Chapter 11

Agroecological Transition for Sustainable Cattle Ranching with Silvopastoral Systems in the High Andean Slopes of Colombia

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Abstract Dairy cattle ranching in the high Andean zone is a socioeconomic important activity, relatively efficient compared to other cattle raising systems in Colombia's lowland tropics. However, it relies heavily on imported inputs (fertilizers, concentrated feed, pesticides, etc.) and is highly vulnerable to economic and environmental changes because of the ecosystem conditions in a region that is also recognized for its biodiversity richness and its ecosystem services. Silvopastoral systems are a sustainable production alternative for agroecological intensification of dairy livestock farming. To implement these systems, conventional dairy farmers need to make profound changes and a gradual transition of the production process. An integrated approach is proposed combining land use planning -considering land capability- and the introduction of mixed pastures, trees, and shrubs in the production system, together with the management of local resources and forest conservation. This chapter presents a case study of a dairy cattle ranch transformation in a high Andean hillside area in Colombia, that made land use changes based on conservation criteria in rural landscapes and the application of agroecological principles in its production practices. The most outstanding achievements were the maintenance of the economic viability of the production system in a period of financial crisis for the country's dairy industry, thanks to a greater efficiency in the use of non-renewable energy and nitrogen (external inputs). At the same time, the system preserved and restored forest areas and increased connectivity between forest fragments. Agroecological production also enhanced biodiversity conservation and the provision of ecosystem services such as water regulation and plant and soil carbon storage.

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11.1 Introduction

Because of the growing global population, it is estimated that the demand for meat and dairy products will continue to increase and double by 2050 in relation with 2010 levels, especially driven by urban consumers in developing countries (Peters et al. 2013; Herrero et al. 2009). The challenge of increasing livestock production per area unit and, at the same time, restoring and conserving areas of natural ecosystems, requires the integration of agroecological principles into agricultural production (Zuluaga and Etter 2018). This challenge requires technological and institutional innovations where local actors play a fundamental role (Tapasco et al. 2019).

The Northern Andean zone is a globally significant region for biodiversity conservation (Orme et al. 2005). Specialized dairy livestock is part of the productive matrix in Colombian high mountain areas between 2000 and 3200 m.a.s.l., with average temperatures between 12 and 17 °C (Murgueitio 2008). It produces 24% of the country's total milk in 3.5% of the total grazing areas, and is developed mainly in small and medium-sized farms (UPRA 2020; FEDEGAN 2022) that include highland and hillside areas. In the last ones, current livestock production models have greater impacts on ecosystems (Zúñiga et al. 2013).

The importance of high Andean ecosystems and the complexity of dairy production in these areas requires the development of new ways of land use that contribute at once to biodiversity conservation, ecosystem services provision and social development in these rural landscapes. It is suggested that failures in natural resources management in agricultural production are caused by a linear vision framed in a human dominance position over nature (Berkes and Folke 1994) which is materialized in extractive systems where economic rationality prevails. This process, where economic efficiency is the main criterion, generates unforeseen results and unexpected effects that impact the productive activity itself and other social sectors (Giampietro 2003). The possible solutions, framed within the same paradigm, are partial and ineffective. For this reason, different fields of environmental and social studies are proposing a change of the approach to address the sustainability problem (Giampietro 2003; Berkes et al. 2000).

Along these lines, agroecology appeared in the second half of the twentieth century as a new science with a systemic and interdisciplinary vision that also validates other types of knowledge with the objective of achieving food security, social justice, and environmental sustainability in agricultural production (Altieri 1995; Gliessman 1997; León-Siccard 2014). With the current global food, energy and climate crises, its importance has grown to demand its application on a larger scale, which implies the development of gradual and consistent transition processes towards sustainability, as well as the generation of knowledge to support them (Altieri and Nicholls 2020, 2022).

The agroecological transition of productive systems has been studied with different methods, including indicators to evaluate the application of agroecological principles at various scales, as well as the agroecological structure (Altieri 2022; León-Sicard et al. 2018). In livestock systems, different types of indicators have been proposed, among which the following stand out: (a) Vegetation cover, (b) Plant diversity, and (c) Soil organic matter (Sarandon and Flores 2014). These environmental indicators are integrated in other studies with economic and social variables to analyze sustainability (Astier et al. 2011). Also, the socioecological metabolism approach is applied to livestock production systems, analyzing the energy efficiency, nutrient balance, life cycle and ecological footprint (Denoia et al. 2008; Funes-Monzote 2009; Jiménez-Castro and Elizondo-Salazar 2014; Llanos et al. 2018; Rotz et al. 2020).

