrix of grasses and forest species in separate strips and can be composed of one, two or three rows. The spacing between the strips (alleys) allows the formation of corridors through which cattle circulate, facilitating grazing and allowing natural connection between paddocks (Barrera et al. 2017).

The second design consists of placing tree and shrub species along a dividing fence between two paddocks, in a space 10–20 m wide along the length of the paddock. These strips provide shade areas for adjacent paddocks and allow the introduction of short-cycle crops while the tree species develop. Species that provide shade for livestock and those that are of high commercial value in order to protect them from being consumed or damaged by livestock, they should be sown in double furrows, five or six meters apart and 1.5 m from the fence. Between the tramlines, cover legumes and short-cycle crops are planted. This type of arrangement facilitates natural regeneration and the biodiversity of species, and they become biological corridors that cross the grazing areas and serve for the movement of birds and other species of fauna. It is also attractive for the producer because of its ease of management and because he can obtain products from short-cycle crops, which help to compensate for the non-use of the grazing area and amortize the costs of establishment and fences, while the tree species develop (Cipagauta and Orjuela 2003).

- ***Mixed Fodder Banks (MFB)***

Mixed fodder banks combine high protein value shrubs and grasses that provide energy to the animal's diet (Tafur et al. 2011) and forage, fruit and medicinal species that provide food sovereignty for the family. These are small areas located near the corral, milking facilities and the house, where the associated species are densely cultivated to provide abundant good quality forage as a supplement to pasture fodder or as a staple food in semi-intensive and intensive livestock management systems. An alternative to conserve a high volume of forage in optimal conditions of nutritional quality is the ensilage of the harvested material in the banks through the use of plastic bins (Cipagauta and Orjuela 2003).

The mixed bank requires cutting, transporting and chopping the forage to offer it to livestock, which, together with maintenance and fertilization, generates a relatively high demand for labor; for this reason, its adoption is limited by producers in some areas of the department. Among its advantages is the good availability of quality forage that contributes to increased production, reducing supplementation costs and providing a source of feed for critical periods (Zapata and Silva 2016).

- ***Forage Hedges (FH)***

Fodder hedges are strips 2–3 m wide that serve the multiple functions of dividing paddocks, producing fodder for livestock feeding and allowing the development of trees. They integrate the characteristics of multi-layer live fences and mixed fodder banks into a kind of complex live fence, considered an intensive linear silvopastoral system. It is a strip of three meters wide, delimited by an electric fence made up of trees and forage plants in three lines: one line of trees, and on each side, forage plants in line. These systems act as a windbreak and biological corridor, allowing the integration of livestock production with forestry production (Zapata and Silva 2020).

- ***Intensive silvopastoral systems (iSPS)***

Intensive silvopastoral systems (iSPS) are characterized by combining forage shrubs at high density (more than 5000 plants per hectare) and improved pastures, with trees dispersed or in strips at densities of 30–50 individuals per hectare (Zapata and Silva 2020; Uribe et al. 2011). These systems improve carrying capacity (Murgueitio et al. 2011), serve to rehabilitate degraded lands, increase the production of livestock goods with low demand for agrochemicals, and at the same time generate ecosystem services such as water quality and quantity, biodiversity conservation and reduction of greenhouse gases. In the case of the Amazonian piedmont, the most suitable shrub species is *Tithonia diversifolia*.

### *10.4.2 Productive, Social and Environmental Contributions of Agrosilvopastoral Systems*

Agrosilvopastoral systems have a positive impact on the production and quality of forage, increased stocking rate per area and meat and milk yields per hectare, while reducing the environmental damage caused by extensive livestock farming, providing a suitable environment to improve the soil biota and fauna associated with the system (Gutiérrez and Mendieta 2022).

- ***Productive aspects***

Silvopastoral systems contribute to an increase in forage production, forage quality and animal comfort, which is reflected in higher production per animal and per unit area. The efficiency of agrosilvopastoral systems in beef production can be up to 12 times higher compared to extensive monoculture pastures, with the need for less grazing area (Mauricio et al. 2019). The diversification of forage species in the pasture should consider the inclusion of legumes, due to their potential nutritional value and capacity to fix nitrogen, which improves the production and nutritional quality of grasses and soil fertility (Sánchez and Villaneda 2009), improving production per animal by 20–40% (Pérez et al. 2019).

