Chapter 8
Development of Silvopastoral Systems in the Peruvian Amazon

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Abstract Pasture-based livestock systems in the Peruvian Amazon region are characterized by degraded pastureland and their association with deforestation processes. Silvopastoral systems are an alternative to traditional tree-less pastures that has been recently developed and studied in this region of the country. This chapter provides information about the progress in the development of silvopastoral systems (SPS) in the Peruvian Amazon and the perspectives at national level for the next years. To accomplish these goals, we first review the experiences of establishing and evaluating SPS in five departments of the Peruvian Amazon. Then, we present a list of barriers for the implementation of SPS practices in the country and the current initiatives at the regional and national levels to promote and develop sustainable livestock production systems in the Peruvian Amazon region. We conclude that barriers such as available technology, capacity building, market access and associativity, financing and favorable environmental conditions need to be cleared first for the promotion and successful implementation of SPS in the Peruvian Amazon. Moreover, some of them need to be assumed by the producers, and others by the State at local, regional and national levels.

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8.1 Introduction

The Peruvian Amazon region represents 62% of the national territory. It concentrates 13.4% of the national population, with 27% of them living under poverty. The country faces significant deforestation problems recently with an annual deforestation of 160,000 hectares between 2012 and 2016, led mainly by agriculture (49–54% of total deforestation) and livestock activities (32–39%), followed by the exploitation of hydrocarbons, gold mining, hydraulic energy and road construction. Agriculture alone is responsible for approximately 70,000 ha year^{-1} of forest loss, while livestock farming contributes to approximately 40,000 ha -year^{-1}.

Small-scale agriculture is the main driver of deforestation in Peru (ENBCC 2016). According to the ENBCC, between 2001 and 2014 around 1.6 million hectares were deforested for the expansion of coffee, cocoa, oil palm and cattle raising. Seventy nine percent (1,311,884 ha) of this loss occurred in San Martín, Loreto, Ucayali, Huánuco, and Madre de Dios departments. Deforestation caused by livestock activity is more permanent compared to agriculture, because grasslands are used for many years and even if they are abandoned, take longer to recover as secondary forests.

The total cattle population of Peru in 2012 was 5.2 million heads, 14.7% higher than that of 1994 (CENAGRO 2012). Cattle production is mainly practiced by small-scale farmers and only 21% of all agricultural producers belong to farmers' associations. Lack of a formal organization among farmers reduces their possibility to access credits from financial institutions and limits their ability to cover the expenses associated with technical support and new technologies for improving pasture management (CDP 2018).

Nearly 17% (887,299) of cattle population is concentrated in the Peruvian Amazon. Livestock activities in this region are developed in fragmented forest areas, as a result of early successional forests (locally called *purma*), or in abandoned land covered by native grasses such as *Axonopus, Paspalum* and *Homolepsis* after deforestation (Meza et al. 2007). According to CENAGRO (2012), 353,458 hectares of natural pastures (*Axonopus compressus*) are used for livestock in the Amazon region. In this regard, Rosenberg (2017) reported that around 80% of the pastures in the Peruvian Amazon are degraded or in the process of degradation.

Traditional animal production systems in the Peruvian Amazon are based on grass monocultures that, due to the lack of fertilization and inadequate grazing management, result in a high rate of land degradation and soil erosion. These cattle raising practices are characterized by low capital investment, and are viewed by farmers as a low-risk activity compared to crops that are subject to price fluctuations. However, the productivity is low and results in poor economic returns, contributing to rural poverty, vulnerability, and malnutrition, which in turn increases the need of farmers to continue deforesting. Loreto, Ucayali, Madre de Dios, San

Martín and Huánuco are the five departments located in the Amazon region that are most affected by deforestation, representing 86% of forest loss (355,555 ha) in the period 2010–2014. According to CENAGRO (2012) and the Ministry of Agriculture, cattle farms in the Amazon region of Peru have on average 25.4 hectares, and 10.6 animals, with milk production of 4.1 Kg per lactating cow per day and an average meat production per beef animal of 134.3 kg per year.

Peru plans to increase its per capita consumption of milk and beef by 16 and 28% respectively, and to reduce the imports of these goods by 2027. Such goal requires the increase in cattle production, that could increase deforestation in the Amazon region if a transformational change does not occur in the livestock sector. To prevent this situation, Peru launched in 2017 The National Livestock Farming Development Plan (MINAGRI 2017). This plan is focused on five key areas including: adequate management of natural resources, increasing competitiveness and value-added products, improving coverage of services to improve access to markets, and strengthening producers' technical capacity. This strategy generates space for improvement in the livestock sector through more sustainable production including silvopastoral systems (SPS). The SPS could increase productivity while increasing and diversifying farm income. This alternative is relevant environmentally, if we consider the 353,458 hectares of degraded pastures in the Amazonian region of Peru that could be improved, and the Peruvian Government commitment to implement 119,000 hectares of SPS by 2030 for reducing carbon emissions in the framework of The Nationally Determined Contributions (NDC). Although SPS have been used for decades and have shown the ability to increase land-sparing and to reduce deforestation (Loconto et al. 2019), their development and adoption in Peru is still limited when compared with other countries of Latin America. Hence, this chapter provides a review of SPS experiences in five significant departments of the Peruvian Amazon, the current constraints for the implementation of these practices in the country, and the initiatives at a regional and national level to promote and develop a more sustainable livestock production in the Peruvian Amazon region.

