LEAVES | Leveraging Agricultural Value Chains to Enhance Tropical Tree Cover and Slow Deforestation

BACKGROUND PAPER

PROFOR
INNOVATION AND ACTION FOR FORESTS

Silvopastoral Systems for Intensifying Cattle Production and Enhancing Forest Cover: The Case of Costa Rica

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Executive Summary

In the last 50 years, significant increases in human population and per capita consumption of animal source foods have been observed in Latin America and the Caribbean (LAC), resulting in increased demand for livestock products in the region. Moreover, some LAC countries are net exporters of milk or beef. The growth in global demand for livestock products is increasing the pressure to increase production in LAC. Projections to 2050 suggest that regional and global demand will continue to grow. The traditional cattle ranching approach, which increases the area under pastures to maintain the growing animal population at expense of forests, is not the option anymore for LAC. The dominant, extensive pasture-based livestock production systems need to shift from their current paths that degrade natural and social capital to more intensive silvopastoral (SP) systems that generate goods such as milk, meat, and timber, that contribute to increase tree cover on farm and landscapes to maintain ecosystems, and that render environmental services including the reduction of GHG emissions and climate change vulnerability. The pillars for such change should: (a) promote the rehabilitation of degraded pastures and soils and prevent further degradation of those resources; (b) increase the availability, quality, diversity, and persistence of plant biomass; (c) protect and rationally use water sources; and (d) increase animal productivity on a per hectare basis.

SP systems are considered win-win options as they are oriented to increase livestock productivity, to augment incomes and products diversification, to enhance resilience to climate change by the microclimatic conditions that trees and shrubs provide to animals and pastures, to harness mitigation benefits by reducing GHG emissions, and to increase Carbon sequestration in pasture and woody perennial root systems that in the end render valuable ecosystem services such as water, soil, and biodiversity conservation along with other contributions to avoid deforestation. Several SP options can respond to the objectives described above. However, the decision on which innovations to recommend will depend on the prevalent constraints on a given site and a farmer´s objectives. Therefore, it is possible and even desirable to have a mosaic of SP options for diverse farms and landscapes.

This report describes, discusses, and shows the geographical distribution of the following nine SP options: (a) scattered trees and shrubs in pastures; (b) grazing under native or secondary forests; (c) grazing under tree plantations; (d) live fences;(e) fodder banks; (f) alley farming with pastures; (g) windbreaks; (h) hedgerows; and (i) riparian forests. Based on more than 150 references found in the literature for LAC, the highest diversity of SP options is found in tropical environments, followed by the temperate region, and followed by the boreal agroecological zones. The SP option most frequently practiced in all regions is scattered trees in pastures, followed by live fences in the tropical agroecological zones. In temperate and boreal regions, the most frequent practice is grazing under tree plantations. The potential application of such options for the case of Africa is also discussed.

The potential biophysical benefits and co-benefits of silvopastoral approaches for the sustainable intensification of livestock production systems are also discussed in the report. Among those are: (a) animal nutrition and welfare; (b) nutrient cycling; (c) nitrogen fixation and carbon sequestration; (d) biodiversity conservation; (e) water conservation; (f) greenhouse gas mitigation; and (g) climate change resilience. The socioeconomic benefits associated with the change of traditional pasture systems to SP approaches are analyzed for this report using *ex ante* procedures, given the limited availability of such data in the literature. The analysis carried out for this report showed that SP systems are more profitable than traditional systems, even in the absence of payment for environmental services schemes.

The adoption rate for SP systems has remained relatively low despite abundant information documenting the benefits of SP innovations for increasing productivity, improving economic performance, and adapting to/mitigating climate change in livestock systems. The contribution of SP systems to halting deforestation and increasing the presence of trees in livestock farms is also well documented. This situation has been attributed to the complexity of SP innovations, the reluctance of farmers to invest and take risks with new technologies that have a time lag before profits, the limited access to information and technical assistance on SP systems, the fact that few financial institutions have SP options in their credit agenda, and the lack of financial and non-financial incentives for promoting SP options, among other factors.

It is suggested that some enabling mechanisms for promoting the adoption of SP innovations are: (a) the existence of premium prices for certified products coming from environmental friendly and sustainable cattle systems; (b) a well-organized, trusted, and affordable certification and traceability system to verify that products respond to the conditions; (c) access to payments for environmental services schemes; (d) the availability of reforestation incentives programs accessible to all types of livestock farmers; (e) financial system offering "green credit" lines, in which the interest rate is lower for those producers who comply to a set of environmental friendly technologies than the regular rate in the market. Also, it is recognized that the faster adoption of SP innovations could be enabled by knowledge management interventions such as (a) coordinated research and technology transfer efforts on SP systems involving institutions with mandates and expertise on livestock production, forestry, and environmental issues, (b) capacity building, training, and outreach efforts for spreading the principles of SP systems, (c) more efficient use of information and communication technologies to facilitate the dissemination of SP innovations and to survey landscapes to assess the extent of adoption of SP systems and their impact, (c) participatory learning and action research for testing promising SP options in different agroecosystems, (e) implementation of successful pilot projects to demonstrate the potential of SP interventions, followed by large-scale projects aimed at mainstreaming lessons learned, and (f) the development of appropriate legal framework, policy, and planning regulations as well as adjustments in the wood processing enterprises to support the conservation and sustainable management of forests under SP use.

The different climate change initiatives will serve as boosters to promote structural adjustments to the current livestock production systems including the adoption of SP innovations. The World Bank Group (WBG) could facilitate adoption of such initiatives. Three WB/GEF projects are presented as examples of the relevant role the WBG can play to promote the adoption of SP systems in LAC and elsewhere. The relevance of cross-fertilization between regions through south-south cooperation efforts facilitated by the WBG are also discussed.

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Dynamics of Human and Livestock Population and Use of Natural Resources in Latin America and the Caribbean

1.1 The Livestock Revolution

In the late 1990s, Delgado et al (1999) coined the term *livestock revolution* to refer to the continuous increase in meat and milk consumption due to population growth, urbanization, and income growth. They suggested that such changes will continue in the 21st century. Global data for the past 50 years has shown that the *livestock revolution* has occurred in emergent economies and the most developing countries including those from Latin America and the Caribbean (LAC). This resulted in significant increases in demand for animal source food (Gerber et al. 2013).

In the last 50 years, the human population in LAC increased almost 2.5 times from 260 to 639 million, while the rural population declined from 45.9 to 19.9% (FAOSTAT 2017). It was not possible to obtain data on per capita income for the same time interval, but between 1990 and 2016 the average per capita income in LAC increased from US$6,185 to US$8,872 (CEPALSTAT 2017). This increase in income has been reflected on the increase in per capita consumption of animal products, although with some differences between regions. The increase in per capita beef consumption in the last 50 years was higher in South America than in Central America at 2.24 vs. 0.36 times respectively. In contrast, the per capita milk consumption increased more in Central America than in South America at 0.87 vs. 0.69 times respectively. All regions witnessed an extremely high increase in per capita consumption of poultry meat at 7.93 times in Central America, 5.24 times in the Caribbean, and 14.10 times in South America respectively. This was mainly due to national policies favoring the growth of the monogastric livestock sector by facilitating access to cheaper grains, even though most LAC countries imported these grains.

Cattle population in LAC almost doubled in the last 50 years from 201 to 418 million heads. However, pasture area changed little from 461 to 560 million ha. As a result, the stocking rate increased from 0.437 to 0.746 animals per ha during this period. However, those values are far below the estimated optimum carrying capacity for most tropical and temperate pastures, except for those in the semiarid ecosystems. This confirms that extensive approaches to cattle ranching and pasture degradation problems have dominated the scene of cattle production in the region (Szott et al. 2000; Días-Filho 2007; Betancourt et al. 2007).

Another aspect to be considered is that LAC is an important net exporter of agricultural commodities to the world (Duff and Padilla 2015). The increase in demand for livestock products, particularly in the emerging economies, had an impact on the growth of the livestock sector in LAC. In the case of beef, LAC exports almost 30% of the global trade with the South American countries (e.g. Brazil, Argentina, Uruguay, Paraguay and Colombia) accounting for 80%. Mexico and Central America account for the remaining 20% (Chaherli and Nash 2013). However, export restrictions on beef have led to reductions in the national herd size in countries like Argentina and Brazil. The same has not occurred in the case of Uruguay (McConnell and Mathews 2008; Chaherli and Nash 2013).

The intra-regional beef export/import is relevant as part of legal business, but there is illegal trading of live animals across porous borders. For example, there is significant illegal movement of live animals from Nicaragua, Honduras, and Guatemala towards Mexico with the associated risks of disease spreading in the absence of sanitary control. This kind of business has resulted in the clearance of one-third of the forest in the Selva Lacandon Reserve (Soberanes 2018).

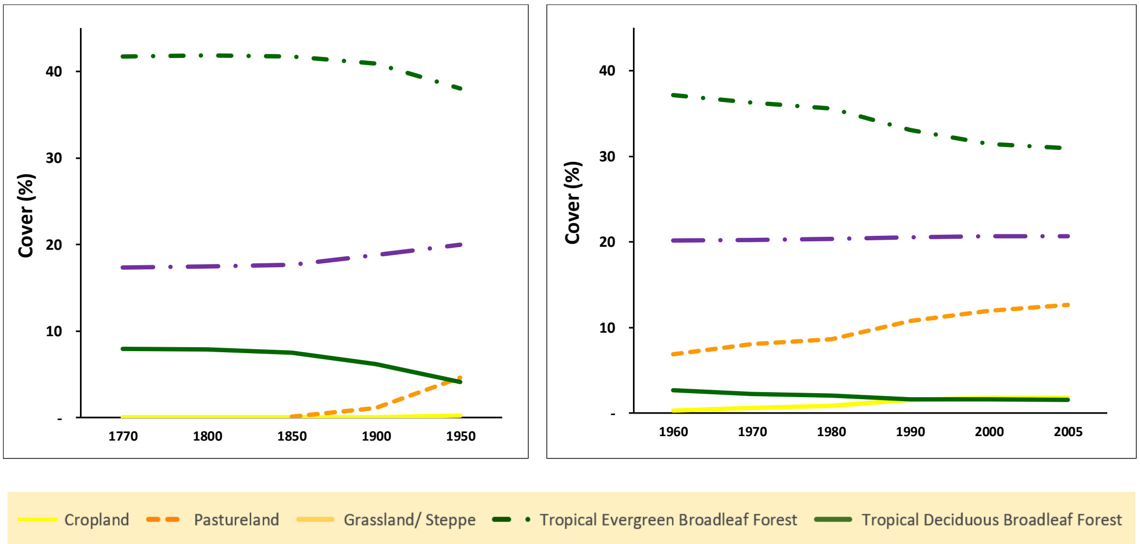
In the case of milk, Central America and the Caribbean are net importers of milk, whereas South America moved from a net importer in 1993 to a net exporter in 2013. Argentina and

Uruguay are the main milk exporters (FAOSTAT 2017). Another aspect to consider is that the dairy sector in LAC is highly fragmented. There is a tendency to the consolidation of few large players as well as a shift of decision-making centers toward urban and peri-urban areas where multinationals and large domestic firms have their headquarters (Dirven 2001). In terms of milk production systems, a high proportion of those are in the hands of smallholder farmers. As a result, there is an enormous variation in terms of the scale, sophistication, and contribution to the economy (Duff and Padilla 2015).

1.2 Land Use Changes

Land use changes in LAC has been a continuous process because of population growth and colonization among other factors. Historical analysis of those changes evidenced that after the independence of most LAC countries around 1850, the area devoted to pasturelands started increasing, mostly at the expense of the Tropical Deciduous Broadleaf Forest (TDBLF) (Figure 1). Changes became more important starting in the early 20th century. At that time, the Tropical Evergreen Broadleaf Forest (TEBLF) started to become compromised as well. Starting in the 1960s, the decline in the area covered by TEBLF was even more important while changes in pasturelands and croplands became evident (UI-UC/ATMO 2018). During this period, no significant changes were observed in the area covered by rangelands.

Figure 1. Estimated Changes in Land Use in Latin America and the Caribbean between 1770 and 2005



Source: UI-UC/ATMO 2018

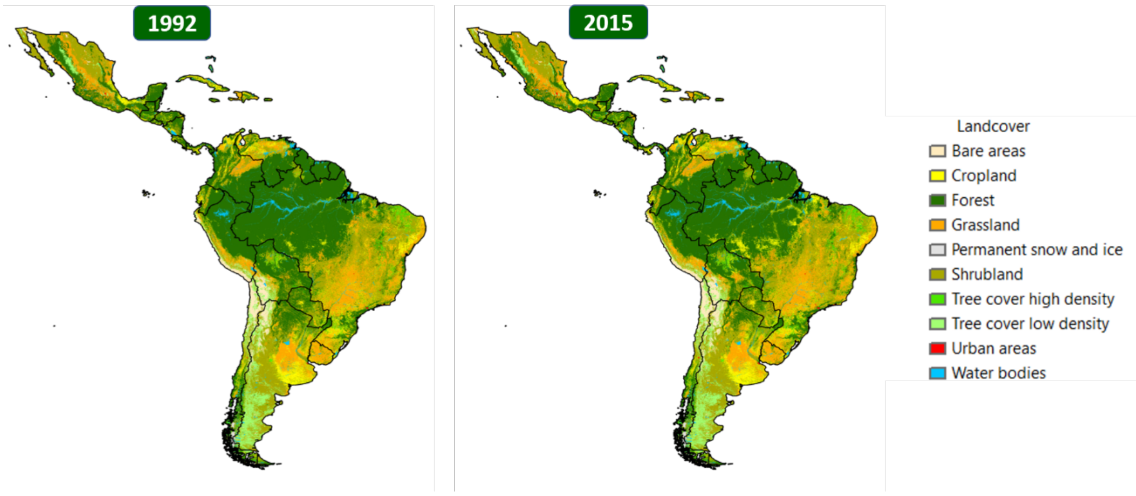
Within LAC, many studies have documented extensive deforestation at different intervals, but frequently those are presented at local/national level and emphasize the hotspots and the possible driving factors for change. For example, deforestation in Costa Rica started from the 1940s and proceeded at a rapid pace between 1960 and 1990 (Ibrahim et al. 2010). In the early 80s, attention was drawn to the linkage between the expansion of Central America's pastures and the loss of its tropical forests via the so-called "hamburger connection," which eventually resulted in the banning of Costa Rican beef imports by one of the largest buyers in the USA (Szott et al. 2000). However, the expansion of the cattle industry in Central America came largely to a halt in the mid-80s due to decreases in beef world prices, pressure from environmentalist groups that resulted in the withdrawal of subsidies, soft credits for the livestock sector, an increase of foreign competition, the civil war violence in Nicaragua, El

Salvador, and Guatemala, and some changes in dietary preferences at the domestic and international levels, among other factors (Kaimowitz 1996).

In contrast, Brazil has been the world leader in tropical deforestation (Fearnside 2005). Clearing averaged 19,500 km^2/year from 1996 to 2005 (Nepstad et al. 2009).[1] Ninety two percent (92%) of Brazil's loss occurred in the Amazon region (Ibrahim et al. 2010). Initially, the domestic demand for beef was one of the main drivers for the expansion of Brazil's cattle industry (Hoelle 2017). Later, other factors such as the increase in demand from Europe due to bovine spongiform encephalopathy (mad-cow disease) and progress in eradicating foot-and-mouth disease (FMD) opened opportunities for Brazilian beef to Europe. However, as prices for beef and soy products decreased between 2005 and 2006, and as the Brazilian currency gained strength against the US dollar, Brazil observed a decline in deforestation rates (Nepstad et al. 2009). Better implementation of government policies, trying to connect deforestation halting efforts with international emissions-offset programs in the Amazon contributed to this decrease.

Even though it would be desirable to present changes in land use in a continuous way, Figure 2 presents a comparison of land use changes between 1992 and 2015 for LAC based on data obtained from the European Space Agency (ESA).[1] This map shows an evident decline in forested areas in Southern and Eastern South America, a topic that will be discussed in the following paragraphs.