López-Vigoa et al. (2017), mention that agrosilvopastoral systems achieve guaranteed weight gain of between 0.42 and 1.10 kg animal$^{-1}$ day$^{-1}$ and a meat production per hectare between 500 and 1340 kg year$^{-1}$, approximately. In mixed fodder banks, an improvement of up to 38.33% in weight gain is achieved, reaching 0.6 kg animal$^{-1}$ day$^{-1}$, with silage supply in conditions of the Colombian Amazon, with respect to traditional management (0.33 kg animal$^{-1}$ day$^{-1}$) (Cipagauta and Orjuela 2003).

For agrosilvopastoral systems, Lopera-Marin et al. (2019a) reported an increase in production from 3.83 l cow$^{-1}$ day$^{-1}$ in continuous grazing with alternate rotations without forage trees or shrubs to 5.03; 4.37 and 3.91 l cow$^{-1}$ day$^{-1}$ in intensive silvopastoral systems, mixed fodder banks and trees dispersed in paddocks respectively, in conditions of the Amazonian piedmont of Caquetá. Likewise, Rivera et al. (2015), in a work in the same region evaluated an intensive silvopastoral system with *Tithonia diversifolia*, and found that milk production went from 4.59 kg cow$^{-1}$ day$^{-1}$ (3556 kg/ha/year) in a conventional system without trees to 4.92 kg cow$^{-1}$ day$^{-1}$ (5615 kg ha$^{-1}$ year$^{-1}$) in the intensive silvopastoral system thanks to the increase in production per cow and the increase in the carrying capacity of the system.

In another study, Álvarez et al. (2021) evaluated the effect of different levels of tree cover on milk production in dual-purpose livestock systems in conditions of the

Colombian Amazon under grazing of *B. decumbens*, and found that milk production increased in pastures with medium (4.43 kg $cow^{-1}$ $day^{-1}$) and high (4.39 kg $cow^{-1}$ $day^{-1}$) tree cover, compared to those with low tree cover (4.13 ± 0.21 kg $cow^{-1}$ $day^{-1}$).

Considering the results of these studies, the use of herbaceous and woody legumes as protein banks, or in association with existing grasses, leads to improve availability, supply, and quality of the diet of cattle throughout the year, giving the possibility of increasing milk and meat production per hectare compared to pasture monocultures (Aguilar et al. 2019; Mahecha et al. 2011).

- ***Socioeconomic aspects***

Agrosilvopastoral systems generate economic benefits for cattle-raising families due to the profitability of milk, meat and products derived from the tree layer (poles, wood, firewood, fruit, etc.). These systems have lower production costs and higher gross profit per liter of milk compared to farms with traditional management and the benefit/cost ratio is improved in these arrangements, exceeding the minimum threshold (1 point) up to three times, while conventional farms are below it (Lopera-Marin et al. 2019b). When performing economic analyses related to profitability indicators (NPV: net present value, B/C: benefit/cost ratio, IRR: internal rate of return, LEV: land expectation value) at different temporal spaces, these indicators increase with time, since they depend on the structure of the agrosilvopastoral arrangement; where the B/C is higher in the protein banks – PB (1. 64), intensive silvopastoral system – iSPS (1.61) and forage hedges – FH (1.57); it presents lower values in improved pasture (1.17) and improved pasture plus legumes (1.18). As for the IRR, they are perceived with higher values in systems with greater complexity (iSPS and PB) reaching up to 30% profitability (Sotelo et al. 2017).

These systems contribute to an increase in family income to the extent that the agrosilvopastoral systems are properly established and managed, and favor the generation of more legal jobs per year and ensure the participation of new generations (Lopera-Marin et al. 2019b). In addition to the above, they are a sustainable alternative to change the current poor image of livestock farming, not only increasing production (milk, meat and goods), but also recovering the landscape and producing ecosystem services (Mauricio et al. 2019).

- ***Environmental aspects***

Agrosilvopastoral systems generate ecosystem services that generate ecosystem restoration, connectivity from forest patches to denser forests, protection and conservation of water, generate microclimates, soil protection and climate change mitigation and adaptation.