8.2 Characteristics of the Peruvian Amazon

The Peruvian Amazon covers an area of approximately 78,456,483 hectares. Geographically, this area is located between 0°2′20,76″ and 14°30′55″ south, and between 68°39′12″ and 79°29′01″ west (Fig. 8.1). The Peruvian Amazon consists of two distinct ecoregions: the lowland or thick jungle of the Amazon basin and the highland jungle or semi-tropical forest on the mountain slopes (Klarén 2017). The lowland jungle, is the largest ecoregion of Peru, standing between 80 and 1000 meters above sea level (masl). It has very warm weather with an average temperature of 27 °C, high relative humidity (over 75%) and yearly rainfall of approximately 1000 mm (MIDAGRI 2022). Because of high temperatures and high rainfall, soil fertility is generally low. The highland jungle is the ecoregion that extends into the eastern foothills of the Andes, between 1000 and 3800 masl with an average

Fig. 8.1 Map of the Peruvian Amazon (left) and the five most representative departments (right). (Source: MINAM (2015))

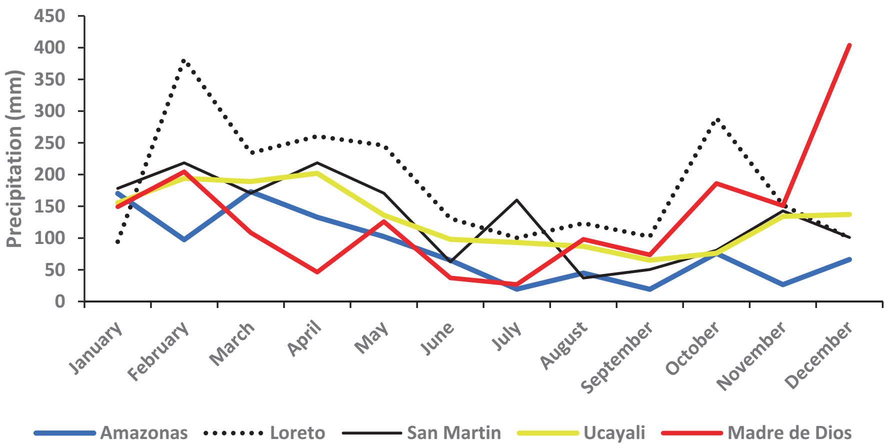

Fig. 8.2 Annual precipitation (2022) in five most representative departments of the Peruvian Amazon

temperature of 23 °C, average relative humidity of 75%, and yearly rainfall of approximately 2600 mm to 4000 mm. (see Figs. 8.2 and 8.3) (MINAGRI 2020).

These eastern slopes of the Andes are home to a diverse fauna and flora because of the different altitudes and climates (Pulgar Vidal 1979). In the Amazon region of Peru, the departments with more geographical extension are Loreto (47.8%), Ucayali (13.4%), Madre de Dios (10.8%), San Martín (6.2%) and Amazonas (4.7%) that together represent 83.0% of the region (MINAM 2015). Elevation, rainfall,

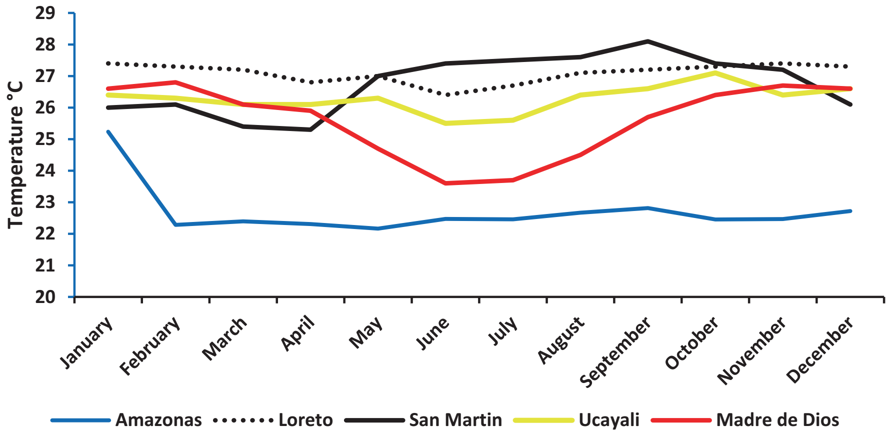

Fig. 8.3 Annual temperature (2022) in five most representative departments of the Peruvian Amazon (MIDAGRI 2022)

Holdridge's life zone and temperature affect the development of SPS in terms of trees species, pasture species and the type of spatial arrangements used.