In Colombia, sustainability analysis in dairy production systems has been addressed by identifying the main challenges of the conventional model based on external inputs (Carulla and Ortega 2016; Holmann et al. 2003), comparing different indicators according to their intensification level (Ruiz et al. 2019), developing life cycle analysis (Rivera et al. 2014), and non-renewable energy and nitrogen balances (Benavides Patiño 2016). Other livestock studies in the Colombian Andes extend the production system sustainability to livestock landscapes that are crucial for food production, livelihood support, and biodiversity conservation (Calle et al. 2012; Gu and Subramanian 2014). Due to the socioeconomic importance of dairy cattle ranching in the high northern Andean mountains, and the environmental problems of the current production models, it is urgent to develop strategies to promote more sustainable systems (Mahecha et al. 2002; Carulla and Ortega 2016).

Silvopastoral systems (SPS), with the incorporation of agroecological principles in their design and management, are part of the set of solutions to global environmental problems, including increasing carbon sequestration and reducing the use of non-renewable energy in the production process (Murgueitio et al. 2011, 2013a; Silva Parra et al. 2019; Chará et al. 2019). Silvopastoral systems are also a technological alternative that sustains productivity while replacing excess of synthetic nitrogen and other chemical inputs to the system, such as pesticides and other synthetic fertilizers (Márquez et al. 2010; Castaño Quintana et al. 2019; Lopera-Marín et al. 2020a). All this could be achieved using agroecological principles such as the promotion of functional diversity, the use of local resources and solar energy, and the protection of soils. The integration of nitrogen-fixing plants, phosphorus-solubilizing species, trees, and shrubs into the livestock system, contribute to increase organic matter content and soil moisture, with direct effects on forage production and self-regulation of the system (Márquez et al. 2010; Zapata Cadavid and Silva Tapasco 2016; Pezo 2019; Lopera-Marín et al. 2020b).

11.2 Silvopastoral Systems (SPS): An Agroecological Option for Livestock Sustainability on High Andean Slopes

11.2.1 General Information on Sustainable Livestock Farming with SPS and Agroecological Principles on High Andean Slopes

High Andean or mountain areas are crucial for ecosystem services related to biodiversity, which benefit local farmers and the society (Hall et al. 2015; Castaño 2002; Cuesta et al. 2012). Part of the remaining biodiversity in these sites is found within cattle ranches where relicts of native forests are preserved (Chaves et al. 2007). In addition, milk production, which was traditionally carried out in areas of high plateaus and low slopes near urban centers, has increasingly spread to hillsides or mountain areas (Hall et al. 2015), where ecosystems are more fragile and production conditions are less favorable, presenting lower productive performance and more impact on the environment and natural resources (Agudelo et al. 2003; Zúñiga et al. 2013).

The characteristics of dairy cattle production and the biological importance of high Andean slopes urgently require the generation of knowledge on sustainable cattle ranching models with mountain SPS (Gómez Mora et al. 2005; Hall et al. 2015). Sustainable cattle ranching is based in the use of primary production of grasses and other fodder species grown under agroecological principles and with local resources to feed domestic herbivorous animals (Dietl et al. 2009). On the matrix of grasslands managed with agroecological principles, it is possible to incorporate shrubs and trees in Silvopastoral Systems (SPS) in different arrangements achieving multiple purposes: (a) Protect and use water, soil and local biodiversity rationally in synergistic relationship with domestic animals for the production of high quality and strategic food, (b) Promote formal employment, (c) Afford good quality of life for people in the countryside, (d) Enhance animal welfare, and (e) Generate ecosystem services for all, among others (Murgueitio et al. 2020). The introduction of tree and shrub species in agricultural production based on agroforestry recreates some of the conditions of the forest for the self-regulation of the production system (Montagnini 2017).