These types of sustainable livestock systems are strategies that reduce deforestation to establish pastures, because they provide sufficient and quality forage availability for animals, which reduces pressure on forests, water resource conservation and biodiversity (Baldassini and Paruelo 2020). They provide diverse habitats that conserve biodiversity, where they constitute new scenarios or habitats (Williams et al. 2020) that provide refuge to wild animals and especially to the fauna present in the soil (Gutiérrez et al. 2020; Chávez et al. 2016), being systems in dynamic and constant development (Ruiz et al. 2007).

Likewise, they generate microclimates, where Barragán et al. (2017) found a reduction of the maximum temperature on grass without cover and agrosilvopastoral systems of up to 3.7 °C, where it was evidenced that animals in agrosilvopastoral systems with tree cover grazed up to 1.8 hours more, compared to animals that were exposed to direct solar radiation. Under tropical environments, it is reported that under the shade of trees, reductions in rectal temperature of 0.5 °C and skin temperature of 3 °C were observed, compared to animals grazing in the open (Ferreira-Britto 2010); thus, improving animal comfort (Murgueitio et al. 2019).

Agrosilvopastoral systems are also an option to reverse the processes of rangeland degradation (Nair et al. 2009), by increasing the physical protection of the soil and contributing to the recovery of fertility with the intervention of leguminous plants that fix nitrogen in the soil and trees with taproots that take advantage of the deep layers and recycle nutrients (Alonso 2011), incorporate organic matter to the soil, retaining moisture and increasing biota; and at the same time, with the capacity to increase biomass production, generate environmental services of carbon sequestration and biodiversity (Murgueitio et al. 2019).

They contribute to the direct storage of carbon in the short and medium term (decades to centuries) in trees and soil, and indirectly reduce greenhouse gas emissions (Nair et al. 2009). According to the Nationally Appropriate Mitigation Action – NAMA for Sustainable Cattle Ranching in Colombia, the Colombian cattle herd in 2020 (baseline year) totaled 33.2 million t $CO_2$ eq emitted, of which 1,427,837 t $CO_2$ eq year$^{-1}$ were from the Southeast ecoregion, of which Caquetá is part. They also determined the carbon dioxide removal potential of five agrosilvopastoral systems on pastures without cover (Table 10.3).

In a study on carbon stored in the tree stratum of cattle-ranching and natural systems in the municipality of Albania, Caquetá, Colombia, it was found that the highest $CO_2$ storage occurred in forest with 124.52 t $CO_2$ ha$^{-1}$, followed by areas of natural regeneration (32.32 t $CO_2$ ha$^{-1}$), agrosilvopastoral system (2.59 t $CO_2$ ha$^{-1}$), traditional pasture (0.69 t $CO_2$ ha$^{-1}$) and improved pasture of the genus *Brachiaria sp.* (0.37 t $CO_2$ ha$^{-1}$) (Rojas-Vargas et al. 2019).

**Table 10.3** Carbon removal potential for different land uses in the Southeast ecoregion

| System | Removal (t $CO_2$ eq ha$^{-1}$ year$^{-1}$) |
|---|---|
| Pasture improvement | 0.296 |
| Live fences | 3.7 |
| Scattered trees in paddocks | 1.08–5.4 |
| Mixed Fodder Banks | 3.88 |
| Forage hedges | 9.1 |
| Intensive silvopastoral systems | 11.5 |

Source: Banco Mundial et al. 2021

Landholm et al. (2019), estimated the greenhouse gas mitigation potential of agrosilvopastoral systems in Caquetá, modeling scenarios in improved pasture -IP, forage bank -MFB and agrosilvopastoral system -SPS, finding that the carbon sequestration of the three modeled technologies differed substantially in relation to a degraded pasture -DP (1.4 Mg $CO_2$ $ha^{-1}$ $year^{-1}$), where total carbon stocks amounted to 0.57; 6.24 and 2.06 Mg $CO^2$ $ha^{-1}$ $yr^{-1}$, respectively, for the IP, MFB and SPS technologies during the 25-year period considered. They also observed that for each of the future scenarios, total GHG emissions are reduced in relation to the base scenario DP; presenting an average GHG mitigation potential of −1.4; −2.4 and −5.8 Mg $CO_2$ $ha^{-1}$ $yr^{-1}$ for the modeled IM, MFB and SPS scenarios.