8.3 SPS Technology Available in the Peruvian Amazon

In the last decades, various silvopastoral initiatives have been developed in the Peruvian Amazon at experimental stations and small-scale farms, but mainly for research purposes. The national government, through the Directorate General for Livestock Development, the National Institute of Agrarian Innovation (INIA) and regional governments have been conducting actions to promote and implement SPS in regions such as San Martín, Amazonas and Madre de Dios. Local and national universities have also been conducting research activities in the area, whereas non-governmental organizations (NGO) have been focused to provide training and assistance to farmers on technical issues.

Livestock production systems in the Peruvian Amazon are predominantly extensive and semi-extensive. However, production is limited due to inadequate grazing management. SPS consist mainly of live fences and scattered trees in pastures (Fig. 8.4).

8.3.1 Loreto

Loreto department is located in the lowland jungle and has a surface of 37,503,942 hectares. In this department, Agroforestry systems have been studied during the last 30 years in order to improve degraded soils, which are prevalently classified as Ultisols. In Yurimaguas province, SPS with grass-legume mixtures as the forage

Fig. 8.4 Silvopastoral system with trees arranged as live fences, and dispersed in the paddocks (left) and conventional system with trees arranged as live fences (right)

component of the system are some of the main alternatives evaluated to recover degraded lands (Arevalo et al. 1998). Livestockis predominantly oriented to beef production. Land degradation in this area has been induced mainly by overgrazing with long-term changes in soil physical properties and surface soil compaction (Alegre and Lara 1991). Alegre et al. (2012) evaluated a SPS with brachiaria (*Brachiaria sp.*), peach palms (*Bactris gasipaes*) planted at a 5 × 5 m distance, and a legume cover crop (*Centrosema macrocarpum*) for beef production. Cattle was managed in rotational grazing (14-days resting and 14-days grazing periods) with a stocking rate of 3 animals ha^{-1}. As a result, there was an improvement in soil fertility and a reduction of soil compaction in the grazing area. The average daily weight gain was 445 g – $animal^{-1}$ day^{-1} during the 4 years of the study. These results are substantially better than the values registered in traditional grazing systems. Current work in the area is focused on recovering degraded brachiaria (*Brachiaria brizantha*) pastures (Alegre et al. 2017). The approach consists of fertilizing with 40 kg ha^{-1} of P and then overseeding the legume *Centrosema*. After the full establishment of the pasture component, fast-growing trees are planted at a density of 3 × 3 m. The trees include capirona (*Calycophylum spruceanum*), bolaina (*Guazuma crinita*) and marupa (*Simarouba amara*). After 5 years of tree growth, the tree stand is thinned to a distance of 6 × 6 m. Cattle is managed under rotational grazing at a stocking rate of 3 animals ha^{-1}, based on previous experience. The carbon stocks for different land-use systems were also evaluated in Yurimaguas. The average carbon stock of a 10-year-old peach palm plantation with *Centrosema macrocarpum* was 55 t C ha^{-1} with a flux of 5.5 t C ha^{-1} y^{-1}; and in a 10-year multistrata system with *Centrosema* the carbon stock was 59 t C ha^{-1} with a flux of 5.9 t C ha^{-1} y^{-1} (Alegre et al. 2002; Palm et al. 2002).

8.3.2 Ucayali

Ucayali department is located in the lowland jungle and has a surface of 10,532,795 hectares. Livestock production systems in this department are predominantly extensive and semi-extensive and farming practices are characterized by low level of inputs and mainly oriented to beef production with a small proportion oriented to dairy production. However, production is limited due to inadequate grazing management which has led to soil erosion and the presence of invasive species. Vela et al. (2010) developed a baseline of silvopastoral initiatives in Ucayali, observing the different designs of SPS (trees in paddocks, forage banks, live fences and windbreaks), and identified that 50% of farmers implement SPS as a complement of cultivated pastures, 19% to improve the nutritional value of natural pastures, 13% to diversify production systems, 13% to recover degraded land used for pastures or crops, and 5% to improve the sustainability of the soil – plant – animal system. Farmers also indicated as main benefits for implementing SPS the improved management of their productive system (46% of farmers), the increased knowledge of livestock systems (34%), the improved value of the land (8%), the higher economic income (8%), and the introduction of new production systems (4%). Studies conducted by Riesco et al. (1995), Clavo et al. (2006) and Vela et al. (2019), identified livestock farms that incorporate primary forests trees such as *Amburana cearensis, Ceiba samauma, Swietenia macrophylla, Aspidosperma macrocarpon* and *Dipteryx odorata*; and secondary forest trees such as *Calycophyllum spruceanum, Simaruba amara, Guazuma crinita, Tabebuia serratifolia, Terminalia oblonga, Erythrina spp., Inga edulis, Ficus insipida, Inga* spp*., Gmelina arborea, Jatropha curcas, Crescentia cujete, Schizolobium amazonicum* and *Vitex pseudolea;* for providing shade to cattle, firewood, timber, fruits and medicinal products. In this regard, Clavo and Fernandez-Baca (1999) suggested the importance of natural regeneration as an alternative to tree planting during the establishment of silvopastoral systems in Ucayali. They identified *Cordia ucayalensis, Ochroma pyramidale, Tabebuia serratifolia,* and *Trema micrantha* as potential natural tree species due to their frequency (42 plants ha^{-1}), survival rate (86%), noninterference with planted tree species and potential economic value.