In SPSs forage plants are combined in an intentional, intensive, integral, and interactive manner with trees and shrubs for animal nutrition and complementary uses (Jose et al., Chap. 1, this volume; Montagnini 2008; Murgueitio et al. 2011; Calle et al. 2012; Chará et al. 2017; Calle 2020). Silvopastoral systems can also be integrated with conservation and ecological restoration actions in rural landscapes (Calle, Chap. 3, this volume; Calle et al. 2012; Calle and Holl 2019). In this land use strategy, grazing is reduced to agroecologically appropriate areas and released areas are devoted to conservation, ecological restoration and connectivity corridors, while the pasture matrix is diversified (Lopera et al. 2015). Trees, shrubs, legumes, and grasses associated with livestock can become a production subsystem, in which forestry generates a long-term income, optimizing, together with cattle production, productivity and profitability indicators per unit area (Chará et al. 2019). In addition to the benefits for livestock farmers, SPSs contribute to climate change mitigation by capturing carbon and reducing greenhouse gas (GHG) emissions (Mahecha et al. 2002; Murgueitio et al. 2013a; Peri et al. 2019).

In the mountain regions, SPSs are especially relevant considering that livestock production occupies areas that were previously covered by forests strategic for the conservation of rural-urban ecosystem balances (Calle and Holl 2019). SPS are based on developments and applications supported by research in the last decades on different plant species adapted to these areas (Murgueitio et al. 2013b). Some of these are *Tithonia diversifolia* (Hemsl.) A. Gray (Mahecha et al. 2021), *Sambucus peruviana* H.B.K. (Cárdenas et al. 2011; Grajales Atehortúa et al. 2015; Rodríguez Molano et al. 2019; Durana et al. 2022), *Alnus acuminata* H.B.K. (Silva-Parra et al. 2018; Escobar et al. 2020a, b), *Smallanthus sonchifolius* (Poepp. & Endl.) H. Rob. (Lopera-Marín et al. 2020b). Other studies have focused on the silvopastoral arrangements (Murgueitio et al. 2013b; Escobar-Pachajoa et al. 2019) and the evaluation of their impact on grass pest management (Lopera et al. 2015; Ochoa et al. 2017). However, although SPS generate recognized benefits, their implementation is more complex than conventional systems and therefore it requires to provide technical assistance and reinforce the farmer's knowledge (Lopera et al. 2015).

11.2.2 Benefits of SPS in Mountain Areas

In general, SPSs contribute to the generation of a more suitable environment for livestock production, given that: (i) Trees and shrubs roots take nutrients in deeper layers and produce plant litter that enriches the soil with organic matter, while preventing erosion (Zapata Cadavid and Silva Tapasco 2016). (ii) Foliage diversity generates better soil cover, as well as greater production of quality forage (Grajales Atehortúa et al. 2015; Navas-Pandero et al. 2021). (iii) The improved soil cover increases water retention and infiltration rates, reducing runoff, landslides, and gully formations (FAO 2018). (iv) The different strata of vegetation, especially trees, act as a barrier preserving humidity and protecting pastures from frost and wind (Snyder and de Melo-Abreu 2010).

In hillside or mountain areas, agroecological transition with SPS requires to combinate different actions in the production system that should be carried out simultaneously to condition the agroecosystem and obtain benefits for livestock, while contributing to biodiversity conservation and ecosystem services generation. These practices are complemented by proper livestock management applying business and zootechnical concepts (Rivera et al. 2014) that generate employment and better opportunities in the countryside. These practices include rotational grazing with electric fences in small paddocks with short consumption periods and adequate pasture recovery times (Bacab et al. 2013), division into groups of cattle by age, supply of water in each paddock, and the use of animal draft power

(Mahecha-Ledesma et al. 2022). This should be complemented with animal genetic selection according to environmental conditions, adequate reproductive management, and administrative efficiency (Murgueitio et al. 2016).

11.3 El Silencio Nature Reserve: A Case Study of Agroecological Transition and Sustainable Livestock Production on High Andean Slopes in Colombia

11.3.1 Location and Description of the Farm

El Silencio Nature Reserve stands in the upper part (hillside areas) of the municipality of San Francisco (Cundinamarca, Colombia) at 4° 57′ 21″ N and 74° 14′ 20″ W, in the western mountain range of the Bogota Plateau known as El Tablazo. This is part of a biological corridor of Low Montane Rainforest relevant for water regulation (Holdridge 1966; CAR 2019). The elevation of the property ranges from 2650 to 2850 m.a.s.l., with an annual rainfall of 1500 mm, an average temperature of 14 °C (minimum of 8 °C and maximum of 18 °C), undulating topography and moderate to steep slopes (>45 °C).

It is a private property where people from three generations participate in the management. It has an area of 114 ha that includes 42 ha of protected Andean cloud forest with oak trees (*Quercus humboldtii* Bonpl.), and about 20 ha in ecological restoration, altogether with more than 600 species of plants and 120 species of birds (Fig. 11.1).