The SPS, by including trees and shrubs in the livestock systems, increases up to 4.6 times the carbon storage in the aerial biomass with respect to traditional systems without trees, reaching a carbon stock of 8.69 and 1.88 Mg C $ha^{-1}$, respectively, results obtained in conditions of the Colombian Amazonian piedmont (Villegas et al. 2021).

Silva-Olaya et al. (2021), in their evaluation of soil health, detected the benefits (chemical, physical and biological) promoted by the long-term implementation (15 years) of agrosilvopastoral management on extensive pastures in the Amazon region, becoming an important strategy to restore degraded land pastures and recover soil health, among them the improvement of soil organic C in the SPS favored biological activity, also mitigating the processes of physical soil degradation caused by livestock activity.

Extensive conversion of forests to pasture managed to degrade the soil's capacity to provide all measured ecosystem services, with a greater impact on the reduction of soil C storage (47%), support for plant growth (40%) and erosion control (31%) (Silva-Olaya et al. 2022).

On the other hand, Rivera et al. (2021) in conditions of the Amazon piedmont, determined the effect of SPS on $N_2O$ and $CH_4$ emissions from manure of dual-purpose cows, finding that the traditional system -ST emitted 52.48% less $N_2O$-N in the soil, and in the case of $CH_4$ the pastures under SPS emitted 23.89% less of this gas. As for urine emissions, cumulative fluxes of $CH_4$ and $N_2O$ were 76.46 and 42.02% lower in SPS, and in feces emissions were 34.27 and 1.14% lower in these same systems with respect to the ST; concluding that the silvopastoral systems have the capacity to generate lower emission factors from urine ($N_2O$-N) and feces ($CH_4$) deposited in the pastures, so they can be systems that mitigate the emissions of these gases in livestock systems.

In a study on the effect of *Tithonia diversifolia* (Hemsl.) A. Gray on methane ($CH_4$) emissions, they found that a diet of *B. humidicola* (85%) + *T. diversifolia* (15%) generated lower $CH_4$ emissions produced by enteric fermentation (g/animal/d) compared to a diet of only *B. humidicola*. The inclusion of *T. diversifolia* reduced absolute $CH_4$ emissions ($P = 0.016$), Ym and emissions intensity (per unit of fat, protein and milk yield corrected per kilogram of fat and protein) in both moderate and rainy seasons ($P < 0.05$); where these types of systems can be a tool to both mitigate enteric $CH_4$ emissions and increase animal productivity and therefore reduce emissions intensity (Rivera et al. 2023).

### 10.4.3 Barriers to Adoption and Strategies for Scaling Up Sustainable Alternatives

Despite the environmental, economic, and social benefits of agrosilvopastoral systems that have been discussed and documented in the literature (Gutierrez and Mendieta 2022; World Bank et al. 2021; Rivera et al. 2021; Mauricio et al. 2019; Lopera-Marín et al. 2019a, b; Aguilar et al. 2019; Sotelo et al. 2017; Murgueitio et al. 2019), barriers of different types persist that prevent reaching a larger scale of adoption.

A study conducted in Caquetá by Sandoval et al. (2021), in which they compared different groups of SPS adopters vs. farms with traditional livestock management, found that improved pastures (*Brachiarias sp.*) are more widely adopted than SPSs as a technology that has been incorporated in the region for several decades.

In the case of SPS, the study reported that simpler systems such as dispersed trees in paddocks and mixed fodder banks are adopted first. Subsequently, more complex systems are adopted in terms of establishment and management, requiring greater investment, including pasture renovation and the division of paddocks with trees in strips, rotational grazing and water management with a livestock aqueduct.

The following were identified as factors that positively influenced adoption: participation in projects, training and having established conservation agreements as part of land management. These factors are related to common requirements of cooperative projects that have promoted SPSs in the region.