Vela et al. (2019) reported the performance of a multistrata SPS prototype in Ucayali department based on pasture (*Brachiaria dictyoneura)*, shrubs and forage trees (*Crescentia cujete, Cratylia argentea, Erythrina berteroana* and *Leucaena leucocephala*), short-cycle tree (*Simarouba amara*) and long-cycle tree (*Dipteryx odorata),* compared with a monoculture plot of *Brachiaria dictyoneura* grazed by Holstein × Zebu Gyr cows. Results showed improved soil physical and chemical characteristics, increased macrofauna, lower luminosity (189.9 *vs*. 463.7 °lux before), decreased temperature (32.5 vs. 35.4 °C before), increased system relative humidity (63.6 *vs*. 50.8% before), average daily milk production of 5.0 kg cow^{-1} day^{-1}, stocking rates of 5 Livestock Units ha^{-1} and a potential of carbon sequestration equivalent to 133 t C ha^{-1}. These results suggest that there is a wide variety of shrubs and tree species that can be used as fodder, wood, and live fences among other purposes. Currently, the average carrying capacity of the improved grass is 2.5 mature cattle ha^{-1}; nevertheless, it has been commercially possible to increase the carrying capacity to 4–5 mature cattle ha^{-1} in intensively managed systems by supplementing forage using cut and carry, polishing rice or other supplements available in the department. Additionally, supplementation with brewery residue and palm oil byproducts promote increases in milk production up to 3400 kg of milk per lactation with F1 Holstein × Zebu Gyr cows. In terms of carbon sequestration, an evaluation of a SPS based on a 30-year rubber (*Hevea brasiliensis*) plantation with kudzu (*Pueraria phaseoloides*) produced an average carbon stock of above and below ground of 152.6 t C ha^{-1}. Similarly, legumes and grasses within the different tree species increased the carbon stocks by 2–5 t C ha^{-1} (Alegre et al. 2002; Palm et al. 2002). Concha et al. (2002) reported a difference of 22.5 t C ha^{-1} of carbon stock between a SPS based on scattered trees and pasture on degraded land in Ucayali; demonstrating the potential environmental contribution of SPS in this department.

8.3.3 Madre de Dios

Madre de Dios department is located in the lowland jungle and has a surface of 8,503,657 hectares. It is located in southeastern Peru, on the border with Bolivia and Brazil. This department is considered the capital of the Peruvian biodiversity since it hosts more than fifteen protected areas. Livestock production is mainly located in the provinces of Tambopata and Tahuamanu and is predominantly oriented to beef production. A baseline study conducted by The Ministry of Agriculture (MINAGRI 2019a) in the area, reported average livestock farms with 67 hectares of cultivated pasture and different crosses of Brown swiss cattle with Zebu breed. MINAGRI (2019b) also evaluated chemical characteristics of the soil in the department, determining low soil fertility and the need of fertilization using phosphoric rock and agricultural dolomite prior to the implementation of cultivated pastures. Silvopastoral systems present in the area are based on timber and fruit trees such as *Inga edulis, Guazuma crinita, Calycophyllum spruceanum, Guazuma ulmifolia, Gliricidia sepium, Bactris gasipaes, Dipteryx Micrantha, Gmelina arborea,* and *Cedrela odorata*, in association with different varieties of *Brachiaria*. MINAGRI is currently promoting the implementation of SPS in Madre de Dios, as an alternative of sustainable land use against illegal mining activities and deforestation. They are supporting the establishment of 600 hectares of trees (*Guazuma crinita* and *Dipteryx micrantha*) in live fences associated with cultivated grasses, using a pasture density of 4.0 Kg seed of *Brachiaria* sp. per hectare. Additionally, MINAGRI is also encouraging the implementation of high-density protein banks for improving livestock production, prioritizing the use of *Leucaena leucocephala* and *Centrosema macrocarpum*.