Figure 2. Changes in Land Use in LAC between 1992 – 2015

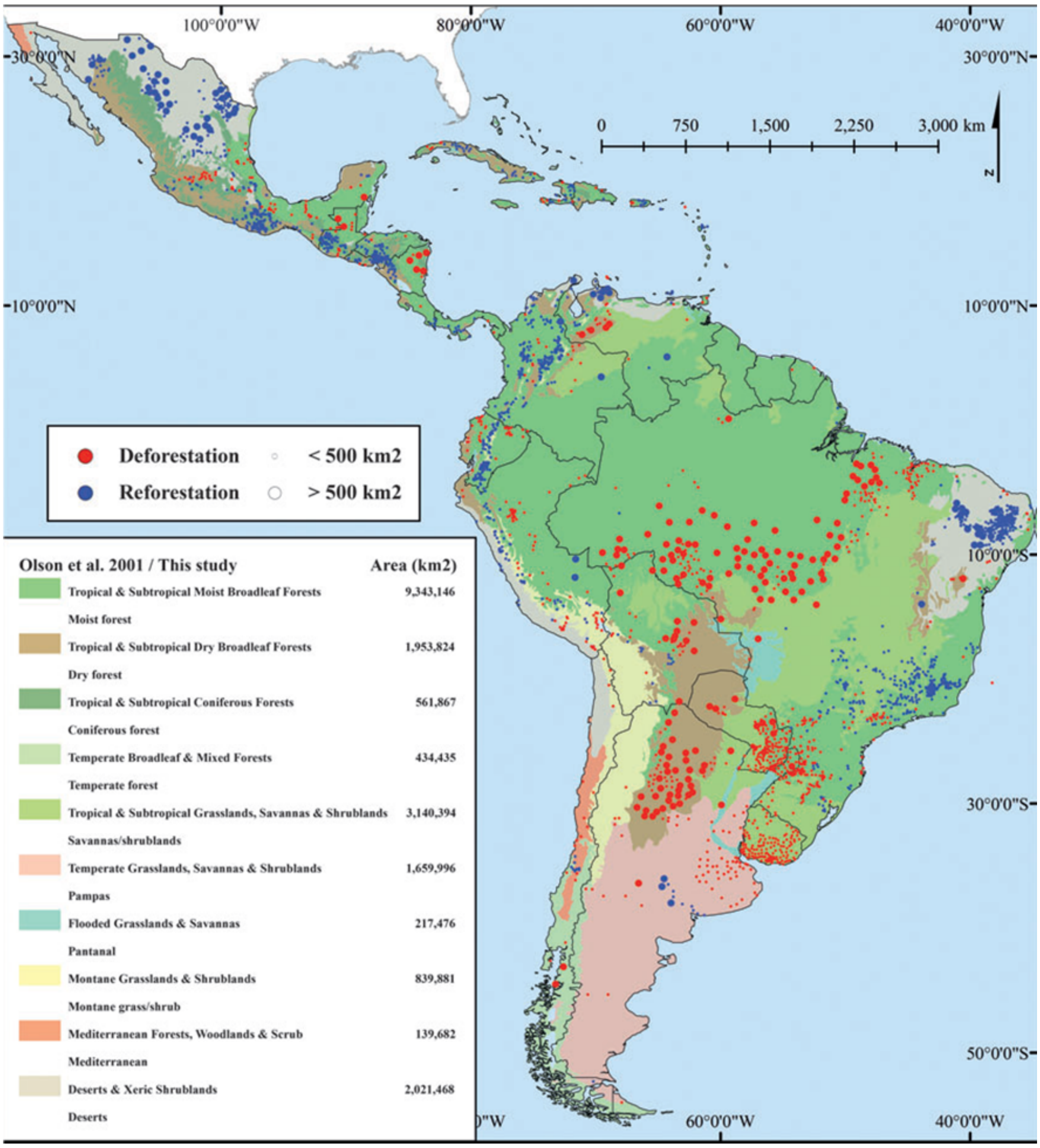


Source: ESA, 2017

Between 2001 and 2010, LAC experienced both extensive deforestation and significant reforestation (Figure 3). In the Caribbean, there was a net gain in forests. Most of the increase occurred in Cuba, Puerto Rico and Haiti. Also, the Mesoamerican region (Mexico/Central America) experienced a net increase in forests, the majority of which occurred in Mexico, Honduras, Costa Rica, and El Salvador. Significant forest clearance to create pastures was observed in eastern Nicaragua, northeastern Honduras, and Petén in Guatemala (Szott et al. 2000; Austin 2010). Net deforestation prevailed in South America, in which Argentina, Brazil, Paraguay, and Bolivia accounted for 80% of the deforestation in the whole LAC. Colombia and Venezuela were the two countries in South America with the largest net gains in forests (Aide et al. 2013).

Figure 3. The Distribution of Hotspots of Deforestation and Reforestation, 2001-2010

[1] http://maps.elie.ucl.ac.be/CCI/viewer/index.php



Source: Aide et al. 2013

The deforestation and reforestation that occurred between 2001-2010 varied greatly among the ten major biomes in LAC. More than 80% of deforestation occurred in the moist forest, dry forest, and savannas/shrublands biomes. In the dry forest biome, losses occurred mainly in the dry Chaco in northern Argentina, the Santa Cruz region of Bolivia, western Paraguay, and the southern part of Lake Maracaibo in Venezuela. More than 40% of the increase in forest cover occurred in the desert/xeric shrub biome, particularly in northeast Brazil and northcentral Mexico. Other large gains of woody vegetation occurred in the Andes of Colombia, Venezuela, Peru, and Ecuador, in the savannas/shrublands biome of eastern Brazil, in the dry forest ecoregions of Mexico, Cuba, and Peru, and in the coniferous forest of Mexico and Central America. In general terms, one could say that deforestation has been mostly in the humid/wet lowlands, whereas reforestation occurred in the mountainous areas of LAC (Aide et al. 2013).

The traditional cattle ranching approach increases the area under pastures at the expense of forests to maintain the growing animal population. This approach is not an option anymore for LAC. Pasture-based livestock production systems need to shift from their current paths that degrade natural and social capital to one that generates goods such milk, meat, and timber and contributes to maintaining the ecosystem and rendering ecosystem services, including the reduction of GHG emissions and climate change vulnerability (Murgueitio et al. 2011). The pillars and goals for such change should be:

i. To increase plant biomass availability, quality, diversity and persistence;

ii. To control soil degradation and promote its recovery;

iii. To protect and rationally use available water sources; and

iv. To increase animal productivity measured by kg per animal product per ha^{-1})

The first element is a prerequisite for the other three. Enhancing the vegetation cover through a combination of grasses, legumes, trees, palms, shrubs and edible weeds contributes to increased net photosynthesis, improved nutrient cycling, recovered soil biota and fertility, and enhanced biodiversity (Murgueitio and Calle 1999; Trilleras et al. 2015; Solorio et al. 2017). There is a diversity of forage germplasm for tropical and temperate areas of LAC that could be used for the reclamation of degraded pastures (Peters et al. 2013). However, the problems of pasture degradation will reappear with consequences for additional deforestation if mistakes are made in the identification of those that fit best to each site conditions, failures occur during the establishment phase, or inadequate grazing management practices are applied, among other factors (Días-Filho 2007; Pezo 2017).

2 Silvopastoral Systems: A Climate-smart Strategy for Sustainable Intensification of Livestock Production

SP systems are livestock production options involving multi-purpose woody perennials (trees and shrubs) in combination with herbaceous grasses and legumes and livestock species. All of these are managed in an integrated manner (Pezo and Ibrahim 1999; Dagang and Nair 2003; Cubbage et al. 2012). Properly managed SP systems are an option for the intensification of cattle production based on natural processes, but at the same time are an integrated approach for sustainable land use (Reyes et al. 2017). SP systems are considered win-win options as they are oriented to increase livestock productivity, to augment income and product diversification, to enhance resilience to climate change by the microclimatic conditions that trees and shrubs provide to animals and pastures, to harness mitigation benefits by reducing GHG emissions and increasing Carbon-sequestration in pasture and woody perennial root systems (Ibrahim et al. 2001; Sotelo et al. 2017). In the end, SP systems render valuable ecosystem services such as water, soil, and biodiversity conservation and contribute to avoided deforestation (Ibrahim et al. 2009; Solorio et al. 2017). The following paragraphs describe and discuss the most relevant SP options and both traditional and products of technological innovations developed by researchers and livestock practitioners, in many cases in collaboration with farmers.

2.1 Silvopastoral Options

Several options for integrating trees in livestock systems found in Latin America and the Caribbean are practiced in the different agroecological zones present in the continent as described in Annex 1 (Figure 4). The geographical distribution is illustrated in Figures 5 and 6. Based on the different publications consulted for this report, in general, the highest diversity of SP practices occur in tropical environments, followed by the temperate region, and lastly in the boreal agroecological zones. The most frequently practiced SP option in all regions is scattered trees in pastures, followed by live fences in the tropical agroecological zones. In the temperate and boreal regions, the most frequently practiced SP option is grazing under tree plantations. (Figure 6)

All SP systems consist of pastures growing in combination with trees of several different species, ages, and sizes ranging from older large trees left from the original forest to young ones that are the result of natural regeneration or that have been recently planted (Montagnini et al. 2013). The relative importance and the frequency of these practices vary across agroecological zones and promotion efforts. Some of these practices are part of the production culture in each region, whereas others have been designed by researchers, practitioners, and/or farmers as a means to take advantage of the contribution of woody perennials in livestock systems or to benefit from the role animals could play in forestry systems through weed control, fire-risk reduction, income diversification, and advanced partial recovery of investment (Pezo and Ibrahim 1999; Peri et al. 2016a).

Figure 4. Silvopastoral Options Involving Different Component Arrangements and Purposes

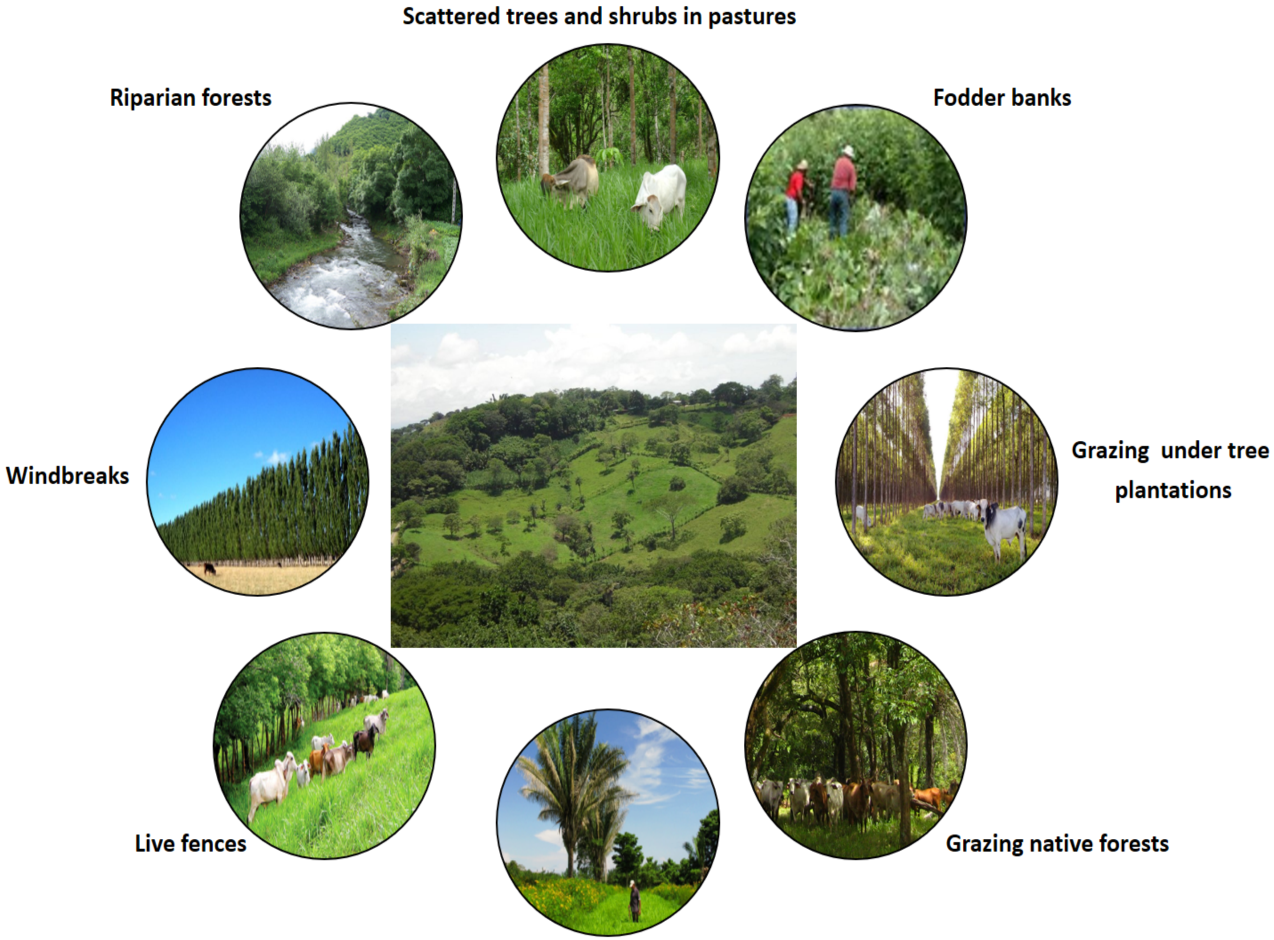


Figure 5. Geographical Distribution of a Sample of Silvopastoral Systems Identi Different Agroecological Zones in Latin America and the Caribbean

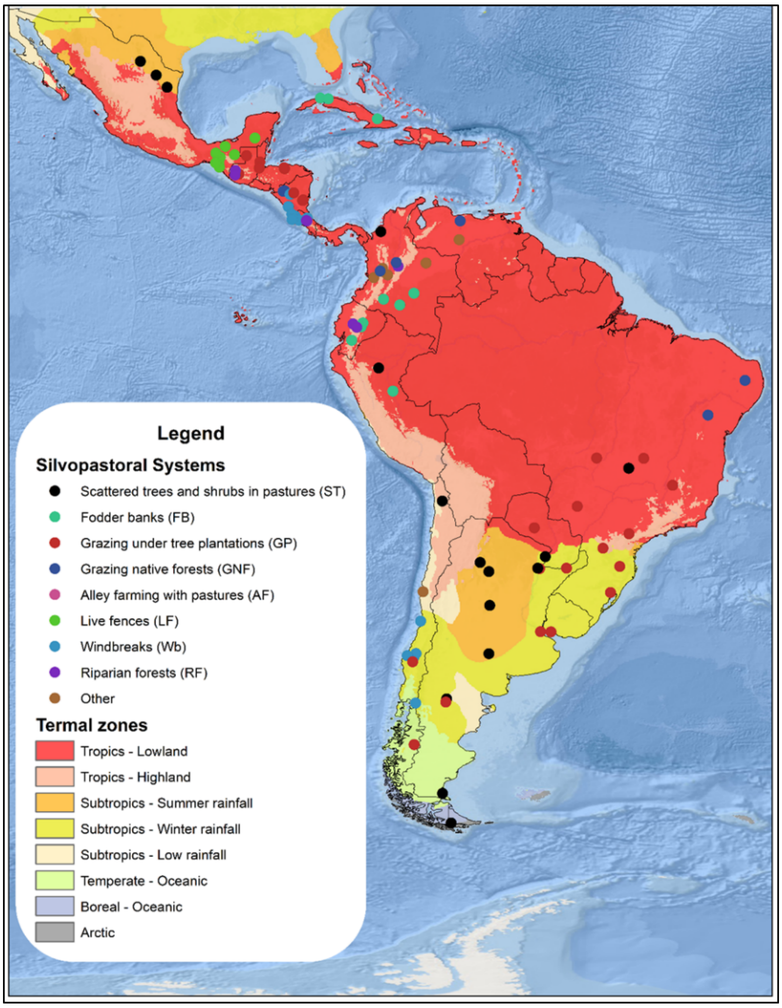
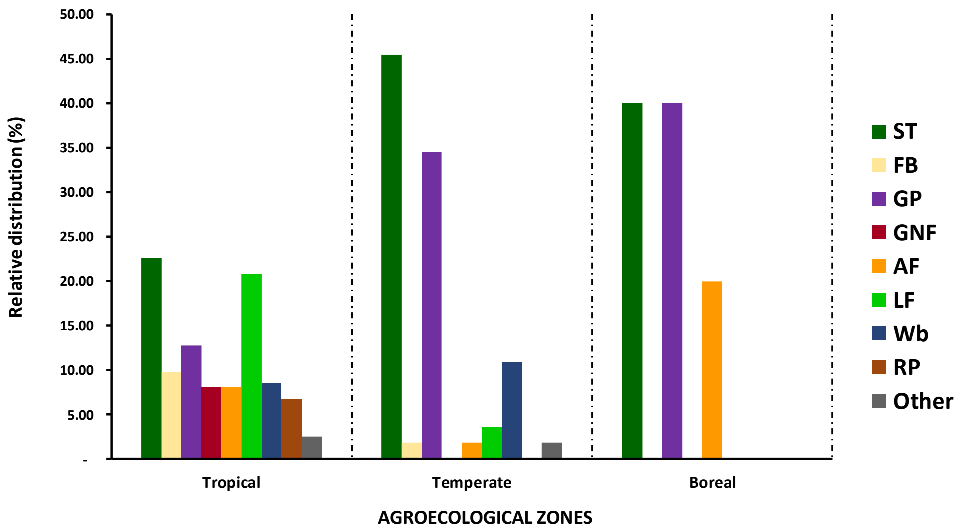


Figure 6. Relative Distribution of the Different Silvopastoral Options in LAC as Function of Agroecological Zones. (Same Legend as Figure 5)



a) ***Scattered trees/shrubs in pastures***

Options frequently found naturally are savanna-type ecosystems in arid, semi-arid, and sub-humid areas in the tropics and temperate areas (Mastrangelo and Gavin 2012; Almeida et al. 2013; Soler et al. 2013; Foroughbakhch et al. 2014; Marinaro and Grau 2015; Peri et al. 2016b; Caballé et al. 2016; Rojas et al. 2016; Figueiredo et al. 2017). These ecosystems can be the result of natural regeneration, selective partial deforestation, or purposely planted trees dispersed in the pastures as sources of shade, fruit, and timber for the market for on-farm use (Andrade 2006; Esquivel 2007; Montagnini et al. 2013). Most farmers prefer to manage native trees that result from natural regeneration as opposed to planting trees themselves. The former is a natural process. In addition, the species are already adapted to the site's agroecological conditions and do not require major investments except for labor and measures for protecting young trees (Villanueva et al. 2018). However, sometimes the problem is that farmers and/or workers do not recognize the trees at young stages and eliminate them during weeding. Geographical distribution of the scattered trees in pasture SP system in LAC is presented in Figure 7.