To determine the barriers to adoption and strategies for scaling up, Solarte et al. (2022b) identified the following categories: social; skills and knowledge; economic; environmental; and technical-operational. From this study the following considerations are highlighted:

For the group of social barriers, resistance to change and attitudes towards new technologies of the families are identified, which requires policies to promote sustainable livestock farming that are inter-institutionally coordinated, both with the public and private sectors and that incorporate gender and generational change.

There is a lack of knowledge about sustainable livestock models and alternatives, both among producers and technical assistants, and there are limitations in agricultural extension services. There is a need to work on knowledge management, since there is information that is not available; on capacity building for human resources at the producer and technical levels; and on improving agricultural extension services.

In terms of economic aspects, the need for financing to establish the SPS and credit payment conditions are identified as factors limiting the possibility of establishing the SPS. There is an opportunity to organize the cattle ranch towards sustainable conservation production, including diversification of activities, access to incentives in environmental markets, the creation of differentiated products with added value, and the design of special lines of credit with adequate conditions for users.

Environmental barriers include the region's climate and soil conditions and pasture degradation processes, the availability of conservation areas and water sources for livestock farming. To overcome these barriers, it is necessary to work on the environmental management of the property, the conservation and restoration of ecosystems, and research and monitoring processes to evaluate progress.

Technical and operational barriers include the low level of administration, the limited availability of plant material adapted to local conditions, agricultural machinery, labor, and transportation of materials to the farms. Progress is needed in the technical, administrative and financial management of the cattle ranches, establishing production records and costs through specialized technical assistance.

**Acknowledgments** The authors thank the projects:

(i) Sustainable development options and land-use based alternatives to: Enhance climate change mitigation and adaptation capacities in the Colombian and Peruvian Amazon, while enhancing ecosystem services and local livelihoods (Proyecto Paisajes Sostenibles para la Amazonía)
(ii) Implementing sustainable land use systems to contribute to forest conservation, climate protection (REDD+) and the peace-building process in Colombia (Project 18_III_106_COL_A_Sustainable Production Strategies)

Funded by the International Climate Initiative (IKI). The German Federal Ministry for the Environment, Nature Conservation, Building and Nuclear Safety (BMUB) supports this initiative on the basis of a decision of the German Bundestag.The authors thankfully acknowledge the help received from M.A. Chará with the translation from Spanish and suggestions during the preparation of the manuscript.

## Annexes

### *Annex 1. Species Used in Silvopastoral Systems and Their Different Uses*

*STP* scattered trees in pastures, *LF* live fences, *SPD* sustainable division of pastures, *PDTS* pasture division with tree strips, *PDAS* pasture division with agrosilvopastoral strips, *WS* woodlots or stands, *MFB* mixed fodder banks, *FH* forage hedges, *iSPS* intensive silvopastoral systems, *FW* fire wood, *W* wood, *WF* wildlife feed, *HF* human feed, *S* shade, *LF* livestock feed

Source: Calle and Murguetitio 2020; Ángel et al. 2017; Barrera et al. 2017; Martínez et al. 2017; Castañeda-Álvarez et al. 2016; Ángel et al. 2014; Pimentel et al. 2014; Álvarez et al. 2013; Hurtado and Guayara 2013; Tafur et al. 2011; Guayara et al. 2009; Cipagauta and Orjuela 2003

| No | Stratum | Common name | Scientific name | Agrosilvopastoral system where is used | | | | | | | | | Use | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | STP | LF | SPD | PDTS | PDAS | WS | MFB | FH | iSPS | FW | W | WF | HF | S | LF |
| 1 | Graminea | Sugar cane | *Saccarum officinarum* (L.) | | | | | | | X | | | | | | | | X |
| 2 | Graminea | Cuba 22 | *Pennisetum purpureum x P. glaucum* | | | | | | | X | | | | | | | | X |
| 3 | Graminea | Grama dulce | *Paspalum notatum* Flugge | X | X | X | X | X | X | | X | X | | | | | | X |
| 4 | Graminea | Guaduilla | *Homolepis aturensis* (Kunth) Chase | X | X | X | X | X | X | | X | X | | | | | | X |
| 5 | Graminea | Guinea Mombasa | *Megathyrsus maximus* (Jacq.) *cv Mombasa* | X | X | X | X | X | X | X | X | X | | | | | | X |
| 6 | Graminea | King Grass Morado | *Pennisetum purpureun x p. typhoides* | | | | | | | X | | | | | | | | X |
| 7 | Graminea | Manradu | *B. brizantha* cv. Marandu | X | X | X | X | X | X | | X | X | | | | | | X |
| 8 | Graminea | Pasto brizantha | *Brachiaria brizantha* (Hochst. ex A. Rich.) Stapf. | X | X | X | X | X | X | | X | X | | | | | | X |
| 9 | Graminea | Pasto Caimán | Brachiaria Híbrido BR02/1752 cv. Cayman | X | X | X | X | X | X | | X | X | | | | | | X |
| 10 | Graminea | Pasto decumbens | *Brachiaria decumbe*ns Stapf. | X | X | X | X | X | X | | X | X | | | | | | X |