8.3.4 San Martin

San Martin department is located mainly in the high jungle and has a surface of 4,907,221 hectares. Out of 70 surveyed farms in this region, Pizarro et al. (2020) reported that more than 47% of farmers with SPS in this department have on average less than 10 ha of total land while 35% of landowners have between 10 and

30 ha. Livestock in the department is oriented to dairy and beef production mainly in dual purpose systems. In Moyobamba province, the predominant livestock breeds are Zebu x *Bos taurus* crossbreds (36%) followed by Brown Swiss (34%). Silvopastoral systems consist mainly of live fences and scattered trees in pastures. The tree species in SPS are mainly used as a source of firewood, timber or fruits. The most predominant species are *Inga edulis, Eucalyptus* sp., *Ormosia coccinea, Psidium* sp., *Cedrelinga catenaeformis, Colubrina glandulosa* and *Mangifera indica*. These trees were observed in associations with the following pastures: *Digitaria decumbens, Brachiaria brizantha, Arachis pintoi, Pueraria phaseoloides, Brachiaria decumbens, Axonopus compressus* and *Paspalum dilatatum.* Holmann & Lascano (2001) reported increased stocking rates in farms of San Martin compared with pasture on degraded land by the use of *Centrosema macrocarpum, Brachiaria decumbens* and *Brachiaria brizantha*. Similarly, SPS with *Eucalyptus torelliana* in live fences and *Brachiaria decumbens* supported a stocking rate of 1.8 livestock units (LU) ha^{-1} and a productivity of 2200 kg of milk per lactation (Pizarro et al. 2020). Alegre et al. (2019) reported chemical soil attributes in three types of SPS of Moyobamba province, showing acid pH (4.83), high organic matter (4.3%), low phosphorus (2.36 ppm) and low to medium potassium (114 ppm). In relation to environmental aspects of SPS in San Martin department, Ruiz-Llontop et al. (2022) determined the carbon footprint (CF) of milk production (in kg of CO_2 equivalents (CO_2e) per kg of fat and protein corrected milk (FPCM)) on eight representative dairy farms of Juan Guerra district based on cultivated grasses such as *Brachiaria brizantha*, and living fences with *Guazuma ulmifolia* as the predominant silvopastoral arrangement, and low level of external inputs, obtaining an average value of 2.26 ± 0.49 kg CO_2e per kg of FPCM, with enteric fermentation as the most important source (1.81 ± 0.51 kg CO_2e per kg of FPCM), followed by manure management, land use, and energy/transport (0.26 ± 0.06, 0.14 ± 0.04, and 0.05 ± 0.04 kg CO_2e per kg FPCM, respectively).

8.3.5 Amazonas

Amazonas department is located mainly in the high jungle region and has a surface of 3,724,462 hectares. Out of 219 surveyed farms in Molinopampa (n = 130) and Huayabamba (n = 89), Pizarro et al. (2020) reported that more than 80% of farmers located in the Amazonas have less than 30 ha of average total area. The SPS are predominant in the southern part of the department, and livestock is mainly oriented to dairy production. Alegre et al. (2019) reported SPS based on the associations of *Populus alba, Inga edulis* and *Eucalyptus torelliana* trees with *Brachiaria mutica* at 1200 masl and *Pinus patula, Cupressus sempervirens L., Ceroxylon peruvianum* and *Alnus acuminata* trees with *Dactylis glomerata* and *Lolium perenne* pastures at 2400 masl. Vasquez et al. (2020) evaluated the average carbon stock of above and below ground of four types of SPS: *Alnus acuminata* in alleys, *Pinus patula* in alleys, *Cupressus macrocarpa* in live fences and *Ceroxylon quindiuense* in scattered trees, associated in all the cases with *Dactylis glomerata, Lolium multiflorum* and *Trifolium repens.* In this study, researchers reported average biomass and soil carbon stock of 179.5 t C ha^{-1} for *Ceroxylon quindiuense*, 160.8 for *Pinus patula*, 150.1 for *Cupressus macrocarpa* and 108.2 for *Alnus acuminata*. They also observed high dry matter yields (0.3 kg m^{-2}) and nutritional quality (Crude Protein: 16.1% and IVDMD: 66.1%) in pastures of SPS associated with *Alnus acuminata*. Similarly, Oliva et al. (2018a) reported positive effects of *Erythrina edulis*, *Alnus acuminata* and *Salix babylonica* on yield and nutritional values of *Lolium multiflorum* and *Trifolium repens.* In terms of financial aspects, Chizmar (2018) evaluated a SPS model comparing with a typical cattle forage system at Amazonas department determining higher net present values (992.5 vs. 796.9 US Dollars ha^{-1}) and benefit-cost ratio (1.16 vs. 1.11) at a 4% discount rate. However, SPS showed higher establishment cost (1203.4 vs. 1197.5 \$ ha^{-1}) and payback period (4 vs 3 years).

8.4 Barriers for Implementation of SPS Practices

To achieve the required scale of SPS in Latin America there is a need to ensure that farmers have access to inputs, capital and information (Arango et al. 2020). There are 350,000 ha of degraded pastures in the Amazonian region of Peru that could be improved by implementing SPS aimed at enhancing carbon sinks as well as reducing the carbon emissions associated with deforestation and forest degradation. Here we present, based on an exchange of ideas with relevant actors in Peru associated with land use options, the main constraints to implement SPS practices in the Amazon region:

8.4.1 Technology

The technical knowledge required for pasture management, livestock management, and forest management are perceived to be major difficulties during SPS adoption (Frey et al. 2012). More specifically, new rotational grazing systems (Bussoni et al. 2015), planting, pruning, and harvesting of trees and shrubs (Dubeux Junior et al. 2017) are the main challenges of small-scale farmers for implementing SPS. We have described examples of SPS practices, validated with farmers, for certain areas in the Amazon region of Peru. In order to determine the appropriate species to include in SPS, it is necessary to conduct research activities and participatory workshops with farmers to recover indigenous and local knowledge and exchanging experiences with specialists of Latin America working in SPS. Indeed, successful SPS implementation requires compatibility with farmers' previous experience and knowledge, the priorities and objectives of the farm, and the ease of incorporation into current farming practices (Zabala 2015). Proper selection of species is critical to the success and sustainability of SPS, since the costs of introducing tree and shrub species and the time required for their development can be considerable. It is also important to consider that the technical and economic feasibility of establishing a specific technology will be decisive for its adoption. Oliva et al. (2018b) reported for example that the land size, the total number of cattle, the number of cows in production, the soil conservation, the trees inside the property, and the access to support in planting activities are some of the factors that determine the adoption of SPS technology in the Amazonas department. Experience is also needed in designing and testing silvopastoral innovations such as the rational use of adapted forages, new spatial and temporal arrangements of trees and pastures, improved feeding strategies, and more studies related to the beneficial effect of prevalent tree species in Peruvian SPS. In all cases, the presence of an efficient value chain for products derived from SPS should be considered. For example, lack of technology and supply providers (seeds, fertilizers, tree seedlings, electric fences, etc.) has been identified in most of the amazon region for the establishment of SPS. Furthermore, when markets are distant, the probability of selling value added products from the SPS is reduced, thus reducing the potential probability of adopting new systems. The physical infrastructure also reduces farmers' access to cheap seeds and seedlings, fertilizers, and other vegetal material critical for SPS implementation. This situation is similar for most Latin American countries where formal grass and legume seed sale systems are underdeveloped, limiting the purchase of planting material or the number of varieties available (Arango et al. 2020).

8.4.2 Training

Considering that silvopastoral practices are relatively new in the Amazon region of Peru, it is necessary to develop and implement technical extension activities that consider specific characteristics of the farmers in the region such as the size of the production unit and the farmer's level of education. Aspects of forestry management, crop and livestock practices, genetic improvement of cattle, farm economic management, environmental impacts of SPS measures, irrigation practices, and market access should be discussed with the farmers in order to ensure a full understanding of the potential of SPS. In this regard, technical assistance sustained beyond the timeframe of initial adoption and implementation is critical to ensure the continued adaption of specific SPS management practices to each farmer's needs (Chará et al. 2019; Frey et al. 2012; Zabala 2015). In addition, to assess land use options, it will also be necessary to define the impacts of sociocultural characteristics of farmers, as they could significantly affect the implementation of SPS. When looking at cultural and behavioral factors, many livestock producers in Latin America prefer traditional production systems over more technical and sustainable ones for reasons of simplicity and risk aversion. It is important to understand how livestock producers make decisions, regarding the adoption of technologies or the factors that influence those decisions. Certainly, this is, as indicated by Arango et al. (2020), a knowledge gap that needs to be addressed in order to assure a more widespread adoption of strategies such as SPS. Another important issue that Peruvian Government has to face for offering an adequate extension service to farmers, is related to the establishment of strategies oriented to ensure the availability of extension agents in the Amazon region and to cover their training needs related to the production of SPS. Barrantes et al. (2017) found that only 10.2% of Peruvian agricultural and livestock producers in the country had access to extension services. Limited road connectivity and rural road deterioration also prevent free movement of extension agents and inhibit service delivery to farms. Universities of the Amazon region may play a key role in this aspect by providing trained professionals in SPS management.

8.4.3 Incentives

It is frequently recognized that there is a need to provide farmers with incentives to adopt silvopastoral practices such as those that have already been defined in other countries. A financial mechanism to cover the initial investment and to alleviate farmers' negative cash flow during the first 5 years of operation is needed. A key element is the definition and valorization of the primary ecosystem services that SPS provides. These mechanisms are oriented to those benefits, direct and indirect, that people obtain from properly functioning ecosystems, such as water regulation, biodiversity maintenance and carbon sequestration (Casasola et al. 2009). The lack of information about ecosystem services related to carbon under specific SPS conditions in the Peruvian Amazon is a gap we need to fill. Specifically, there is limited information in the Amazon about the differences between SPS and prevalent land use for raising cattle on degraded land, particularly in relation to GHG emissions and carbon capture. A mechanism by which SPS can contribute to the mitigation of GHG emissions is the reduction of enteric methane emissions. Specifically, these emissions from ruminants could be mitigated by supplying forages, either herbaceous and shrubby or tree-legumes containing secondary plant metabolites such as condensed tannins and saponins (Martin et al. 2016). Reports in the literature indicate between 5% and 10% emission reduction compared to similar diets lacking the aforementioned components (Molina-Botero et al. 2019). This mechanism requires further studies before it can be included in inventories of enteric methane emitted by herbivores, especially because of the diversity of forages that prevail in the Amazon region of Peru.