Figure 7. Geographical Distribution of the Scattered Trees in Pasture SP System in LAC

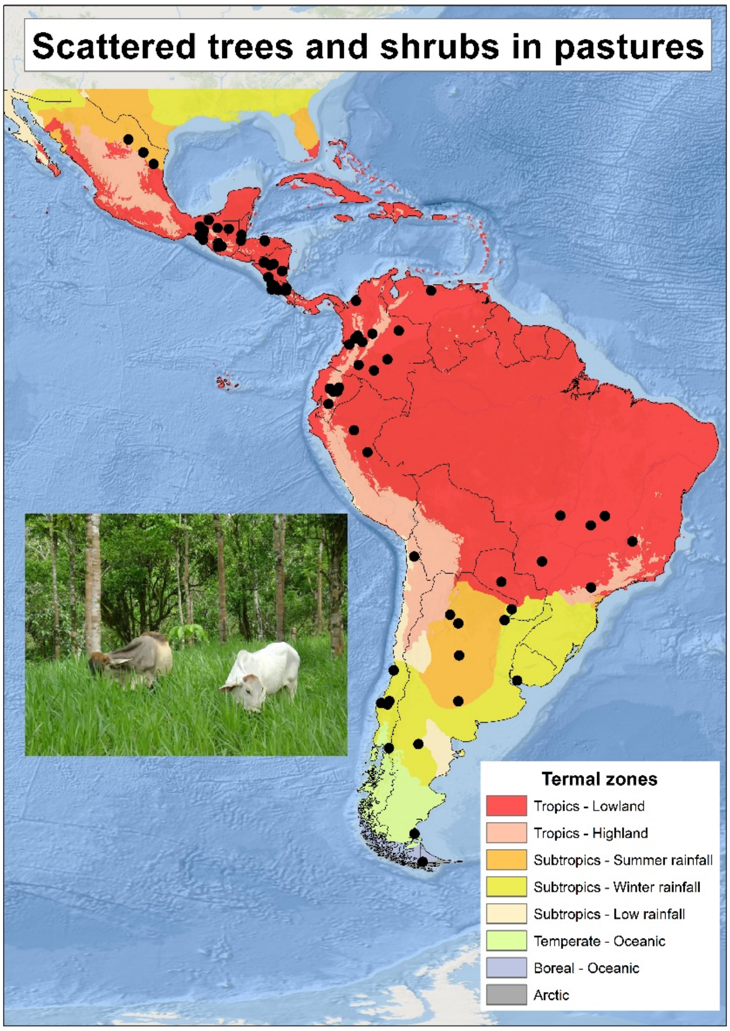


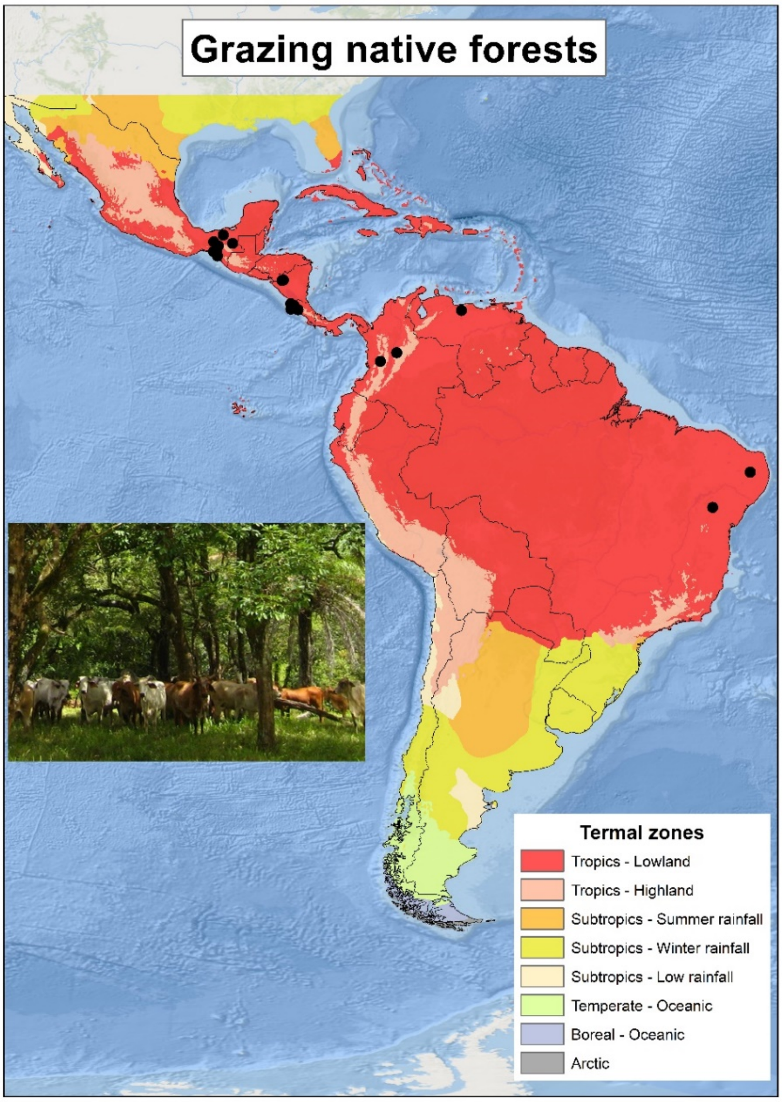
Photo 1. Animals Grazing under Scattered Trees in Pastures, Muy Muy, Nicaragua

Source: D. Pezo

b) Grazing under native or secondary forests

The system named, grazing under native or secondary forests, is similar to the one described in the last section in the sense that trees do not have a fixed arrangement and could have a dominant species like in the Pinus forests of the Sierra Madre in Mexico and the Ñire forests in the Patagonia (Peri et al. 2016b; López-Carmona et al. 2001). There could also be a diversity of deciduous trees and shrub species with an herbaceous understory of vegetation (Sánchez 1998; Manacorda and Bonvisutto 2001). Another possibility is that pastures are next to an area purposely left as primary forest or where secondary forests result from natural regeneration in abandoned areas previously under degraded pastures or croplands. In those forests, one could find edible biomass that animals consume in critical periods of food scarcity or when entering into the forest looking for shade or protection (Ramirez-Marcial et al. 2001; González-Tagle et al. 2007; Ibrahim et al. 2007; Miliani et al. 2008; Muñoz et al. 2013; Nahed-Toral et al. 2013). The geographical distribution of this SP system in LAC is presented in Figure 8.

Figure 8. Geographical Distribution of the Grazing Native Forests SP System in LAC

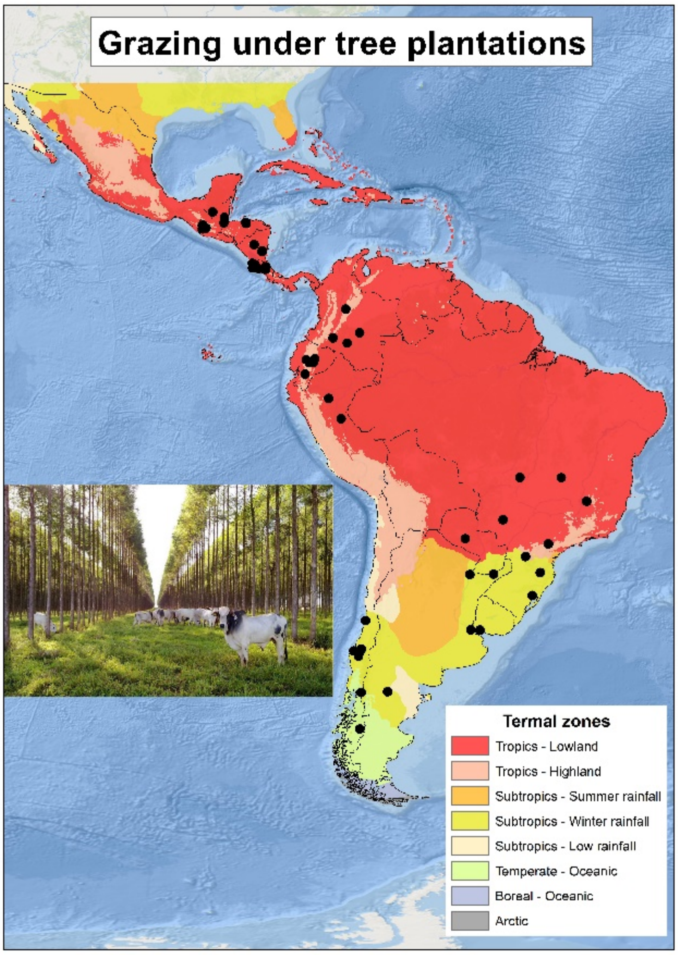


c) Grazing under tree plantations

Grazing the understory vegetation in timber plantations is more commonly practiced in temperate zones than tropical agroecological zones in LAC (Cubbage et al. 2012; Lacorte et al. 2016; Caballé et al. 2016). In recent years, there have been efforts to promote such systems under tropical conditions (Somarriba and Lega 1991; Pezo and Ibrahim 1999; Cubbage et al. 2012). In contrast, grazing under coconuts, rubber, and oil palm plantations is a traditional practice in Southeast Asia (Reynolds, 1995). It is also practiced in other fruit tree plantations in LAC, such as in the cases of oranges, cashew, mangoes, etc. (Lascano and Pezo 1994). Initially, only fast-growing timber trees (*Eucalyptus spp., Pinus spp., Acacia mangium, Gmelina arborea, T. grandis*) were preferred for this SP option, but more recently attention has been paid to the use of native timber trees as well (Calle et al. 2012).

Several benefits have been attributed to grazing under tree plantations system including increased income and diversification, faster recovery of investment, more uniform use of labor over the year, better soil coverage, reduced weeding costs, the provision of shelter and shade to animals by trees, and fewer fire-risks because of understory vegetation control. However, potential problems have been identified. These problems include the fact that not all grasses and legumes tolerate shade and competition for growth factors and that livestock could damage planted or naturally regenerated trees, particularly during young stages such as less than 2-3 years after establishment (Pezo and Ibrahim 1999). Some modifications in the spatial arrangements of trees in forest plantations for SP purposes have been implemented to reduce competition between trees and pastures (Cubbage et al. 2012; Sotomayor et al. 2016). The geographic distribution of the grazing under tree plantations SP system in LAC is presented in Figure 9.

Figure 9. Geographical Distribution of the Grazing under Tree Plantations SP System in LAC



c) Live fences

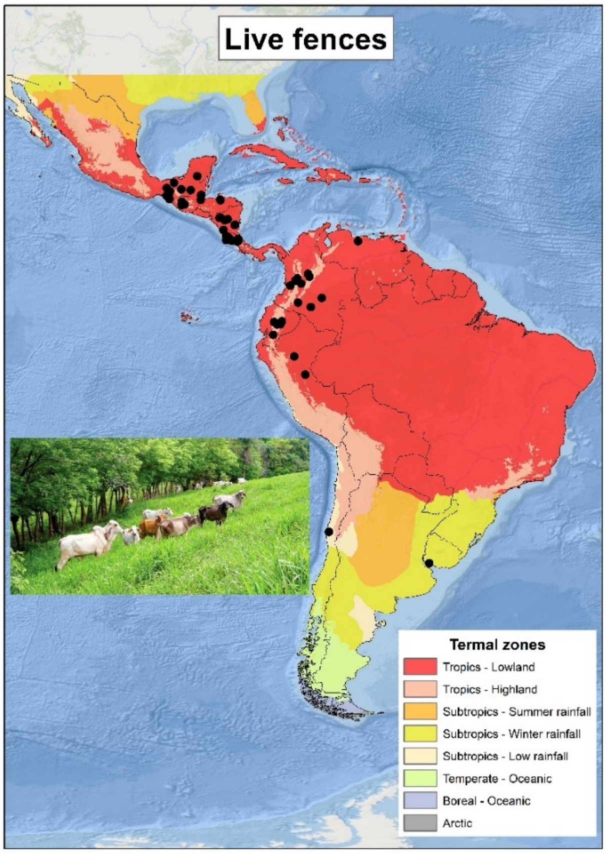
The use of woody perennials in live fences to delimit farms and pastures is traditionally practiced in tropical America. Live fences could be simple or multi-strata. The simple ones have one or two dominant species, which are pruned at least once a year to maintain them at uniform height. In contrast, the multi-strata fences have more than two species of different heights and purposes such as for the production of timber, fruits, medicinal materials, and ornaments (Villanueva et al. 2018). The type of species used vary with agroecological zones. Some of the species used under tropical, sub-humid conditions in simple live fences are *Bursera simaruba*, *Gliricidia sepium*, *Spondias spp*., *Anacardium occidentale* and *Jatropha curcas*. In the year-round humid tropics, *Erythrina berteroana,* and *Gliricidia sepium* are more frequently used (Muñoz 2004; Murgueitio et al. 2011; Montagnini et al. 2013). In the mid-altitude highlands, *Eryhtrina spp*., *Sambucus mexicanus*, and *Cupressus lusitanica* are more common (Pezo and

Ibrahim 1999). In multi-strata live fences, timber species such as *Cordia alliodora*, *Tabebuia rosea*, and *Bombacopsis quinata* are found. The number of trees in live fences vary from 67 to 242 trees km[1] on average (Ibrahim et al. 2007). In such multi-strata live fences, the average distance between timber trees is about 10 m. As a result, their potential ecological and economical contribution could be significant (Montagnini et al 2013; Rivera-Céspedes et al. 2016). The geographical distribution of reports on the use of live fences in LAC is presented in Figure 10.

Photo 2. Dual-purpose Calves Browsing *Gliricidia sepium* Cut from a Live Fence, Petén, Guatemala

Source: D. Pezo

Figure 10. Geographical Distribution of Reports on the Use of Live Fences in LAC



d) Fodder banks

Fodder trees and shrubs planted at high density (from 10,000 up to 40,000 plants/ha) can be used under direct browsing or managed under "cut & carry" systems. They are called fodder banks or protein banks (Ibrahim et al. 2007; Montagnini et al. 2013). The frequency of use varies with the species, agroecological conditions, agronomic management, and intensity of defoliation as all of these affect the speed of regrowth (Pezo and Ibrahim 1999). When fodder banks are browsed, plants eventually need to be pruned on the top to assure that animals have access to foliage. Animals usually enter the fodder banks for few hours during the day (Milera et al. 2016). Most species used in fodder banks are legume shrubs/trees rich in protein such as *Gliricidia sepium*, *Leucaena leucocephala*, *Erythrina spp*., and *Cratylia argentea* (Ibrahim et al. 2001). However, there are other non-legume fodder shrubs such as *Morus alba*, *Tithonia diversifolia*, *Trichantera gigantea*, *Brossimum alicastrum,* and *Guazuma ulmifolia* that also are important for their high content of digestible energy (Ibrahim et al. 2007; Calle et al. 2013). This technology has been applied in tropical areas of LAC as a means to intensify livestock production and to reduce feeding costs by partial replacement of commercial feeds (Villanueva et al. 2010). It is also well recognized that it contributes to reducing GHG emissions and to increasing resilience to climate change (Ibrahim et al. 2010; Pezo 2017). The geographical distribution of fodder banks system in LAC is presented in Figure 11.

Figure 11. Geographical Distribution of the Use of Fodder Banks in LAC

Photo 3. ***Morus alba*** **+** ***Erythrina poeppigiana*** **in a Fodder Bank, Pavones,Turrialba, Costa Rica**

Source: D.Pezo

e) Alley farming with pastures

The high density of trees and shrubs in fodder banks does not allow herbaceous species to grow. As a result, opening the distance between rows of woody perennials reduces competition for light, water, and nutrients when high yielding grass/legume species are introduced into the system. It also helps animals to move freely between rows of fodder trees. In this case, the density of fodder trees are less than 10,000 plants ha[1]. Up to 500 timber trees ha[1] can be planted in east-west lines to minimize shading (Murgueitio et al. 2011; Calle et al. 2013). This system is also known in the literature as the *Intensive SP System*. It is a technology that can contribute to mitigating climate change due to its high production capacity of both plant biomass and animal productivity that enables this system to have a positive GHG balance when compared to degraded pastures that dominate many of the grazing lands in LAC (Montagnini et al. 2013). More importantly, it is economically feasible (Murgueitio et al. 2010). Several combinations of fodder trees, pastures, and timber trees have been tested in different tropical agroecological zones. Details are shown in Table 1. The geographical distribution of the use of alley farming with pastures system in LAC is presented in Figure 12.