(continued)

| No | Stratum | Common name | Scientific name | Agrosilvopastoral system where is used | | | | | | | | | Use | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | STP | LF | SPD | PDTS | PDAS | WS | MFB | FH | iSPS | FW | W | WF | HF | S | LF |
| 11 | Graminea | Pasto Elefante | *Pennisetum purpureum* (Schum) | | | | | | | X | | | | | | | | X |
| 12 | Graminea | Pasto humidicola | *Brachiaria humidicola.* (Rendle) Schweick | X | X | X | X | X | X | | X | X | | | | | | X |
| 13 | Graminea | Pasto Imperial | *Axonopus scoparius* (Hitchc) | | | | | | | X | | | | | | | | X |
| 14 | Graminea | Pasto llanero | *Brachiaria dictyoneura* | X | X | X | X | X | X | | X | X | | | | | | X |
| 15 | Graminea | Pasto Mulato II | *Brachiaria* híbrido cultivar (cv.) Mulato II (CIAT 36087) | X | X | X | X | X | X | | X | X | | | | | | X |
| 16 | Herbaceous legume | Campanilla | *Centrosema molle* Mart. ex Benth. | X | X | X | X | X | X | X | X | X | | | | | | X |
| 17 | Herbaceous legume | Campanita ó zapatico | *Clitoria ternataea L.* | X | X | X | X | X | X | X | X | X | | | | | | X |
| 18 | Herbaceous legume | Frijolillo | *Desmodium orinocense* (DC.) Cuello | X | X | X | X | X | X | X | X | X | | | | | | X |
| 19 | Herbaceous legume | Hoja de plata ó pega-pega | *Desmodium heterocarpon* (L.) | X | X | X | X | X | X | X | X | X | | | | | | X |
| 20 | Herbaceous legume | Kudzú | *Pueraria phaseoloides* (Roxb.) Benth | X | X | X | X | X | X | X | X | X | | | | | | X |
| 21 | Herbaceous legume | Mani forrajero | *Arachis pintoi* (Krap. Y Greg.) | X | X | X | X | X | X | X | X | X | | | | | | X |

| | | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 22 | Shrub | Avocado | *Persea americana* | | | | | x | | x | | | | | | x | x | |
| 23 | Shrub | Araza | *Eugenia stipitata* | | | | | X | X | X | | | | | X | X | X | |
| 24 | Shrub | Boca de Indio, indio viejo | *Piptocoma discolor* (Kunth) Pruski | X | X | | | | X | X | X | X | | | | | X | X |
| 25 | Shrub | Bohío | *Clitoria fairchildiana* (R. Howard) | | | | | | X | X | X | X | | | | | | X |
| 26 | Shrub | Bore | *Alocasia macrorrhiza* (L) Schott | | | | | | X | X | X | X | | | | X | | X |
| 27 | Shrub | Mexican sunflower | *Tithonia diversifolia* (Hemsl.) Gray | | | | | | X | X | X | X | | | | | | X |
| 28 | Shrub | Cítrics | | | | | | X | | X | | | | | | X | X | |
| 29 | Shrub | Cratylia | *Cratylia argentea* (Desvaux) O. Kuntze) | | | | | | X | X | X | X | | | | | X | X |
| 30 | Shrub | Golgoto | *Hibiscus rosa-sinensis* L. | | | | | | X | X | X | X | | | | | | X |
| 31 | Shrub | Leucaena | *Leucaena diversifolia* (Schltdl.) Benth. | | | | | | X | X | X | X | | | | | X | X |
| 32 | Graminea | Maize | *Zea mays* | | | | X | X | | X | | | | | X | X | | |
| 33 | Shrub | Matarratón | *Gliricidia sepium* (Jacq.) Stend | | | | | | X | X | X | X | | | | | | X |
| 34 | Shrub | Morera | *Morus alba* L. | | | | | | X | X | X | X | | | | X | | X |