The Amazon region requires development and field evaluation of financial mechanisms for the promotion of SPS to match farmers investment needs with national and international financial sources. Investment in livestock activity based on SPS at the Peruvian Amazon could not be considerably leveraged by the smallholder; thus, financial incentives from external agents are important to consider. Regarding the credit system in Peru, though bank loans are granted by some financial entities, such as Corporación Financiera de Desarrollo (COFIDE) and Banco Agropecuario (AGROBANCO), unattractive proposals are often offered to the smallholder. For instance, short and medium-term credits, no grace period, and annual interest rates between 20% and 25% for working capital and between 17% and 23% for fixed assets (AGROBANCO 2017). In addition, because of the several requirements imposed by private banking to farmers to accept credit, applications are not completed, especially those related to handing over of a property title or financial guarantee (AGROBANCO 2020). Besides, agricultural activity is considered as a risky investment by financial entities because this sector is vulnerable to extreme climate changes and farmer payment defaults. In favor of this, an active role from the government is important to generate financial mechanisms for the implementation of pastoral systems, such as SPS, which give the smallholders access to loans with lower interest rates and longer payment periods. Thus, interventions on grassland areas of 104 farms to convert them into SPS were fostered in countries, such as Colombia (Pagiola and Rios 2013; Rivera et al. 2013). In addition, granting of credits with differentiated interest rates of 2%, 4%, and 5% for small, medium, and large cattle ranchers, respectively, and a grace period of up to 2 years have been established by the second-tier bank FINAGRO and implemented, among others, by Banco Agrario de Colombia as a strategy to finance the purchase and planting of tree species, electric fences, windbreaks, and others, which support the implementation of SPS (Banco Agrario de Colombia 2020).

This also occurs in other parts of Latin America in which, as indicated by Calle et al. (2013), lack of capital and the high cost of establishment and management represent the two most important barriers to adopting these systems. Furthermore, as described by Saunders et al. (2016), the costs of establishing and subsequently managing, agroforestry systems are generally higher than those of conventional woodlands and forests since individual trees require protection from livestock, while the forest canopy requires active management in order to maintain the productivity of both the grass sward and the trees to produce high-quality timber. However, when both the potential economic and environmental benefits associated with agroforestry systems are identified and assessed, the combined returns are potentially greater than those of plantation forests alone.

Working through cooperatives or associations can also benefit agribusiness as an incentive. In Uruguay, Paraguay and Costa Rica, cooperatives control the dairy chain, providing more profits and lower transaction costs to members. In Nicaragua, Ecuador and Paraguay, small-scale farmers are organized in associations or cooperatives that emphasize a vertical integration, organizational model, market articulation and business strategies (FAO 2012). Cooperatives and farmer associations offer the possibility to implement collective voluntary approaches and achieve competitive levels similar to those of larger companies (Liendo and Martínez 2011).

8.4.4 Planning and Policies

In order to promote SPS practices, support of governments at local and national levels and the engagement of both the private sector and all key local institutions are required. Strengthening institutional capacities of local and regional governments for improving their planning and evaluation processes are also necessary. Effective policies targeting both the demand and supply-side of cattle value chains are needed to generate market opportunities, increasing in this way the livestock competitiveness and sustainability in the country. Additionally, the Peruvian Government has to establish clear policies that ensure the sustainable use of degraded areas and the conservation of protected zones. Regions targeted for intervention should be aligned to specific ecological zoning protocols. However, ecological zoning has not been carried out in the Peruvian tropics. Implementing a system to measure, report and verify emissions is also required by the agricultural sector as this will contribute to the promotion of SPS implementation based on its provision of carbon sequestration. Furthermore, the lack of property rights among farmers is widespread and affects decision-making processes, including implementation of long-term investments such as SPS; therefore, specific policies need to be implemented in the public sector in order to solve this constraint. In this regard, it is important to mention that government incentivization of decentralization in the livestock sector has had consequences for smallholders. Land consolidation under private land developers has reduced farmer land holdings in the past 30 years, facilitated by a series of government legislative actions. In 2002, Law N° 28059 and Legislative Decrees 994 and 1089 promoted private sector investment in land for development purposes (World Bank 2017). However, the legislation had the added effect of increasing land prices beyond an affordable level for farmers entering agriculture, leading to an increasing number of small farmers becoming renters, rather than purchasing land outright (World Bank 2017). A study by Pokorny et al. (2021) found that of cocoa farmers interviewed in San Martín, many of which keep cattle, fewer than 20% held a legal title for the land they occupied. This lack of formal land tenure documentation and consequent lack of tenure security is understood to extend to farmers producing other commodities in the region. Land tenancy laws can incentivize limited-length land rental contracts, which in turn de-incentivize investments in the land that farmers may never realize the benefits of, i.e., improved soil quality and structure, improved forage production, and increased dairy cattle productivity from SPS (Frey 2009).