Figure 12. Geographical Distribution of Alley Farming with Pasture Systems in LAC

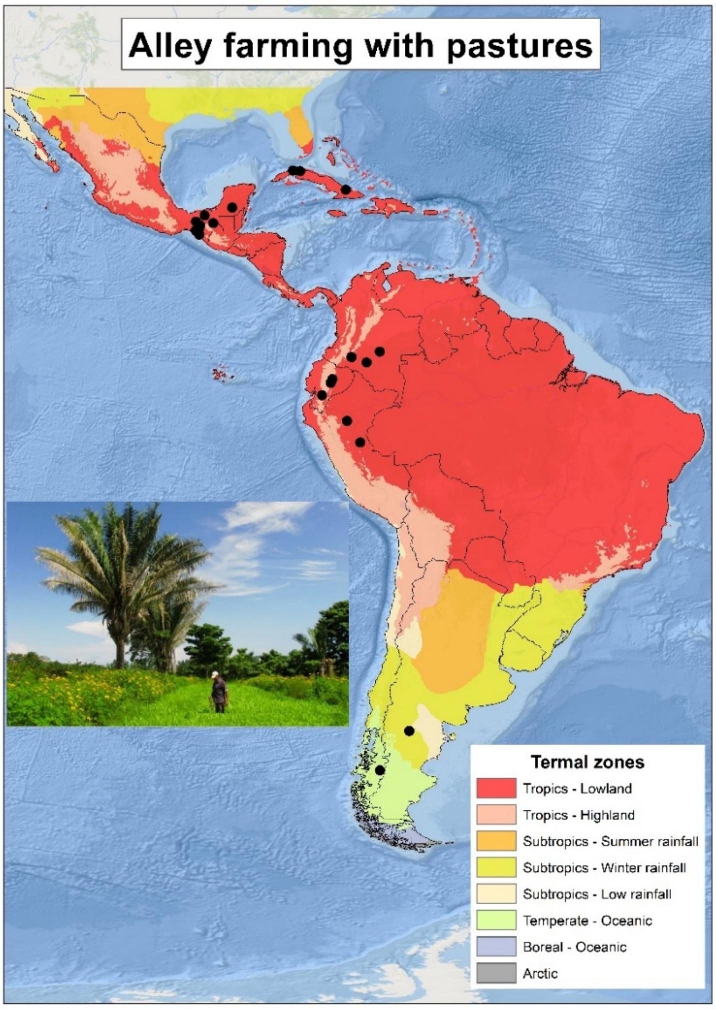


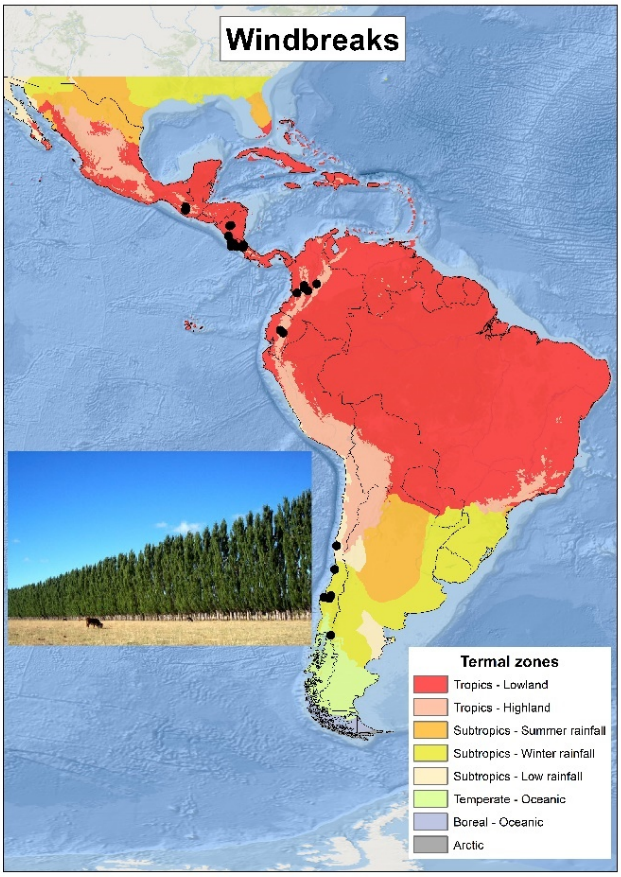
Photo 4. Animals Grazing in an Alley Farming System with *L. leucocephala* + *B. brizantha*, Peten, Guatemala

Source: D. Pezo

f) Windbreaks

Trees windbreaks are a traditional system in LAC and in other parts of the world. In areas with little remaining forests and agriculturally modified landscapes, windbreaks can be critical for biodiversity conservation not only as a source of seeds for forest restoration, but also for enhancing connectivity between forest patches (Harvey 2000). In livestock systems, windbreaks contribute to animal welfare by reducing the impact of cold winds and rains (Montagnini et al. 2013). In sub-humid and semi-arid agroecological zones, windbreaks also help to reduce the drying effect of wind on herbage (Pezo and Ibrahim 1999). An attempt to represent the geographical distribution of the windbreaks SP system in LAC is shown in Figure 13. The points identified in the map reflect what has been found reported in the references cited in Annex 1. However, those do not represent the real distribution of such SP option, because we have observed that this system is practiced almost in all agroecosystems in LAC, but not found reported in literature.

Figure 13. Geographical Distribution of Windbreaks in LAC



g) Hedgerows

In farms with steep slopes, it has been suggested to plant herbaceous vegetation in hedgerows. However, livestock farms present good opportunities for planting fodder trees and shrubs beside edible grasses and legumes as components of hedgerows. These are used as part of "cut and carry" fodder schemes (Fujisaka et al. 1994; Pezo 2017). The potential use of the species to be included in hedgerows have been critical for adoption, particularly by farmers with very limited availability of land and who need as much land as possible for production purposes. They must put food security and economics in front of any ecological goals (Murray and Banister 2004).

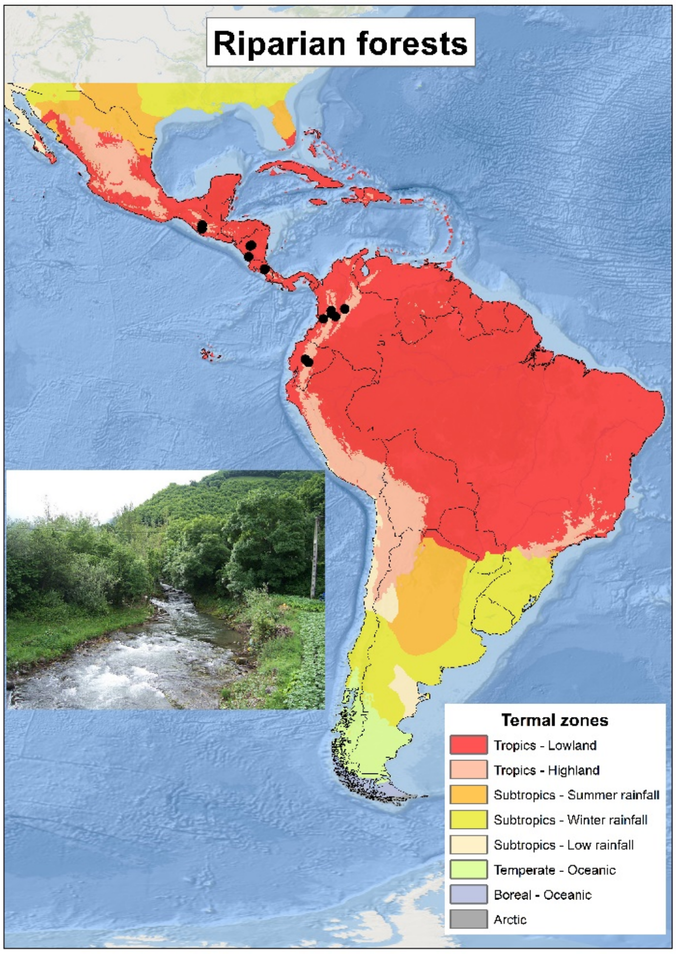
Photo 5. ***M. alba*** **+** ***E. poeppigiana*** **in Hedgerows with Grasses, Pavones, Turrialba, Costa Rica**

Source: D. Pezo

h) Riparian forests

Arrangements of woody perennial vegetation around water bodies, in many cases just streams, constitute a riparian forest. A riparian forest has a disproportionate reliance on running waters relative to its land area because of its immediate effects on the transport of water, nutrients, and sediments that act as a natural filter to reduce the organic, nutrient, and sediment load reaching the stream (Chará and Murgueitio 2005). It restricts the penetration of light to the streams helping to reduce fluctuation in water temperature, but also contributes to increased connectivity between forest patches that helps to maintain biodiversity. This is the reason why it is also known as riparian buffer (Murgueitio et al. 2010; Calle et al. 2013). A riparian buffer is highly recommended to prevent animals from entering into the riparian forest and stream banks, because of the damages they could make by affecting channel morphology, water chemistry and habitat diversity (Chará and Murgueitio 2005). The geographical distribution of riparian forests as silvopastoral system is presented in Figure 14.

Figure 14. Geographical Distribution of Riparian Forests as Silvopastoral Systems in LAC

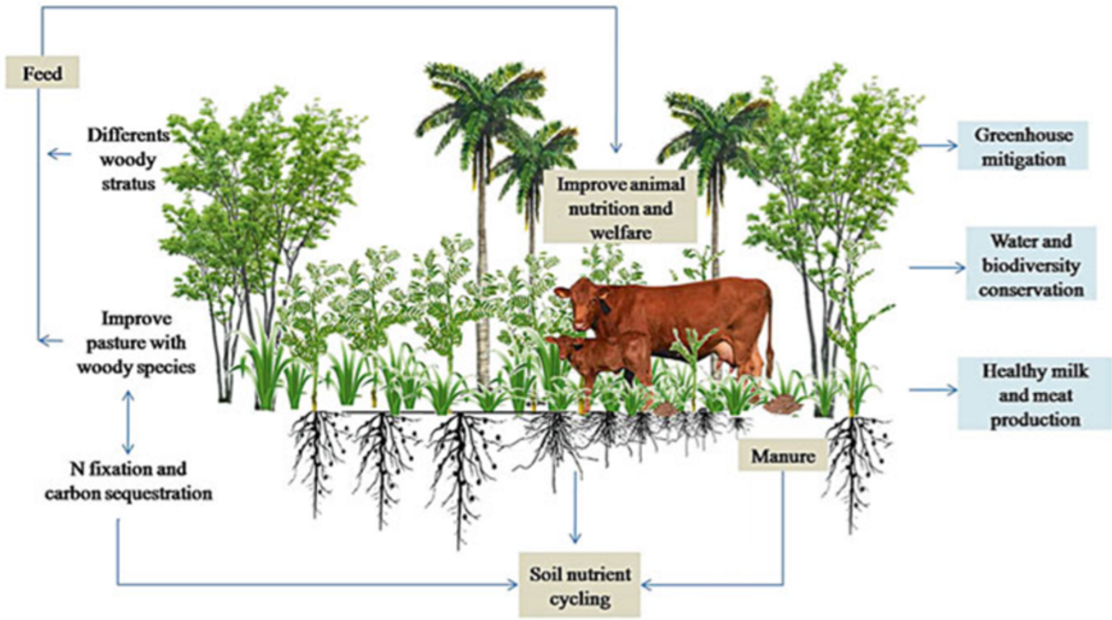


As described in previous paragraphs, there are several SP options. However, to make better use of the potential contribution of each, a careful evidence-based analysis must be made on the pros and cons of each for a given site before taking decisions. This analysis must consider not only the prevalent agroecological conditions, production systems, and role of the woody perennials, but also when restoration of degraded lands is required. Attention should be paid to the planning of interventions, because some areas will be removed from livestock use temporarily or permanently. Therefore, attention should be paid on how the change in animal productivity will affect the economic feasibility of the livestock enterprise. Also, it is important to consider changes beyond the farm, because of the multiple interactions between farm units, especially in connection to biodiversity and water resources impacts, which are relevant at landscape or territorial level.

2.2 Biophysical Benefits and Co-benefits of Applying Silvopastoral Approaches for Sustainable Intensification of Livestock Production

A simplified model describing the components, processes, and interactions occurring in silvopastoral systems is presented in Figure 15.

Figure 15. Components, Interactions, Processes, and Outputs in a SP Systems



Source: Solorio, et al. 2017

a) Animal nutrition and welfare

The presence of trees in pastures may compete with understory herbaceous biomass for light, water, and nutrients, but may affect forage yield markedly only if there is high density of trees and/or the understory grasses and legumes are poorly tolerant to shade (Pezo and Ibrahim 1999; Sotelo et al. 2017). Moreover, trees help increasing nutrient availability for the understory vegetation through organic matter decomposition, Nitrogen-fixation, and by pumping nutrients from lower strata of the soil profile where roots of most herbaceous vegetation do not reach (Andrade 2006; Botero and Russo 2016, Sotomayor et al. 2016). In terms of forage quality, grasses and legumes growing in association with trees show higher contents of crude protein and minerals. If fodder trees are part of the system, they are richer in nutrients than grasses and contribute to improve diet quality, particularly during the dry season (Ibrahim et al. 2001; Esquivel 2007). All these contribute to achieve higher animal productivity in silvopastoral than pastoral systems.

Box 1. Opportunities for Mutual Learning on Silvopastoral Systems between Latin America, The Caribbean, And Africa

Africa has almost the same agroecological zones that are present in Latin America and the Caribbean (LAC). In both regions, silvopastoral options are part of the traditional livestock production systems, although some differences in tree and forage species, management practices, and production intensities have been observed. For example, scattered trees in pastures are more common in the semi-arid and arid agroecological zones (AEZs), whereas fodder banks for browsing and "cut and carry" are mainly present in the tropical, wet, and moist regions. Protective systems such as windbreaks are more common in the arid, semi-arid, and coastal regions in hedgerows on sloping lands in the moist mountainous areas, and live fences are found almost throughout all AEZs (Nair and Nair 2014).

In the arid and semiarid AEZs of Africa, agro-silvopastoral systems have been the traditional practice for centuries with crops grown during the short rainy season, and animals coming back to those areas during the dry season. However, recently this practice has become less frequent due to the increase in numbers of people and animals, and to cropping lands encroaching on areas formerly reserved for pastures. Livestock production is relevant for the communities in the region, and some lessons learned on silvopastoral options under similar AEZ in LAC could be valuable for intensification. For example, more productive fodder shrubs and trees may be used to supplement the presently available edible biomass and thus improve animal nutrition and animal productivity as well as to improve water availability and soil fertility. However, some land use policies such as the allocation of land to pastoral and crop uses and land tenure rights need to be revised (von Maydell 2002).

SP systems are also commonly practiced in the dominant wooded savanna in the lower elevation, sub-humid, and humid AEZs in Africa, but an important threat to livestock under SP systems is the presence of trypanosomiasis, because trees favor the presence of tse-tse flies. The identification of trypano-tolerant cattle genotypes would help to overcome such constraints (Le Houerou 2002). Again, experience with scattered trees in pastures and intensification of these systems developed in similar AEZ in LAC are quite valuable. Moreover, many of the grass species used in LAC are originally from Africa.

In the highlands of Eastern Africa, where over 200,000 smallholders plant fodder trees to feed dairy cows, there are great opportunities for knowledge sharing with LAC, considering the relevance of more intensive use of fodder trees for smallholder dairy farmers (Place et al. 2009). South-south cooperation programs may help to overcome some of the constraints to wider adoption of those systems such as the limited availability of tree species appropriate to different agroecological zones, shortages of seed, and the lack of knowledge and skills needed by farmers to grow them (Franzel et al. 2014). Also, experiences on the introduction of valuable timber trees in live fences, the use of improved grasses and herbaceous legumes in SP systems, and the role of incentives for promoting tree cover on farms are other areas of potential knowledge sharing between regions.