(continued)

| No | Stratum | Common name | Scientific name | Agrosilvopastoral system where is used | | | | | | | | | Use | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | STP | LF | SPD | PDTS | PDAS | WS | MFB | FH | iSPS | FW | W | WF | HF | S | LF |
| 35 | Shrub | Nacedero | *Trichanthera gigantea* (Bonpl.) Nees | | | | | | X | X | X | X | | | | | X | X |
| 36 | Shrub | Papaya | *Carica papaya* | | | | | X | | X | | | | | X | X | X | |
| 37 | Herb | Pinaple | *Ananas comosus (L.) Merr.* | | | | | | X | X | X | X | | | | | | |
| 38 | Shrub | Platain | *Musa* sp | | | | | X | X | X | | | | | X | X | | X |
| 39 | Shrub | Cassava | *Manihot esculenta* | | | | | X | | X | | | | | X | X | | |
| 40 | Arboreal | Abarco | *Cariniana pyriformis* Miers. | | X | X | X | X | X | | X | X | | X | | | X | |
| 41 | Arboreal | Acacia | *Acacia mangium* Wild | | X | X | X | X | | | X | X | | X | | | X | |
| 42 | Arboreal | Aceituno | *Vitex cymosa* Bertero ex Spreng | X | | | X | X | X | | | | | X | X | X | X | |
| 43 | Arboreal | Achapo | *Cedrelinga cateniformis* (Ducke)Ducke | X | X | X | X | | X | | | | | X | | | X | |
| 44 | Arboreal | Ahumado | *Minquartia guianensis* Aubl. | X | X | X | X | | X | | X | | | X | | | X | |
| 45 | Arboreal | Arrayan | *Eugenia anastomosans* DC. | X | X | X | X | | X | | X | | | X | | | X | |
| 46 | Palm | Asai | *Euterpe precatoria Mart* | X | | | | X | X | X | | | | | X | X | X | |
| 47 | Arboreal | Balso lano | *Ochroma pyramidale* (Cav. ex La.) Urb. | X | | | | | X | | | | | X | | | X | |

| | | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 48 | Arboreal | Bilibil | *Guarea guidonia* (L.) Sleumer | X | | | | | X | | | | X | X | X | | X | |
| 49 | Arboreal | Cocoa | *Theobroma cacao* L. | X | | | | X | X | | | | | | X | X | X | |
| 50 | Arboreal | Capirona, resbalamono | *Calycophyllum spruceanum* (Benth.) K.Schum | X | X | X | X | X | X | | X | X | | X | | | | |
| 51 | Arboreal | Caracolí | *Anacardium excelsum* (Kunth) Skeels | | X | X | X | X | | | X | X | X | X | | | X | |
| 52 | Arboreal | Carbon | *Zygia longifolia* (Humb. & Bonpl. ex Willd.) Britton & Rose | X | X | | | | X | | | | X | | | | X | |
| 53 | Arboreal | Castaña del barsil | *Bertholletia excelsa Bonpl.* | | | | | X | X | X | | | | | X | X | X | |
| 54 | Arboreal | Cedar | *Cedrela odorata* L. | X | X | X | X | | X | | | | | X | | | X | |
| 55 | Arboreal | Chilco | *Miconia elata* | X | | | X | | X | | | | X | X | | | X | |
| 56 | Arboreal | Chocho | Ormosia nobilis | X | | | X | | X | | | | | X | | | X | |
| 57 | Palm | Chontaduro | *Bactris gasipaes* | X | | | | X | X | X | | | | | X | X | X | |
| 58 | Arboreal | Cobre | *Andira inermis* (W. Wright) Kunth ex DC. | X | X | X | X | | X | | | | X | X | | | X | |
| 59 | Palm | Coconut | *Cocos nucifera* L. | X | | | | X | X | X | | | | | X | X | X | |
| 60 | Arboreal | Dormilon | *Albizia carbonaria* Britton | X | X | X | X | X | X | | X | X | | X | | | X | |
| 61 | Arboreal | Guamo machete | *Inga spectabilis* (Vahl) Willd. | X | X | X | X | X | X | | X | X | X | X | X | X | X | |