8.4.5 Environmental Conditions

Farmers producing on degraded pastures have raised concerns about nutrient depletion, soil fragility, decreased soil fertility, and a rising need for synthetic fertilizers (Calle et al. 2009). The prolonged dry season was also associated with high rates of tree mortality during the SPS implementation period (Hoch et al. 2012). Under increasingly volatile climate conditions, more severe droughts during the summers pose a major threat to more widespread adoption of SPS. An environmental barrier of somewhat lesser importance to consider is the presence of dangerous wildlife near farms (Bussoni et al. 2015). In the Madre de Dios region of Peru, farmers reported disruptions in fruit production on SPS by monkeys, while other SPS adopters in the region lost calves to hunting jaguars. Increased biodiversity was noticed by farmers in studies from Lee (2020) and Calle et al. (2009), as well as a 2016 study from Solymosi et al. (2016). While this is often listed as a benefit and an ecological improvement, many farmers remain wary of the losses to harvests wildlife can be responsible for, as well as the dangers predators can pose to livestock (Bussoni et al. 2015; Calle et al. 2009; Peri et al. 2016).

8.5 Initiatives of the Peruvian Government to Promote SPS

Silvopastoral systems in Peru largely aim to create productive regimes out of improved fallows abandoned during a period of civil unrest during the 1980s and 1990s in which the ruminant populations were decimated (Cotta 2017; Vera 2006). The Peruvian Government has defined the Nationally Determined Contributions (NDC), which includes a reduction of 30% of GHG emissions by the year 2030 (GTM-NDC 2018). This projected GHG reduction considers, among other strategies, the recovery of degraded soils via SPS in the Peruvian Amazon to mitigate 1.1 Mt CO_2 eq arising from intervention on 119,000 ha. Furthermore, Peruvian Amazonian departments have already started the development of action plans and related policy for "Low -emission rural development strategies" which have the potential to be scaled. However, this initiative is not well articulated with the national government, and there is a lack of a sense of urgency for the protection of forests.

Since 2018, the Peruvian Government is taking action to promote the adoption of new paradigms for consumption and low carbon production. The normative and institutional framework that accompanies this approach is observed in the Climate Change Framework Law, the National Agrarian Policy, the Forestry and Wildlife Law, the National Competitiveness and Productivity Plan, the Guidelines for green growth, and the National Livestock Development Plan, among others. The Peruvian Government is also advancing in the cross-sectoral coordination to guide the identification and implementation of the NDCs through the Multisectoral Working Group. However, this group is temporal and has made progress especially on the identification of the measures to achieve NDCs in the different sectors, but little progress has been made on the implementation. Currently, there is a lack of a coordination mechanisms within the agricultural sector in order to align the technical, financial and political efforts for implementing the identified actions to reduce emissions from this sector. Although few advances towards implementation exist, the Peruvian Government has started allocating public funding to overcome some of the barriers for the transformation of the livestock sector in the Amazon. For example, in 2019, the Peruvian Government, through the Ministry of Agriculture, in coordination with sub-national governments implemented 600 hectares of silvopastoral systems based on forage pastures associated with native trees used as live fences in paddocks, the use of electric fences for rotational grazing and the implementation of protein banks. The purpose of this intervention was to promote sustainable livestock production in the provinces of Tambopata and Tahuamanu (Madre de Dios department), as well as to contribute to the fulfilment of the NDC goals of the agricultural sector, specifically the Mitigation Measure: Implementation of management techniques of pastures through silvopastoral systems to reduce GHG in the jungle. This activity shows the first steps to promote sustainable livestock production at national level. However, rolling out an ambitious plan will demand to move forward alongside a holistic approach that supports sustainable livestock farming production and monitor deforestation trends in Peru. This process should involve all stakeholders in the livestock farming supply chain, including producers, local governments in livestock farming departments, and the private sector.

8.6 Conclusions

Silvopastoral systems in the Amazon region of Peru varied depending on local initiatives and local conditions of each department. Silvopastoral systems have the potential to serve as an overall national and regional management strategy to reduce deforestation and recover degraded land in the Peruvian Amazon, to improve livestock productivity in a sustainable way and, ultimately, to strengthen the resiliency of small- and large-scale farmers while helping to mitigate emissions. However, studies on adoption of SPS in the country have so far been limited and occurred spontaneously and empirically. Barriers to establish SPS need to be worked by the producers, and others by the State at different levels (local, regional and national government). Development of policies and adequate financial incentives are required to expand SPS. Furthermore, adoption and implementation of SPS on degraded lands will require a suite of strategies to disseminate information, train personnel (train-the-trainer type programs) and follow up with land managers at the farm level, including the need of training materials that directly highlight the benefits of implementing SPS. While the benefits of implementing these systems, such as the ecosystem services and the economic factors, can be numerous and, to some extent, a function of the potentially diverse nature of the system's components and the specific environment, a dedicated effort should be made to fund research and extension activities that aim to clearly define the benefits of silvopastures. It is imperative that the Peruvian Government continue promoting SPS on degraded lands to recover them and achieve the NDC commitments, generating at the same time better conditions to motivate farmers to adopt or scale up SPS.

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