In terms of animal welfare, trees that provide shade or reduce wind speed in SP systems protect animals from climatic stress such as hot and cold weather by reducing the temperature, by ameliorating the environment, and by enhancing animal performance in terms of milk yield, live-weight gain, and reproductive performance (Broom et al. 2013; García-Cruz et al. 2013; Sotomayor et al. 2016; Reyes et al. 2017; Sotelo et al. 2017).

b) *Nutrient cycling*

There is a continuous state of dynamic transfer of plant nutrients in silvopastoral systems, with plants using soil minerals for metabolic purposes and returning them back to the soil litter or through root senescence (Dagang and Nair 2003; Martínez et al. 2014; Solorio et al. 2017). Some authors refer to the role of trees as creating fertility islands in pastures (Menezes and Salcedo 1999; Camargo-Ricalde et al. 2010; Avendaño-Yañez et al. 2017). The role of animals enhancing nutrient cycling through feces and urine deposition is relevant, although their distribution in pastures is scattered. However, when tree fodders are in high proportion in the diet, the excess of crude protein results in greater nitrogen losses and N_2O emissions to the atmosphere (Herrero 2011; Lessa et al. 2014; Pezo 2017).

c) *Nitrogen fixation and carbon sequestration*

Several silvopastoral systems include many nitrogen-fixing trees, mostly leguminous, but also some non-leguminous like *Alnus acuminata* (Russo 1990, Sotelo et al. 2017). All these contribute to boost soil N levels, with consequent impacts on pastures and animal productivity. The net carbon flux and primary productivity increase significantly when woody perennials are integrated with grasses and legumes as the former have high potential for carbon sequestration in the stem and root systems (Amézquita et al. 2010, Villanueva et al. 2018). Also, well-managed grasses with deep root systems have a high capacity for carbon sequestration (Peters et al. 2013).

d) *Biodiversity conservation*

Silvopastoral systems are not only a means for conserving and using a wide diversity of plant species, but also such diversity contributes to creating conditions for greater resilience of livestock production systems (Dagang and Nair 2003; Sotelo et al. 2017; Villanueva et al. 2018; Esquivel et al. 2011; Harvey et al. 2011; Solorio et al. 2017). At the territorial level, livestock farms are part of a matrix of production and conservation units in which SPS serve as habitat for many species, enhance landscape connectivity, and retain the potential for forest regeneration and restoration (Harvey et al. 2004; Harvey et al. 2008; Kunst et al. 2014; Marinidou et al. 2017).

e) *Water conservation*

Woody perennials in silvopastoral systems influence water dynamics by acting as barriers to prevent runoff, reducing the impact of rain drops on soil, and increasing water infiltration and retention (Ibrahim et al. 2007; Rios et al. 2007; Villanueva et al. 2018). Forages growing under tree canopy cover show lower evapotranspiration rates than in the open space, contributing to maintain hydric balance in livestock landscapes (Gyenge et al. 2002). Also, the protection of springs and water courses through the presence and enrichment of woody perennials in areas close to water bodies reduces the effect of diffused pollution in water sources (Chará and Murgueitio 2005; Calle et al. 2009; Sotelo et al. 2017).

f) *Greenhouse gas mitigation*

Methane emission from ruminants is one of the largest greenhouse gas emission sources from the livestock sector. The implementation of silvopastoral systems is one of the most important approaches for offsetting emissions in livestock farms, because tree fodders release less methane as a product of rumen fermentation (Pezo 2017). However, the contents of tannins, saponins, and other secondary metabolites contained in some tree leaves and fruits reduce the activity of rumen methanogenic bacteria (Briceño-Poot et al. 2012; Goel and Makkar 2012; Berndt and Tomkins 2013). Also, increasing productivity of livestock systems through the application of SP options contributes indirectly to enhance mitigation by preventing the expansion of pasturelands at the expense of forests (Montagnini et al. 2013). Moreover, the presence of trees in SP systems contributes to enhance carbon sequestration (Hänsel et al. 2009; Amézquita et al. 2010).

g) Climate change resilience

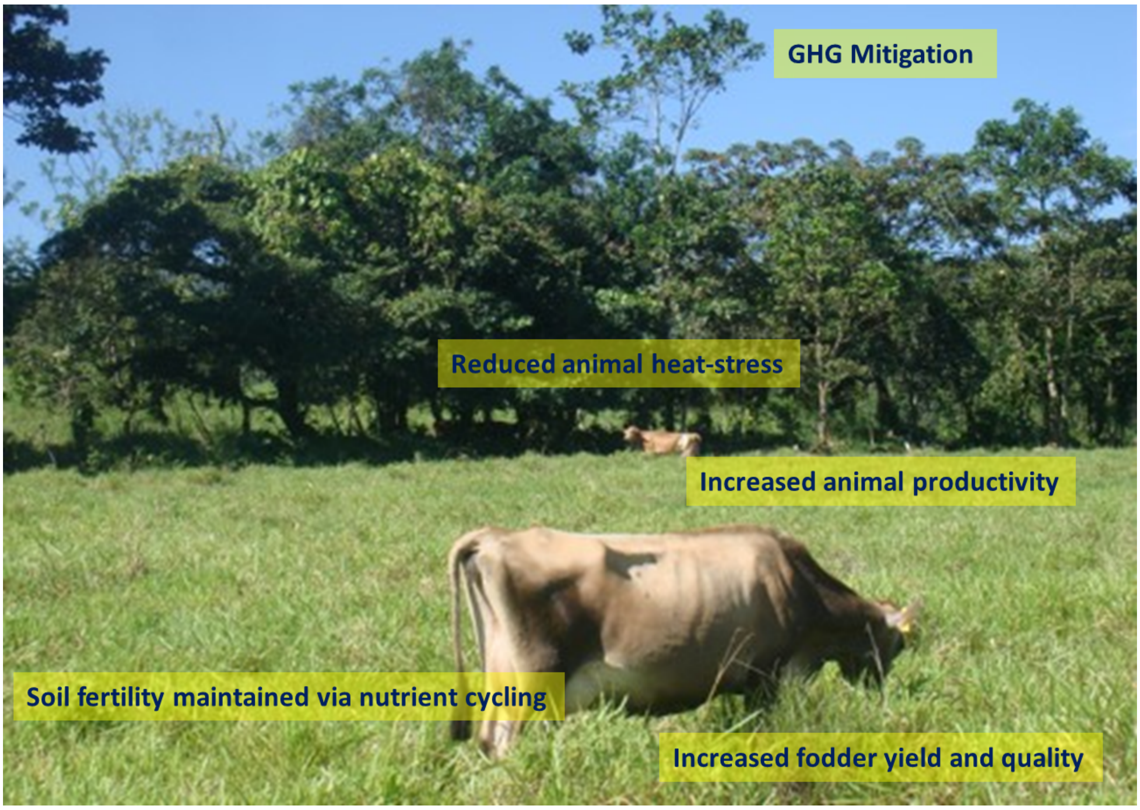
The correct application of different SP options for livestock production plays an important role by reducing vulnerabilities and increasing adaptive capacity of livestock systems (Cuartas et al. 2014; Pezo 2017) as listed below and illustrated in Figure 16:

- Increased forage yield and quality and increased carrying capacity;
- Enhanced animal and forage adaptive capacity through better microclimatic conditions;
- The use of locally produced protein and energy rich feed sources;
- Maintenance of soil fertility via nutrient cycling and protecting soils from erosion;
- Improved soil fertility through the increase in organic matter from woody perennials and atmospheric N-fixation by trees and herbaceous legumes; and
- Reduced inter-annual and seasonal variation in forage availability.

2.3 Socioeconomic Benefits of Applying Silvopastoral Approaches for the Sustainable Intensification of Livestock Production

The historically dominant model of extensive cattle ranching, which occupies a considerable area of land in tropical LAC, is not sustainable in either social or environmental terms. It is not able to provide a decent way of living to a large group of small and medium size livestock farmers, and, in most cases, expansion has represented the loss of forest cover with the consequent impacts on biodiversity, GHG emissions, and hydric balance. (Deutsch et al. 2010; Ibrahim et al. 2010). A technological and social transformation is indispensable to move from an exclusionary production model dominated by cattle raising to diversification into silvopastoral systems (Bermúdez et al. 2015). However, for these options to be adopted, it is necessary that SP interventions be financially competitive when compared to conventional systems, because the former usually demand a high initial investment and farmers need to wait some time before getting any profit (Gobbi and Casasola 2003).

Figure 16. Contributions of SP options to Reduce Vulnerability of Livestock Systems to Climate Change



For the analysis of different SP options, it is important to consider that each has different demands in terms of labor, inputs, and capital investments and each will provide diverse products and benefits after different periods of time (Murgueitio et al. 2006). Products like timber, fodder, or fruits can be easily valued, but services such as shade, carbon sequestration, and biodiversity conservation are more difficult to consider in economic analyses unless they could be properly valued (Peri et al. 2016b). However, most studies have demonstrated that SP systems are more profitable than traditional systems, even in the absence of payment for environmental services (PES) (Alonzo 2000; Gobbi and Casasola 2003; Piotto et al. 2010; Villanueva et al. 2010; Chuncho-Morocho 2011; Scheelje et al. 2012; Avila-Foucat and Revollo-Fernández 2014; Souza 2015; Dube et al. 2016; Sotelo et al. 2017).

Research data generated in the sub-humid tropics of Costa Rica for the most commonly practiced dual-purpose cattle systems were analyzed to illustrate the economic performance of different SP systems using current values for inputs and products and considering the implementation of some of the silvopastoral options described in the previous section.

In the area where these economic analyses were applied, traditional livestock systems are mostly based on the use of non-improved pastures with low density of scattered trees. The innovations considered were the introduction of improved pastures and those associated with trees scattered at a relatively high tree density (15-20% tree cover). The change for improved pastures resulted in a significant increment in the cost-benefit (C/B) ratio and the net present value (NPV), but those economic indicators reduced when scattered trees at relatively high density become part of the system. (Table 1) When fodder banks were added to the improved pastures system, the C/B ratio was slightly less than for improved pastures alone (1.94 versus 2.02), but the NPV per hectare was higher (USD$272.83 versus USD$220.26). In all these cases, the economic value of the contribution of trees into the system by reducing GHG emissions or by providing any other ecosystems services that could be paid in a PES scheme was not considered.

The use of simple and multi-strata live fences incorporating valuable timber trees resulted in higher net present values than the use of the traditional fences with dead posts, because the latter need more investment in posts as well as for maintenance. Also, live fences can provide fodder to the animals, but this contribution was not valued. Another option considered for the analysis was to abandon the degraded pastures letting secondary forest to regenerate, but with some investment on fencing and surveillance to prevent fires. Under those circumstances, a negative NPV was obtained even after deducting the economic incentive given by the Government of Costa Rica to promote such intervention.

Table 1. Cost/Benefit (C/B) Ratio and Net Present Value (NPV) for Different SP Interventions in the Sub-humid Tropics of Costa Rica

SP Interventions	Duration, years (y)	C/B Ratio	NPV US$ ha^{-1} y^{-1}	NPV US$ km^{-1} y^{-1}
Non-improved pastures + trees in low density	12	1.93	140.10	---
Improved pastures	12	2.02	220.26	---
Improved pastures + scattered trees (high density)	12	1.75	186.61	---
Improved pastures + Fodder bank	12	1.94	272.83	---
Traditional live fences	12	---	---	463.58
Multi-strata live fences	12	---	---	547.15
Natural regeneration of forest in degraded pastures	5	---	- 148.93	---

The other set of SP options analyzed was grazing under tree plantations (Table 3), an option more frequently practiced in temperate regions. The other variant considered for the economic analysis compared to others available in the literature was the introduction of annual crops (maize + squash) during the first two years as a source of quick income, also known as the Taungya system, and the establishment of improved pastures before the end of the second year (Sharrow and Buck 1999; Schlöngvoit and Beer 2001). Three tree species with different levels of precocity were considered, and in all cases the grazing animals were dual-purpose cattle. Also, the tree density and spatial arrangement were variables considering the 4x4 m square planting traditionally practiced by foresters in Costa Rica, who prune and thin at given intervals to reduce competition either between trees, but also between trees and pastures. The other option was to reduce tree density by opening the space between double-rows of trees and to plant improved pastures in between. The latter is more frequently practiced in South America than in Central America and the Caribbean. (Casaubon et al. 2016; Dube et al. 2016) All economic indicators showed that SP options consisting of the introduction of annual crops for the first two years and planting pastures to start grazing in the third year were better than the traditional tree plantations in monoculture. Better internal rate of return (IRR) values were obtained for *Gmelina arborea,* a fast-growing and good quality timber tree, and the native *Bombacopsis quinata* that requires up to 30 years before final harvesting but produces a very high-quality timber. The economic performance for *Eucalyptus deglupta* was slightly less than for *Bombacopsis quinate*. (Table 2)

Table 2. Internal Rate of Return (IRR, %) for Different SP Options with Improved Grasses Intercropped with Valuable Timber Trees in the Sub-humid Tropics of Costa Rica

Grazing under Tree Plantations System	*Gmelina arborea*	*Eucalyptus deglupta*	*Bombacopsis quinata*
Duration, years	**12**	**18**	**25**
Traditional, square planting 4x4 m (625 trees/ha)	**16.1**	**10.6**	**11.5**
In square 4x4 m (625 trees/ha) +Taungya + Improved pastures	**26.9**	**18.0**	**18.0**
In lines 14x2 m (357 trees/ha), Taungya + Improved pastures	**27.7**	**18.3**	**21.5**

3 Enabling Mechanisms for Promoting the Adoption of Silvopastoral Innovations

In the last three decades, abundant information has been developed characterizing traditional silvopastoral systems in addition to information documenting other silvopastoral innovations for increased productivity, improved economic performance, and adaptation/mitigation of climate change in livestock systems. Each of these can contribute to reduced deforestation and the increased presence of trees in livestock farms. Much of the knowledge, techniques, and know-how for different agroecological zones have been briefly reviewed in previous sections. However, the adoption rates for SP systems have remained relatively low (Dagang and Nair 2003; Murgueitio et al. 2006; Alas-Martínez 2006; Calle et al. 2009; Botero and Russo 2016). This is despite their potential to create better socio-economic conditions for the farmers as well as their contribution for generating local and global ecosystem services (Ibrahim et al. 2006).

Some researchers have explored the reasons for the limited adoption of SP innovations. They could be grouped in four categories:

a) Complexity of the innovations

SP systems include more components and interactions than crop, pastoral, or forest systems that farmers and technicians need to understand and manage. Moreover, the latter must have the ability to integrate SP technologies into their livelihood strategies (Dagang and Nair 2003; Alas-Martínez 2006; Anfinsen et al. 2009). In many cases, the introduction of SP technologies can interfere with and adversely affect livestock production activities, because animals must be removed from certain areas during the establishment period of trees, putting more pressure in other areas already overgrazed (Casaubon et al. 2016). This can result in a temporary reduction in productivity (Caller et al. 2013). All these reasons can dissuade producers from implementing SP innovations (Dagang and Nair 2003).

b) Capacity of farmers to invest and take risks

The decision to adopt a new SP system involves an investment that requires a significant amount of capital to increase the number and genetic quality of the animals to take advantage of the increase in forage biomass and quality (Murgueitio et al. 2006). The lack of economic incentives for changing traditional systems and the time lag before realizing returns on such investment as well as farmers´ reluctance to take credit were some of the reasons why many farmers did not try SP options (Botero and Russo 2016; Calle et al. 2013). For those innovations that have high labor demands such as fodder banks, the cost of labor is also an important barrier for adoption (López et al. 2006).

c) Institutional aspects

Testing and promotion of SP innovations require interdisciplinary efforts involving livestock, soils, and forestry scientists and technicians, who very frequently belong to different institutions with little coordination and communication among them. Also, it is relevant to get a clear commitment from farmer groups as the promising innovations need to be tested at the farm level before scaling up. There is currently limited access to information and technical assistance in SP systems and very few financial institutions have SP options in their credit agenda. (Ibrahim et al. 2006; Murgueitio et al. 2006; Costa-Varella et al. 2016; Peri et al. 2016a). In many cases, these institutions are more interested in credits with faster recovery (Alas-Martinez 2006). All these institutional barriers need to be overcome to assure increased adoption of SP systems.

d) Market incentives

The growing demand for certified animal products (natural, organic, environmentally friendly, etc.) offers incentives for the development of sustainable cattle production systems in harmony with the environment (Ibrahim et al. 2010). These incentive mechanisms exist when prices for livestock products coming from environmentally friendly and sustainable cattle systems are higher. Exploring this case, CATIE collaborated with Rainforest Alliance to develop a certification system for sustainable cattle production that could help to speed-up adoption (Ochoa et al. 2013). However, no clear signs from the market side were observed. In the case of the Brazilian Amazon, the Cattle Agreement, which required farmers to comply with some forest reserve legislation and to adopt best management practices to be certified for selling beef to big meat processors, contributed to the historical 70% reduction of deforestation rates in the Amazon region (Nepstad et al. 2006a). A similar policy could also help to increase adoption of SP options if this is considered a requisite for selling beef at premium prices. However, it is clear that there is a need for additional work to promote certification of livestock products coming from SP systems and to develop consumers awareness on the valuable contribution of those systems to the environment.