(continued)

| No | Stratum | Common name | Scientific name | Agrosilvopastoral system where is used | | | | | | | | | Use | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | STP | LF | SPD | PDTS | PDAS | WS | MFB | FH | iSPS | FW | W | WF | HF | S | LF |
| 62 | Arboreal | Guamo rabo de mico | *Inga edulis* Mart | X | X | X | X | X | X | | X | X | X | X | X | X | X | |
| 63 | Arboreal | Custard apple | *Annona muricata* | | | | | X | | X | | | | | X | X | X | |
| 64 | Arboreal | Guava | *Psidium guajava* L. | X | | | | X | X | | | | X | | X | | X | |
| 65 | Arboreal | Guayabo coronillo | *Bellucia pentamera* Naudin | X | | | | | X | | | | X | X | X | | X | |
| 66 | Arboreal | Lacre | *Vismia baccifera* (L.) Planch. & Triana | X | | | | | X | | | | X | X | X | | X | |
| 67 | Arboreal | Macano | *Terminalia amazonia* (J.F. Gmel.) Exell | | X | X | X | | | | | | | X | | | X | |
| 68 | Arboreal | Madura plátano, canalete | *Jacaranda copaia* (Aubl.) D. Don | X | X | | X | X | X | | | | X | X | | | X | |
| 69 | Arboreal | Mango | *Mangifera Indica* L. | X | | | | X | X | | | | | | X | X | X | |
| 70 | Arboreal | Marfil | *Siparuna decipiens* (Tul.) A.DC. | X | X | X | X | | X | | X | | | X | | | X | |
| 71 | Arboreal | Melina | *Gmelina arbórea* Roxb | X | X | X | X | X | | | X | X | X | X | | | X | X |
| 72 | Arboreal | Nogal cafetero | *Cordia alliodora* (Ruiz & Pav.) Oken | | X | X | X | X | | | | | | X | | | X | |
| 73 | Arboreal | Oji ancho | *Hieronyma alchorneoides* Allemão | | X | X | X | X | X | | X | X | | X | | | X | |

| | | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 74 | Arboreal | Orejero | *Enterolobium schimburgkii* (Benth.) Benth. | X | X | X | X | | X | | X | | | X | | | X | |
| 75 | Arboreal | Pata de vaca | *Bauhinia arborea* Wunderlin | X | X | | | | X | | | | X | X | | | X | X |
| 76 | Arboreal | Pizamo, Cachimbo | *Erythrina ulei* Harms*Erythrina fusca Lour.* | X | X | X | X | | | | X | | X | X | | | X | X |
| 77 | Arboreal | Roble, Ocobo, Guayacan rosado, Flor morado | *Tabebuia rosea* (Bertol.) A. DC. | X | X | X | X | X | X | X | X | X | | X | | | X | |
| 78 | Arboreal | Samán | *Samanea saman* (Jacq.) Merr. | X | X | X | X | | X | | | | | X | | | X | |
| 79 | Arboreal | Sangregado | *Croton lechleri Müll.Arg.* | X | | | | | X | | | | | X | | | X | |
| 80 | Arboreal | Tabaquillo, nacedero blanco | *Isertia laevis* (Triana) B.M.Boom | | X | X | X | | | | | | | | | | X | |
| 81 | Arboreal | Tachuelo | *Zanthoxylum rhoifolium* Lam. | X | X | X | X | | | | | | X | X | | | X | |
| 82 | Arboreal | Uva Caimarona | *Pourouma cecropifolia* Mart. | X | | | | X | X | X | | | | | X | X | X | |
| 83 | Arboreal | Yopo | *Mimosa trianae* (Benth) . | X | X | X | X | X | | | X | X | X | X | | | X | |

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