There is sufficient scientific and practical evidence supporting the relevance of applying SP approaches to the sustainable intensification of livestock systems in LAC as a means to improve the livelihoods of farming families, to enhance tree cover in livestock systems, and to increase Carbon sequestration, biodiversity, and water conservation in cattle-dominated landscapes (Ibrahim et al. 2009). SP methods cans also serve as a strategy for reducing or even halting deforestation to expand pasturelands into forested areas. However, for these options to be scaled-up, it is necessary to understand which factors are hindering the adoption SP innovations and the risks involved in their application. This information could help to identify the enabling conditions that could help to overcome these barriers (Dagang and Nair 2003). Also, it is important to recognize that the clientele of adopters is not uniform. Because of this, innovations will have to be tailored to the conditions of each group of potential beneficiaries.

3.1 Financial Incentives

a) *Payment for Ecosystem Services (PES)*

Silvopastoral innovations can provide several ecosystem services such as C-sequestration, conservation of water and biodiversity resources, prevention of soil degradation, and others (Pagiola et al. 2005; Ríos et al. 2007; Ibrahim et al. 2009, Montagnini et al. 2013). The key challenge is how to establish a payment mechanism that can work as an incentive for the adoption of environmentally friendly innovations by farmers. The experience developed by CATIE, CIPAV, and NITLAPAN in Costa Rica, Colombia, and Nicaragua with the support of the World Bank Group assessed the use of PES schemes based on the contribution of different land use systems in livestock farms to biodiversity conservation and C-sequestration (Murgueitio 2003). This experience demonstrated the effectiveness of such type of monetary incentive to accelerate adoption of SP innovations (Casasola et al. 2007; Pagiola et al. 2007, Calle et al. 2013; Cárdenas-Gutiérrez 2014). Moreover, available data suggest that PES had an additional impact on prevention of deforestation (Daniels et al. 2010).

Experiences from Colombia and Costa Rica have shown that poorer households were able to benefit from PES at broadly similar or even higher levels than the better-off households, and their participation was not limited to the simpler, least expensive options (Locatelli et al. 2008; Pagiola et al. 2010). It was suggested that additional investment in short-to medium-term technical support will likely be necessary for broader retention of agroforestry practices beyond the life of a PES contract (Cole 2010). However, recent data collected in a site in Costa Rica where SP options were promoted through PES showed that the tree cover in livestock farms continued increasing even seven years after the project ended (Tobar et al. 2016).

b) *Incentives for reforestation*

The funds allocated to compensate landowners for changing land use systems on their properties from any agricultural use to forest is a type of payment for the environmental services that the forests could provide such as the mitigation of GHG emissions, hydrological services including water provision, biodiversity conservation, and the provision of scenic beauty for recreation and ecotourism (Ibrahim et al. 2010). Those incentives should be not only for promoting tree planting, but also for the sustainable management of forests aimed at preserving the primary forest or for regeneration of the so-called "secondary forest" (Chomitz et al. 1999).

In many cases, a portion of the forest incentives received by livestock farmers was used to intensify animal production activities as they had to maintain the same number of animals on a smaller area of pastures. Indirectly, forest incentives have contributed to the adoption of SP technologies such as the rehabilitation of degraded pastures, the use of more intensive grazing management practices, and the implementation of other SP innovations (Rivera-Céspedes et al. 2016). In the case of Costa Rica, at the initial stages of the forest incentives program, large farmers and forest owners were disproportionately represented among participants (Zbinden and Lee 2005). However, after the addition of an agroforestry component to the National Forestry Financing Fund in 2004, significant changes occurred resulting in a considerable increase in the number and diversity of trees planted and in the reduction of seasonal burning in smallholder farms (Cole 2010).

c) *Green credits*

Offering subsidized credits has been effective in promoting the adoption of certain types of activities. In the case of the livestock sector, access to subsidized credits was in the past one of the main factors that contributed to the expansion of livestock farms into forested areas in sever(Hetch 1993; Kaimowitz 1996; Roebeling and Hendrix 2010). Based on these experiences, having affordable credit schemes oriented to promote sustainable systems will always be a catalyst for changes in the livestock sector. In this context, the so-called “green credits,” lines of credit with lower interest rates to promote environmentally friendly investments, have proven to be effective for increasing forest cover in livestock farms. In the case of Nicaragua, NITLAPAN´s Local Development Fund (FDL) created a green credit line for livestock farmers interested in introducing environmentally friendly technologies including SP options (Villanueva et al. 2010). A higher proportion of farmers who took the green credit from FDL adopted the proposed innovations when compared to the control group. This resulted in favorable impacts on biodiversity conservation (Guerrero-Pineda 2012). More importantly, those changes persisted even after the project finished.

3.2 Non-financial Incentives

In recent years, the pressure from all value chain actors on mechanisms to reduce negative social and environmental impacts of production practices has increased. Pressure to improve animal welfare and food safety in livestock production and processing systems have also increased (Ibrahim et al. 2010; Harvey and Hubbard. 2013). Initially, some concerns were expressed by importers from the developed world regarding the type of systems where livestock commodities were produced. More recently, similar reactions are occurring from the internal markets (Nepstad et al. 2006b).

In recent years, there has been an increase in the demand for certified livestock products (natural, organic, environmentally friendly, fair-trade). While each has its own regulations, almost all require certification by authorized entities which in most cases limits individual smallholder farmers who benefit because of the costs associated with the certification process (IFOAM, 2016). An option to overcome this limitation is to mobilize smallholder farmers into groups capable of conducting group negotiations. Another option is for the government, NGOs, or other agents to subsidize or partially subsidize the payment of certification fees. Finally, certification requires a proper traceability system, which is well developed only in very few LAC countries.

There are also some initiatives from the private sector such as that of the Bertin Group in Brazil that source beef only from farms practicing sustainable production strategies including zero deforestation and the adoption of SP systems. However, although the Bertin Group initiative looked promising, some local groups contested it, and the initiative did not progress far (Ibrahim et al. 2010).

It is important to approach groups like the Global Roundtable for Sustainable Beef (GRSB), which includes many international commerce and livestock processing enterprises, food retailers, civil society institutions, and farmer organizations, and encourage them to recognize that SP systems are environmentally friendly approaches for beef production that respond to the key GRSB elements for sustainable beef production. Similar initiatives should be promoted for the dairy sector through the regional dairy organization, Latin American and Caribbean Dairy Federation (FEPALE). In all cases where internal markets are the main destination for beef and milk, efforts should be made to increase consumer awareness of the contribution of SP systems to the environment when compared to traditional systems.

Another example of a non-financial incentives program was one promoted under the Livestock Program, PROGAN in Mexico, which provided technical assistance, medicine, and livestock insurance for farmers who agreed to sustainably conserve and manage the natural resources present in their farms, to use an official animal tag for traceability purposes, and to participate in a monitoring and verification scheme which involved periodic visits and GIS analysis for checking changes implemented on their farm. An evaluation of PROGAN efforts in three communities in Chiapas found that participating farms showed better animal health and nutrition indicators than control farms and implemented some of the proposed SP innovations. However, the program was not as effective as expected, because technical assistance efforts were not tailored to the conditions of each farm, farmers training needs were not fulfilled, and resources promised to farmers did not reach them at the required time (Vargas de la Mora 2013).

3.3 Knowledge Management Interventions

Although some of the SP options are part of the production systems traditionally practiced in several areas in LAC, most livestock farmers and technicians do not have a proper understanding of the complexity of systems involving woody perennials, animals, and pastures and are not familiar with trees and shrub management techniques (Dagang and Nair 2003; Botero and Russo 2016; Costa-Varella 2016). Apparently, this problem is less serious for farmers who have experience with crops like coffee and are familiar with the management of seedlings and young woody plants (Calle et al. 2009). Another important limitation for scaling up SP innovations is that they are rarely on the agendas of extension services and financial institutions (Murgueitio et al. 2006; Peri et al. 2016a).

Potential interventions related to knowledge management that would enable the scale up of SP options are the promotion of:

a) ***Collaborative efforts***

Effective promotion for scaling up SP system will require coordinated efforts between the research and extension divisions of the national institutions with livestock and forestry mandate. Through these farmers could get access to technical assistance on the establishment of woody perennials, the harvest of forest products, selection of forage species better suited to silvopastoral systems, their management, as well as on the other components of livestock management; and on the assessment of the economic and environmental impacts of such interventions (Alas-Martínez, 2006; Costa-Varella et al, 2016);

b) Capacity building

Training and outreach efforts to increase the capacity among farmers, field workers, researchers, extension workers, and policy makers on the principles for proper management of SP systems (Ibrahim et al. 2007; Pezo et al, 2010; Calle et al, 2013);

c) More efficient use of ICTs

More efficient use of ICTs to facilitate dissemination of SP innovations as well as for landscape surveillance to assess the extent of their adoption and impacts (Nakasone et al. 2014; Serna et al. 2017);

d) Participatory learning and research activities

Participatory learning and research activities to test promising SP options in different agroecosystems and to strengthen networks for sharing lessons learned through farmer field schools and farmer-to-farmer exchanges (Pezo et al. 1999; Murgueitio et al. 2006; Pezo et al. 2007; Anfinsen et al. 2009; Aguilar et al. 2010; Villanueva et al. 2010; Calle et al. 2013);

e) Implementation of successful pilot projects

Implementation of successful pilot projects to demonstrate the potential of SP interventions, followed by large-scale projects aimed at mainstreaming SP systems to demonstrate landscape-scale benefits and introduce SP system products to green markets (Calle et al. 2013; Montagnini et al. 2013); and

*f) **Development of a legal framework***

Development of the legal framework, policies, and plans as well as adjustments in wood processing enterprises to support the conservation and sustainable management of forests under SP use (Detlefsen et al. 2008; Scheelje et al. 2012; Caballé et al. 2016; Villanueva et al. 2018).

3.4 The Climate Change Initiatives

Many countries in LAC have identified the livestock sector as part of their Intended Nationally Determined Contributions (INDCs) for Climate Action (FAO 2016). These decisions are catalyzing new government and private sector initiatives to promote structural adjustments to the current livestock production systems including the adoption of SP innovations such as the ones developed in Costa Rica, Colombia, Mexico, and other South American countries. While there are efforts preparing Nationally Appropriate Mitigation Actions in the livestock sector (NAMA-Livestock) initiatives in many countries, Costa Rica and Uruguay have already developed low C-emissions strategies for the livestock sector (MAG-Costa Rica 2013; FAO/UNDP 2017). However, the availability of special funds to support the implementation of such strategies remains a key challenge.

According to Serna et al. (2017), some enabling factors for those changes are:

i. The Paris Agreement signed in 2016 as a window of opportunity to foster national processes on mitigation/adaptation climate change;

ii. The promotion of (PES) schemes, subsidies, and green credits to support sustainable agricultural practices;

iii. The creation of national and international agencies or units to deal exclusively with climate change issues in the agro-environmental sector; and

iv. Opportunities to access special funds through different climate change initiatives such as REDD+, the Green Climate Fund, and the 20x20 Initiative, among others.

Accessing special funds from any of the climate change initiatives should include strengthened coordination between the ministries of environment and the ministries of agriculture. Often climate funds tend to be channeled through the former. In many cases, agricultural activities are considered a threat to the environment and biodiversity conservation. Other potential enabling factors to facilitate adoption of SP innovations is the recognition of their contribution to enhancing productivity, animal welfare, and farm economy; as well as to improving consumer consciousness and their subsequent demand for products that are environmentally friendly (Broom et al. 2013; Tarazona-Morales et al. 2017).

3.5 Potential Role of the World Bank Group to Promote the Adoption of SP Systems

Several governments in LAC are keen to promoting the sustainable intensification of livestock systems using SP approaches as a means to control deforestation and to enhance tree cover in livestock dominated landscapes. Moreover, these options must be important components of NAMA- Livestock initiatives. In those countries where progress has been already made at a pilot level, there is a need to scale up the lessons learned. In other countries, these processes could start building on neighboring experiences.

Building on past and ongoing Bank-supported interventions, The World Bank can serve as a key actor facilitating the promotion of SP interventions with governments and private sector investors such as through the Climate Investment Fund Pilot Program for Climate Resilience (PPCR) or the Forest Investment Program (FIP) windows. The former is designed to support building adaptation and resilience to the impacts of climate change in developing countries and regions. The latter is designed to provide direct investments to address the drivers of deforestation and forest degradation, for which traditional livestock systems have been identified as one of the main drivers in several LAC countries.[2] This report has clearly demonstrated that SP approaches are relevant strategies for conserving land and for limiting harmful environmental impacts by reducing GHG emissions and increasing carbon sequestration in trees and pastures (Godde et al. 2017). At the same time, SP systems are important mechanisms for increasing the productivity, profitability, and competitiveness of intensive livestock systems.

Another option for investing in SP systems is the Global Environment Fund (GEF), for which the World Bank Group has functioned as an effective implementing agency for several projects related to policy development, innovation, and the initiation of new business lines in the environment sector (IEG,2013). An example relevant to this review is the project entitled "Paying for Biodiversity Conservation in Agricultural Landscapes" carried out in Colombia, Costa Rica, and Nicaragua by CATIE, CIPAV and national partners (Pagiola et al. 2004). This project was a pioneer on PES in livestock farms in LAC. The more recent Mainstreaming Sustainable Cattle Ranching Project was carried out by the Colombian Cattle Ranching Organization (FEDEGAN) with the active participation of the Ministry of Environment and Sustainable Development, the Ministry of Agriculture and Rural Development, CIPAV, the Nature Conservancy, and the Fund for Agricultural and Livestock Sector Financing (FINAGRO). FEDEGAN and FINAGRO already had a mechanism to integrate the offer of credit lines with technical assistance for cattle ranchers, with option for smallholder livestock farmers to participate.[3]

The projects and initiatives described in previous paragraphs are only examples of how the World Bank Group can leverage the efforts of government research and development institutions, the private sector, farmer organizations, and financial institutions to scale up experiences developed through pilot projects promoting SP innovations.

4 Conclusions and Recommendations

SP systems are win-win options as they contribute to increased livestock productivity, income generation and diversification, enhanced resilience to climate change, mitigation of GHG emissions, and increased C-sequestration in woody perennials and pasture root systems. In the end, each of these render valuable ecosystem services such as water, soil, and biodiversity conservation as well as contribute to less deforestation and increased tree cover in livestock farms. There is a variety of SP options. Some such as scattered trees in pastures, grazing native forests during critical periods of the year, live fences, and windbreaks have been practiced for several decades by livestock farmers in LAC. Others are the result of research efforts aimed at improving animal performance and/or enhancing the presence of valuable multipurpose trees in the ecosystem through multi-strata live fences, fodder banks, and grazing under tree plantations. Biophysical information on the effects of implementing several SP options in Tropical America is very rich. Nonetheless, more information on the economic and financial benefits of these interventions is still lacking.

Despite their potential to increase productivity, to create better socio-economic conditions for farmers, and to generate local and global ecosystem services, SP systems have remained

[2] http://www.climateinvestmentfunds.org/
[3] http://documents.worldbank.org/curated/en/412321468244518247/pdf/PID-Print-P145732-07-12-2013-1373675253321.pdf

relatively few. This has been attributed to the complexity of SP innovations, the reluctance of farmers to invest and take risks with new technologies that have a lag time before achieving profits, the limited access to information and technical assistance on SP systems, the fact that few financial institutions have SP options on their credit agendas, and the lack or limited availability of financial and non-financial incentives.

The enablers for changing paradigms in production approaches, including the introduction or enhancement of woody perennials in livestock systems, are becoming more important, but still need some institutional adjustments to make them more effective. In that sense, the World Bank Group can play an important facilitation role for promoting SP interventions in livestock systems through pilot projects to generate, validate, and communicate the results obtained and/or through development projects to scale experiences gained.

The World Bank Group should also be a facilitator for south-south cooperation efforts to share LAC experiences on the sustainable intensification of livestock systems and the enhancement of tree cover in livestock dominated landscapes by using SP innovations. Similarities among regions in agroecological conditions do exist, and in many cases even similar forage and woody perennial species are already present on local farms.

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6 Annexes 1

SP systems by Agroecological Zones (AEZs) in Latin America and the Caribbean: A Review from the Literature

Agroecological Zone	Location/ Country	SP Options	Livestock Systems	Main Tree species	Main Understory Forage species	Silvicultural management	Comments	References
Tropical—Humid	Amazonian Region of Perú (Yurimaguas) and Ecuador (Morona)	Live fences, scattered trees and shrubs in pastures, grazing under tree plantations, alley farming with pastures, fodder banks	Cow-calf & fattening beef cattle, dual—purpose cattle systems	Timber trees: *Acacia mangium, Eucalyptus spp., Gmelina arborea, Cordia alliodora, Cedrella odorata, Albizia guachipele*; Fruit and industrial trees: B*ixa orellana, Spondias mombim, Mangifera indica, Hevea brasiliensis*; Other MTP trees: *Terminalia*	Grasses: *Panicum maximum, Brachiaria decumbens, B. brizanth*a, Híbridos de Brachiaria (p.e. cv. Mulato), *Andropogon gayanus, Hyparhenia rufa*, & native grasses (*Axonopus spp., Paspalum spp.*); Legumes: *Cannavalia brasiliensis, Centrosema spp., Desmodium spp., Arachis pintoi, Cratylia argentea*.	Thinning and pruning in plantations, pruning in live fences, promote natural regeneration for other MTP trees.	The trees listed are only a sample of the diversity of species used in traditional and intensive SP systems in the Amazon Valley. The introduction of MTP trees in livestock systems resulted in increased animal productivity, diversification of income sources, higher income in the mid- and long-term, contributes to reduce heat stress, provides several ecosystem services. Also helps to recover degraded lands and improves	Alegre y Lara, 1991; Peck & Bishop, 1992; Arévalo et al, 1998; Suárez & Orjuela, 2011; Sotelo et al, 2017

Agroecological Zone	Location/ Country	SP Options	Livestock Systems	Main Tree species	Main Understory Forage species	Silvicultural management	Comments	References
				Calliandra spp., Ceiba pentandra, Bombacopsis quinata, Pithecellobium dulce, Sapindus saponaria, Tabebuia rosea, Samanea saman, Cecropia, spp.; Palms: *Crescentia cujete, Senna spectabilis*				
Tropical—Humid	Esparza, Puntarenas Cañas, Guanacaste (Costa Rica); Rivas, (Nicaragua).	Fodder banks, windbreaks, live fences, scattered trees and shrubs in pastures, grazing native forests, grazing under tree plantations	Dual purpose & beef cattle	Mid-low elevations: *Guazuma ulmifolia, Brosimum alicastrum, Pithecellobium saman, Enterolobium cyclocarpum, Pinus caribaea, Gliricidia*	*Brachiaria spp, Panicum spp., Pennisetum purpureum,* native grasses & legumes	Natural regeneration of scattered trees; planting of timber trees in fences; thinning in plantation systems; pruning of trees in fences.	A Payment for Ecosystems Services (PES) helped to accelerate adoption of SP options in livestock farms. Important contribution of scattered trees fruits to cattle diets in dry season, and shade	Villanueva et al, 2007; Esquivel, 2007

Agroecological Zone	Location/ Country	SP Options	Livestock Systems	Main Tree species	Main Understory Forage species	Silvicultural management	Comments	References
				sepium, Erythrina spp., *Leucaena leucocephala, Tabebuia rosea, Tectona grandis. Cordia alliodora, Samanea saman.*			provision. Increasing tree cover above 15% reduces forage production.	
	Central and South American highlands (i.e., San Juan de Chicuá and Pacayas in Costa Rica; Western Highlands, Guatemala; Chimborazo & Tungurahua in Ecuador & Cundinamarca in Colombia)	Live fences, scattered trees and shrubs in pastures, grazing under tree plantations, windbreaks, riparian forests.	Dairy & dual-purpose cattle; sheep	*Alnus acuminata, Cupressus lusitanica, Pinus radiata, Casuarina equisetifolia, Montanoa guatemalensis, Acasia decurrens*	*Lolium spp., Pennisetum clandestinum, Axonopus scoparius, P. purpureum, Holcus lanatus, Avena sativa, Triticum spp., Trifolium spp.*	Thinning and pruning. Natural regeneration of tree species.	Timber and fuelwood extracted. Poor wood quality on several sites due to the lack of silvicultural management. Trees in fences and windbreaks contribute to increase connectivity between primary forests. SP use in plantations have potential, but most extension staff & farmers lack knowledge on how to manage those.	Russo, 1990; Garrison & Pita, 1992; Harvey, 2000; Giraldo et al, 2008; Prado—Córdova et al, 2013.

Agroecological Zone	Location/ Country	SP Options	Livestock Systems	Main Tree species	Main Understory Forage species	Silvicultural management	Comments	References
	Sabanas & Valle del Sinú, Caribbean Region, Colombia	Scattered trees and shrubs in pastures, live fences	Dual purpose & beef cattle	Timber trees: *Tabebuia rosea, Albizia caribaea, Sterculia apelata, Pachira quinata, Swietenia macrophylla, Eucalyptus tereticornis* & *Aspidosperma polyneuron*. Fodder trees: *Guazuma ulmifolia*, A*lbizia saman, Spondias mumbim, Crescentia alata, Gliricidia sepium*. Palms: *Sabal mauritiaeformis*	*Dichanthium aristatum, Panicum maximum, Brachiaria mutica, Cynodon nlemfuensis, Brachiaria brizantha, B. híbrido Mulato, Hyparrhenia rufa*	Natural regeneration of trees by protecting or re—siting seedlings or adjusting livestock grazing intensity. Not much planting new trees because of costs for protecting those.	Farmers appreciate the value of trees as shade for grazing animals, and as a source of posts. Farmers need to improve knowledge about tree phenology, except in the case of those providing fruits. More trees in drier areas, with lower soil fertility, and with extensive grazing systems. Plantation systems for pulp and timber.	Cajas & Sinclair, 2001; Giraldo, 2016.

Agroecological Zone	Location/ Country	SP Options	Livestock Systems	Main Tree species	Main Understory Forage species	Silvicultural management	Comments	References
Tropical—Humid (Lowland)	Caribbean Basin of Central America	Live fences, scattered trees and shrubs in pastures, grazing under tree plantations	Beef & dual-purpose cattle	Fodder trees: *Glricidia sepium, Erythrina spp*., Timber trees: *Cordia alliodora, Eucalyptus deglupta, Pinus caribaea, Vochysia guatemalensis, Hieronyma alchorneoides;* Fruit & fuelwood trees*: Psidium guajaba, Inga spectabilis, Mangifera indica;* Shade trees*: Pentachletra macroloba, Ficus spp.*	*Brachiaria spp., Panicum spp., Pennisetum purpureum, Arachis pintoi,* native grasses & legumes	Pruning of live fences, thinning in forest plantations.	In recent decades, an area of livestock expansion, after forest clearing in Nicaragua and Honduras. Silvopastoral options help to increase tree cover (up to 25% in scattered trees in pastures). Valuable local knowledge on MPTs by farmers, but not all interactions between silvopastoral systems components are well understood.	Moulaert et al, 2002., Montagini et al, 2003, Muñoz, 2004.
	El Petén, Guatemala	Live fences, scattered trees and shrubs in pastures, grazing under	Beef & dual-purpose cattle	Fodder trees: *Leucaena leucocephala, Guazuma ulmifolia,*	*Brachiaria spp., Panicum spp., Pennisetum purpureum, Arachis pintoi,*	Natural regeneration of trees. Thinning in forest plantations	Petén is an important beef producer; in many cases yearlings from Honduras are	Ferguson et al, 2003; Carrera et al, 2004; Betancourt et

Agroecological Zone	Location/ Country	SP Options	Livestock Systems	Main Tree species	Main Understory Forage species	Silvicultural management	Comments	References
		tree plantations (very rare)		*Brossimun alicastrum, Glricidia sepium*; Timber trees: *Tectona grandis, Cordia alliodora,Pinus oocarpa, Pinus caribaea, Gmelina arborea; Fruit trees:* allspice *(Pimenta dioica);* oranges *(Citrus sinensis)*.	native grasses and legumes		pre-fattened before exportation to Mexico. Pasture degradation a constraint for successful cattle production. *Leucaena leucocephala* is a native species, however is not commonly used as fodder source by farmers. Seedlings of valuable scattered timber trees frequently treated as weeds by farmers.	al., 2007; Cruz and Nieuwenhuise, 2008
	Pereira, Valle & Quindío; Coffee Andean Region, Tolima, (Colombia)	Live fences, windbreaks, fodder banks, scattered trees and shrubs in pastures, trees in hedgerows, riparian forests (watershed protection)	Dual purpose and beef cattle	Live fences: *Gliricidia sepium, Ceiba pentandra, Eryhtrina fusca*; Fodder banks: *Tithonia diversifolia, Trichanthera gigantea,*	*Cynodon nlemfuensis, Brachiaria spp., Panicum maximum, Cynodon dactylon, Paspalum notatum*	Depending of the silvopastoral options: thinning, pruning, promotion of native trees regeneration.	Model farms operating, but wider permanent adoption of intensive silvopastoral systems ultimately depends on farmers' perception of their costs and benefits compared to traditional systems.	Camargo et al, 2005; Chará and Murgueitio, 2005; Calle et al, 2009; Calle et al, 2013, Serrano et al, 2014.

Agroecological Zone	Location/ Country	SP Options	Livestock Systems	Main Tree species	Main Understory Forage species	Silvicultural management	Comments	References
				Guazuma ulmifolia; Timber trees: *Leucaena leucocephala, Cordia alliodora, Cedrella odorata, Enterolobium cyclocarpum, Swietenia macrophylla, Astronium graveolen; and Palms: Sheelea magdalenensis, Syagrus zancona, Attalea butyracea, and Roystonea regia*; Trees in hedgerows: *Albizia saman, Cassia grandis*; Riparian forest: *Guadua angustifolia*.			PES worked as an incentive. Silvopastoral systems serve to connect riparian buffers and secondary forest fragments.	

Agroecological Zone	Location/ Country	SP Options	Livestock Systems	Main Tree species	Main Understory Forage species	Silvicultural management	Comments	References
Tropical—Humid (Lowland)	La Habana, Holguín, Matanzas (Cuba)	Alley farming with pastures, fodder banks	Dairy and beef cattle systems	*Fodder trees & shrubs: Leucaena leucocephala, Morus alba; Timber trees: Albizia lebbeck*	Grasses: *Panicum maximum, Cynodon nlemfuensis, Digitaria decumbens, Brachiaria decumbens* & native grasses; Legumes: *Neonotonia wightii, Teramnus labialis, Centrosema pubescens*.	Pruning for cut & carry systems, and in alley farming the woody perennial pruned when the plant height did not allow animals browse the tops	Milking cows browsing fodder produce 10 kg milk/cow/day without concentrates; and steers 600-800 g LWG/day. The use of fodder trees also helped to improve soil biology, pasture stability, enhanced the population of beneficial insect, and contributed to reduce the use of concentrates & N fertilizers.	Iglesias et al, 2016; Milera et al, 2016
	Yucatán Peninsula, México	Alley farming with pastures, fodder banks, and live fences	Dual purpose and beef cattle systems.	*Leucaena leucocpehala, Tithonia diversifolia, Guazuma ulmifolia, Enterolobium cyclocarpum*	*Panicum maximum, Pennisetum purpureum, Brachiaria brizantha, Cynodon nlemfuensis*	Pruning of shrubs & trees for cattle to get access to fodder. Collection of fruits for supplementation.	SPS with fast—growing leguminous N-fixing trees can help to recuperate degraded lands, in a short to medium time. SPS contribute to improve livestock welfare controlling heat stress, enhance production and	Briceño-Poot, et al, 2012; Peniche-González et al, 2014; Solorio et al, 2017

Agroecological Zone	Location/ Country	SP Options	Livestock Systems	Main Tree species	Main Understory Forage species	Silvicultural management	Comments	References
							results in less GHG emissions.	
	Florencia, Caquetá, Guaviare (Colombia); Napo, Pastaza (Ecuador); Pucallpa, Tingo María & Yurimaguas(Perú)	Live fences, scattered trees and shrubs in pastures, grazing under tree plantations, alley farming with pastures, and fodder banks	Cow-calf & fattening beef cattle, dual-purpose cattle systems	Timber trees: *Acacia mangium, Eucalyptus spp., Gmelina arborea, Cordia alliodora, Cedrella odorata, Albizia guachipele*; Fruits and industrial trees: B*ixa orellana, Spondias mombim, Mangifera indica, Hevea brasiliensis*; Other MTP trees: T*erminalia catappa, Schyzolobium*	Grasses: *Panicum maximum, Brachiaria decumbens, B. brizanth*a, Brachiaria hybrids (i.e., Mulato), *Andropogon gayanus, Hyparhenia ruda*, & native grasses (*Axonopus spp., Paspalum spp.*); Legumes: *Cannavalia brasiliensis, Centrosema spp., Desmodium spp., Arachis pintoi, Cratylia argentea*.	Thinning and pruning in plantations, pruning in live fences, promoting natural regeneration for MTP trees.	Trees listed are only a sample of the diversity of species in traditional and intensive SPS in the Amazon Valley. MTP trees in livestock systems contributed to enhance animal productivity, diversify income sources, increase income in the mid- and long-term; contributed to reduce heat stress, and provided several ecosystem services. Also helped to recover degraded lands, and to intensify livestock systems in a sustainable manner.	Alegre y Lara, 1991; Peck & Bishop, 1992; Arévalo et al, 1998; Lino, 2011; Suárez & Orjuela, 2011; Sotelo et al, 2017;

Agroecological Zone	Location/ Country	SP Options	Livestock Systems	Main Tree species	Main Understory Forage species	Silvicultural management	Comments	References
				parahybum, Calliandra spp., Ceiba pentandra, Bombacopsis quinata, Pithecellobium dulce, Sapindus saponaria, Tabebuia rosea, Samanea saman, Cecropia spp.; Palms: *Crescentia cujete, Senna spectabilis*				
Tropical Subhumid (Lowlands)	Hojancha, Guanacaste, Costa Rica	Fodder banks, live fences, scattered trees and shrubs in pastures, grazing under native forests, and grazing under tree plantations	Beef & dual-purpose cattle	*Timber trees: Cedrella odorata, Cordia alliodora, Pithecellobium saman, Albizia spp.*, *Tectona grandis*, *Acacia pennatula;*	*Brachiaria spp., Panicum spp., Andropogon gayanus, Tripsacum laxum, Pennisetum purpureum,* native grasses & herbaceous legumes	Natural regeneration of scattered trees; planting of timber trees in multi-strata live fences; thinning in plantation systems; pruning of fodder trees in fences.	Traditional livestock systems have a diversity of woody perennials with significant value for improving animal productivity, as well as for the conservation of natural resources. Some non-leguminous woody	Ibrahim et al, 2001; Rivera-Céspedes et al, 2016

Agroecological Zone	Location/ Country	SP Options	Livestock Systems	Main Tree species	Main Understory Forage species	Silvicultural management	Comments	References
				Fodder tres: Cratylia argentea, Glricidia sepium, Leucaena spp.; Othes: Bursera sumaruba			fodder species (i.e., *Thrichantera gigantea, Morus alba*) have been introduced.	
	Tropical Savannah (Colombian-Venezuelan Llanos)	Grazing under native forests (Gallery forests between pasturelands), restricted or free access to forests next to pastures	Beef cattle	In forests: *Guazuma ulmifolia, Tabebuia chrysantha, Lonchocarpus ernestii, Pythecelobium saman, Hura crepitans, Enterolobium ciclocarpum, Spondias mombin, Cerratonia siliqua, Acacia glomerosa, A. macracantha, Cordia sp., C. thaisiana,*	*Brachiaria spp., Andropogon gayanus, Paspalum atratum, Hyparhenia rufa, Melinis minutiflora, Trachypogon spp., Desmodium spp. Centrosema macrocarpum, Flemingia macrophila,* Stylosanthes spp.,	Not major management of native tree species, except for helping natural regeneration in some cases.	Lower diversity of trees and birds in island forest and hedgerows than in forests patches. During the dry season is significantly important the contribution of tree species to diets.	Espinoza et al, 2008; Muñoz et al, 2013.

Agroecological Zone	Location/ Country	SP Options	Livestock Systems	Main Tree species	Main Understory Forage species	Silvicultural management	Comments	References
				Arabidaea brachypodan; in forest islands: Tall trees: *Perea arborea, Rollinia edulis*; Shrubs: *Erythroxylum spp., Myrsine guianensis*; Palms: *Attalea insignis;* in hedgerows*: Vismia spp., Byrsonima crassifolia*				
	Central Dry Chaco, Paraguay	Scattered trees and shrubs in pastures; grazing under tree plantations (relatively new)	Mainly extensive beef (cow—calf) systems	*Prosopis alba, Prosopis nigra, Leucaena leucocephala, some palm species; some exotic tree species (Pinus spp., Eucalyptus spp.)*	*Trichloris crinita, Elyonurus latiflorus; Andropogon lateralis, Sorghastrum agrostoides* and other native grasses.	Promoting natural regeneration in scattered trees system; thinning in commercial forest plantations	Cattle raising on native vegetation a traditional source of income on relatively extensive ranches. Some large-scale landowners begun forest plantation systems, mostly to access a cost-share payment enacted as law, but never fully	Fretes & Dwyer, 1969; Quiroga et al, 2010; Cubbage et al, 2012

Agroecological Zone	Location/ Country	SP Options	Livestock Systems	Main Tree species	Main Understory Forage species	Silvicultural management	Comments	References
							funded.	
	Moropotente, Estelí, Nicaragua	Scattered trees and shrubs, live fences, grazing under native forests	Beef cattle (Cow-calf) systems.	*Acacia pennatula,* Quercus spp., *Piscidia grandifolia, Guazuma ulmifolia*	*Brachiaria spp. Cynodon nlemfuensis, Cynodon spp, Hyparrhenia rufa, as well as* native grasses & legumes.	Natural regeneration	*Acacia pennatula* an important fodder tree (source of foliage and fruits), mainly at the end of the dry season. It also provides fuelwood, timber and poles.	Casasola et al., 2001
	Matiguás, Rivas & Muy Muy, Nicaragua	Scattered trees, live fences, fodder banks, riparian forests	Dual-purpose and beef cattle systems	*Guazuma ulmifolia, Albizia saman, Enterolobium cyclocarpum, Cassia grandis, Lonchocarpus miniflorus, Ficus sp, Simarouba amara, Cassia grandis,Cordia alliodora, Gliricidia sepium, Guazuma ulmifolia, Enterolobium*	*Brachiaria spp., Brachiaria brizantha (cv. Marandú, Toledo), Brachiaria hybrid (e.g., Mulato), Panicum máximun (cv. Tanzania), Cynodon nlemfuensis, Hyparrhenia rufa. Paspalum spp*. Other native grasses & legumes.	Natural regeneration protecting saplings & seedlings, and maintaining mature trees as sources of seeds, to assure keeping richness of species. Selective weeding to help young trees survival.	High diversity of woody perennials in pastures (47 species in Matiguas & 85 in Muy Muy). Tree cover < 25% affected slightly pasture availability, but not milk yield. Evergreen trees have more effect than deciduous species on net primary forage production. Trees help to reduce heat stress in grazing animals.	Betancourt, 2003; Esquivel et al, 2008; García—Cruz et al. 2013; Ayestas, 2014; Rusch et al, 2014

Agroecological Zone	Location/ Country	SP Options	Livestock Systems	Main Tree species	Main Understory Forage species	Silvicultural management	Comments	References
				cyclocarpum, Samanea saman, Platymiscium parviflorum. En cercas: *Pachira quinata, Bursera simaruba.*				
	Sepultura Biosphere Reserve in the Sierra Madre, Pijijiapan, Frailesca Region; Lacandon Jungle, Raudales, Malpaso & Tacotalpa-Tabasco (Mexico)	Scattered trees and shrubs in pastures, Grazing under native forest, Alley farming with pastures, Live fences	Cow-calf & fattening beef cattle, dual-purpose cattle systems	Fodder trees: *Gliricidia sepium, Guazuma ulmifolia, Leucaena leucocephala, Erythrina spp.;* Fruit trees: *Enterolobium cyclocarpum, Brosimum alicastrum, Mangifera indica, Citrus spp., Cocus nucifera, Anona spp.,* Timber trees: *Cedrella*	*Brachiaria brizantha, Pennisetum purpureum, Cynodon plectostachyus, Paspalum spp.*	Promotion of natural regeneration of scattered trees; tree pruning in live fences.	Extensive cattle raising has strongly impacted vegetation and modified original landscapes. High diversity of MTP trees in SPS (53 species belonging to 24 families). Negative relationship between productivity & resilience; shade trees favor animal welfare, resulting in better reproductive performance and production.	Nahed-Toral et al, 2013; Marinidou et al, 2017;

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				odorata, Cordia alliodora, Bursera simaruba, Tabebuia rosea.				
Tropical-moist semiarid	Caatinga, Central Western Region Paraiba State, Northeast Brazil	Scattered trees and shrubs in pastures, Grazing under tree plantations	Sheep & goat systems, beef cattle (cow-calf) systems	Trees: *Caesalpinia spp., Cnidoscolus phyllacanthus, Senna spectabilis, Geoffroea spinosa, Bauhinia sp., Mimosa caesalpiniifolia, Ziziphus joazeiro*; Shrubs: *Mimosa tenuiflora, Pilosocereus pachycladus, Cereus jamacaru; Cactaceas: Opuntia spp.*	*Cynodon dactylon, Urochloa spp., Pennisetum ciliare, Andropogon spp, and other native grasses & legumes*	Forest extraction for charcoal and fuelwood. Not major silvicultural management. *Mimosa caesalpiniifolia* ('sabiá') management for wood and forage production	Forage biomass produced by most grasses are modest, due to the low and variable rainfall. Overgrazing a problem. Local actors show little support for the implementation of sustainable forest management. SPS provide win–win solutions for reconciling livelihoods needs with conservation goals by promoting forest succession. SPS an alternative for developing competitive, sustainable livestock with	Ricardo de Figuereido et al, 2017; Miccolis et al, 2017; Almeida et al, 2013.

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							minimal environmental impact. Need for PES policies for plant biodiversity, C-sequestration; and OM deposition in the soil	
Subtropical - semiarid	North Eastern Mexico (Tamaulipas, Coahuila & Nuevo León)	Scattered trees and shrubs in pastures (Grazing the matorral vegetation)	Beef cattle, goat & sheep systems	*Diospyros texana, Pithecellobium pallens, Condalia hookeri, Cordia boissieri, Acacia spp. in the xerophytic matorral; and Quercus spp., Pinus spp., CupressuS arizonica in the higher elevations, and Agave spp., Yucca spp., Opuntia spp. in the drier/desert areas.*	B*outeloua spp. Sphaeralcea angustifolia*, buffelgrass (*Pennisetum ciliare*), *Aristida divaricata, Muhlenbergia villosa*. Herbaceous vegetation <10% of goats´ diet.	Control measures to prevent harvesting of native trees, and few reforestation programs in disturbed areas. Results of establishing trees in an unprotected cleared site was variable due to biotic (i.e., ants, grasshoppers and jack rabbits) and climatic factors.	Several shrubs have good value as fodder. Overgrazing and uncontrolled wood extraction from thorn scrub species for construction and charcoal/fuelwood the major threat for sustainability. Some MTP trees planted in forest lots for fuelwood to stop deforestation and recovering forest lands. Planting buffel grass (an exotic species) in a pastoral system has lower primary net production than the complex native	Russell & Felker, 1987; Stienen, 1990; Mellado et al, 1991; Franklin et al, 2006; Foroughbakhch et al., 2014, Quero-Carrillo et al, 2014.

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				Leucaena leucocephala as introduced species.			vegetation. Leucaena is used as vegetable for human consumption, but recently has been promoted as fodder source.	
Temperate - Humid	La Pampa, Argentina	Scattered trees and shrubs in pastures	Extensive beef production with European breeds	*Prosopis caldenia, P. flexuosa, Schinus fasciculatus, Condalia microphylla*	Mostly native grasses (i.e., *Piptochaetium napostaense, Digitaria californica*, and other annuals)	Promoting natural regeneration. No thinning, no pruning.	Cattle can create problems spreading seeds of *Prosopis caldenia*. This SP system is at risk of replacement by soybean and /or cultivated grasses	Cubbage et al, 2011; Cubbage et al, 2012
	Colonia, Uruguay	Grazing under tree plantations, Trees in fence rows, trees in plantations connected to pastures	Mostly beef systems, but also sheep production systems.	*Eucalyptus tereticornis, E. camaldulensis, Pinus spp.*	Motly native grasses (Paspalum notatum, P. plicatulum, P. dilatatum, Stipa sp., Briza sp., Adesmia muricata, Axonopus affinis, Bromus auleticus, B. unioloides, Poa lanigera)	Thinning and intensive management of the forest component.	Relatively new development. Forestry companies usually lease their plantations for grazing. Also, forest companies promote joint ventures with cattle producers who own land. The company provides	Cubbage et al, 2012

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							genetically improved planting stock, site preparation, planting, and harvest operations.	
Temperate - Humid (year round)	Corrientes and Misiones (Argentina)	Grazing under tree plantations	Beef cattle systems/ growing animals	*Pinus spp., Grevillea sp., Paulonia sp.*	*Brachiarias spp, Axonopus spp., Setaria sphacelata, Arachis pintoi*	Thinning and pruning for a higher industrial yield in knot-free timber.	The complexity of management was an initial constraint; now is more the capital investment required for planting trees. However, the availability of financial support for planting trees has been an incentive.	Lacorte et al, 2016
	Delta Parana River/ Argentina	Grazing under tree plantations	Beef cattle systems/ fattening in the Upper & Middle Delta, cow—calf in the Lower Delta	*Salix spp., Populus spp.*	Native grasses, Limpo grass, Lolium *multiflorum, Bromus catharticus, Trifolium repens*	Thinning 30 and 60% of trees with time	Expansion of soybean production in the Pampa forced cattle movement to the Delta. Overgrazing led to vegetation & soil degradation.	Casaubon et al, 2016

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	Santa Catarina, Rio Grande do Sul, Paraná,	Grazing under tree plantations	Beef cattle systems/fattening	*Grevillea robusta, Eucalyptus spp., Corymbia citriodora, Pinus sp.* & *Araucaria angustifolia* native forests	*Lolium multiflorum, Avena spp., Trifolium repens, T. pratense, Lotus corniculatus, Brachiaria spp.*	Thinning and extraction of trees with time. At the end 240 trees/ha	Increased interest of farmers and enterprises on agro-silvopastoral systems. Recently observed relevant advances in research and extension services on silvopastoral systems (screening of forage & trees for silvopastoral systems; animal performance and behavior under trees).	Costa-Varella et al, 2016
	Cerrado, Central West Region of Brazil—— States of Goiás, Mato Grosso, Mato Grosso do Sul, Minas Gerais, Planaltina, Federal District.	Grazing under native forests (Savannahs with gallery forests between pasturelands, similar to the system found in the Colombian Llanos), Grazing under tree	Cow-calf beef cattle systems (The Cerrados contain around 35% of the Brazilian beef herd)	Eucalyptus, Corymbia. Greater diversity in transition areas; either native (*Schizolobium amazonicum, Swietenia macrophylla, Astronium fraxinifolium, Hevea*	Native savannah pasture vegetation species + introduced grasses (*Brachiaria decumbens, B. brizantha, Panicum maximum, B. humidicola).*	Taungya system in tree plantations with annual crops the first 2—3 years. Promotion of natural regeneration in native trees. Thinning and pruning in plantations.	Integrated agro-silvopastoral systems, with cattle production associated with no-till crop systems, involving mostly soybean, maize, sorghum and rice. Need for identifying other tree species to broaden options beyond Eucalyptus. Reclamation of	Reis et al, 2009; Tonucci et al, 2011; Almeida et al, 2013; Castro-Santos et al, 2016

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		plantations		*brasiliensis, Zeyheria tuberculosa*) or introduced species (T*ectona grandis, Ochroma pyramidale, Khaya ivorensis, Eucalyptus urogranids, Acacia mangium, Azadirachta indica*).			degraded pastures will prevent further deforestation.	
Temperate-Subhumid	Tucumán, Formosa, Resistencia & Santiago del Estero (Argentina)	Scattered trees and shrubs in pastures	Cow-calf beef systems (Criollo & Crossbred zebu)	*Schinopsis lorentzii, Aspidosperma spp., Prosopis nigra, Ziziphus mistol*	*Native pasture species + introduced (i.e., Panicum spp., Cenchrus ciliaris)*	Harvesting of trees at 15-20 years.	Woody components managed through planned thinning to meet forage, livestock, wildlife and timber production requirements.	Constanza & Neuman, 1997; Marinaro & Grau, 2015; Kunst et al, 2016;
	Bio-Bio, Concepción, Chillán (Chile)	Grazing under scattered trees in pastures; Grazing under Pinus plantations;	Beef cattle and sheep systems	*Pinus radiata in plantation systems, but also cherry (Prunus avium), poplar*	Native pastures & introduced *(i.e., Trifolium pratense, T. subterraneum, Phalaris aquatica)*	Selective thinning	Silvopastoral systems a better option for smallholder farmers than reforestation for timber. Farmers	Sotomayor, 2010; Dube et al, 2016

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		Windbreaks in areas close to the sea.		*(Populus sp.) and walnut (Juglans regia)*			get income from crops in the first 3 years (Taungya system) and from livestock after the 3rd year until tree harvest.	
	Bariloche (Argentina)	Grazing under tree plantations	Beef cattle (cow-calf) system. Also, goats in the northern region and sheep in the middle part	*Pinus ponderosa*	Native pastures (mainly *Festuca pallescens*) + wetland vegetation	Thinning and pruning of pine trees to favor pasture growth and to increase pines diameter	Transhumance, moving animals to the mountains during summer. Promotion of silvopastoral systems for biodiversity conservation. Need legal framework and planning for sustainable management of silvopastoral systems.	Caballé et al, 2016
Temperate-Moist semiarid	From Valparaiso to the Los Lagos Region (Chile)	Grazing under scattered trees of roble beech in pastures; Grazing under tree plantations; Windbreaks	Beed cattle (cow-calf) system	Indigenous trees, mostly roble beech (*Nothofagus obliquoa)* and *Acacia caven* + introduced *Pinus radiata & Eucalyptus*	*Lolium sp., Festuca arundinacea, Dactylys glomerata, Trifolium incarnatum, T. subterraneum & T. vesiculosum. For*	Selective thinning	Silvopastoral systems helped to improve small farmers´ quality of life, optimizing forage production for livestock and getting regular income from the	Dube et al, 2016

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				sp.	*hay: Avena sativa, Vicia atropurpurea.*		sale of wood and livestock products.	
Temperate-Arid	Tarapacá Region (Chile)	Scattered trees and shrubs in pastures	Mainly goat & sheep systems. Some beef cattle	Native species (*Prosopis tamarugo, P. chilensis* and others).	Mostly native grasses. Many are annual species. *Atriplex spp.* Is an introduced shrub.	Not much silvicultural practices. Cuttings for fuelwood.	Improved technologies built on traditional agroforestry practices. *Prosopis* wood is used as firewood, handcrafts and for floors. Also used to protect water sources.	Ormazábal, 1991; Sotomayor, 2010; Rojas et al, 2016
Temperate - Dry semiarid	Coquimbo Region (Chile)	Fodder protein banks, Windbreaks, Hedgerows, Live fences,	Mainly goat & sheep systems. Some beef cattle	*Acacia caven* (native espinal) & *Acacia saligna* (introduced)	Mostly native grasses. Many are annual species. *Atriplex spp.* as introduced shrubs that remains evergreen providing fodder to animals.	Judicious pruning of inferior stump-sprouts and protection of the selected shoots from livestock,	A. saligna can fix atmospheric N, hence helps to rehabilitate degraded soils, provides feed during long drought and shade for animals.	Ovalle et al, 1990; Rojas et al, 2016

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	Dry Chaco, Cordoba (Argentina)	Scattered trees and shrubs in pastures	Mainly extensive beef systems, goats & sheep to a lesser extent	Trees: *Aspidosperma quebracho blanco Schltdl, Prosopis spp.* Shrubs: *Larrea spp., Cercidium spp., Cassia spp.* Cactaceae: *Opuntia spp., Cereus spp.,*	Mostly C_4 grasses (*Chloris spp., Digitaria spp., Setaria spp.*, *Trichloris spp.) Other a*nnual grasses (*Aristida spp. &* Boutelaua spp.)	Promoting natural regeneration of valuable tree species.	Soybean is displacing cattle from the Pampa Region, putting pressure on the fragile Dry-Chaco ecosystem. Silvopastoral management strategies could help in the sustainable use of natural resources in the region. Also, important for birds´ and mammals´ conservation.	Ayerza, 2010; Mastragelo & Gavin, 2012; Marinaro & Grau, 2015
Boreal-semiarid	Tierra del Fuego (Argentina)	Scattered trees and shrubs in pastures	Beef cattle (cow-calf) and sheep systems. Mainly for maintenance and breeding.	Ñire (*Nothofagus antarctic*a)	Mainly native grasses & herbs. Some introduced pastures (i.e., *Dactylis glomerata, Festuca sp., Trifolium pratense, T. repens*).	Thinning practices help restoring canopy complexity of second-forests stands.	Over-exploitation of forest for charcoal. Cattle and sheep compete with large native herbivores (e.g., guanaco).	Soler et al, 2012; Soler et al, 2013; Peri et al, 2016b

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	Aysen, Patagonia Region (Chile)	Grazing under tree plantations, Alley farming with pastures (fodder crops between tree lines)	Cattle fattening and cow-calf systems. Meat and wool sheep systems	*Pinus contorta, Nothofagus antarctica* (Ñire)	Native grasses + *Dactylis glomerata, Trifolium repens, Holcus lanatus*	Thinning from 1500 to 800 trees/ha in forest plantations, and 400 trees in silvopastoral arrangements. Pruned to 2.0 m	Natural forest was cleared for establishing pastures, but silvopastoral options are now being promoted. Higher pasture yields in silvopastoral than in open pastures. Trees present in silvopastoral systems changed the micro-climate to the farmer's benefit.	Hepp, 1988;Sotomayor, 2010; Cubbage et al, 2012; Sanchez-Jardón et al, 2014; Sotomayor et al, 2016
Boreal—Arid	Santa Cruz Province—Patagonia, Neuquen, Chubut, Río Negro y Tierra del Fuego (Argentina)	Scattered trees and shrubs in pastures	Mostly sheep, some beef cattle (cow-calf) systems. Mainly for maintenance & breeding.	Ñire (*Nothofagus antarctic*a)	Mainly native grasses & herbs.	Natural regeneration and thinning. Less thinning in areas with water stress	Integrated economic analysis quantifying timber products, animal production, and soil conservation benefits are needed, as well as the landscape values associated with ñire forests. Advisory functions fragmented.	Peri et al, 2016b

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