Fig. 11.1 Panoramic view of meadows and live fences on a hillside area in El Silencio Natural Reserve. (Photo: Adolfo Galindo)

In the reserve the main economic activity is milk production with Holstein cattle. On average, 37 cows with a production of 17.2 L/cow/day are milked (twice a day) in the paddocks using a portable milking equipment. The cattle production area has a diversity of forage with mixed grasses (*Cenchrus clandestinus, Lolium perenne, Lolium multiflorum, Holcus lanatus, Dactylis glomerata, Trifolium repens, Trifolium pratense, Lotus uliginosus, Desmodium spp, Taraxacum officinale, Acmella sp.*). The SPS establishment includes live fences, windbreaks, hedgerows, and forage banks with species such as *Tithonia diversifolia, Sambucus. peruviana, Alnus acuminata, Acacia melanoxylon,* and *Eucalyptus globulus*, among others. The Nature Reserve has also areas for agricultural production with short-cycle crops and some annual crops for human-animal food security, horse breeding, as well as areas for ecotourism activities (Fig. 11.2).

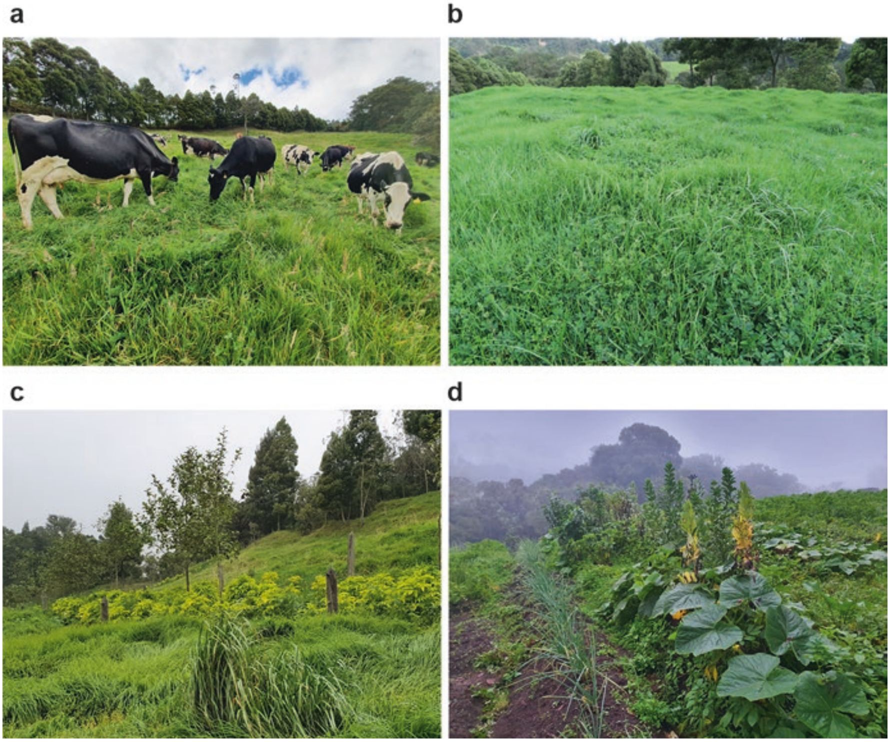

Fig. 11.2 (**a**) Holstein cows grazing in mixed pastures; (**b**) Mixed pastures with grasses and legumes; (**c**) SPS with forage hedges of *S. peruviana* and *A. acuminata* trees. (**d**) Short-cycle crops for human and animal food security. (Photos **a**, **c**, **d**: Claudia Durana; Photo **b**: Adolfo Galindo)

11.3.2 Analysis of the SPS Agroecological Transition in El Silencio Nature Reserve

To identify the relevant factors for the agroecological transition process and its impact on the sustainability of the system, we used information from the farm over a period of 16 years and analyzed it taking into account the following management stages: (a) Low intensification conventional management from 2006 to 2011, (b) Intensification process with improved farm management and increased use of external inputs from 2012 to 2016, and (c) Incorporation of agroecology and SPS from 2017 to 2021. A conceptual and methodological framework was adapted to evaluate the sustainability of the farm at the different stages, considering its technical and economic viability, its environmental feasibility and its desirability or correspondence with societal objectives (Giampietro and Mayumi 2000; Serrano Tovar 2014). Changes in management practices at each stage are presented, as well as the evolution of sustainability indicators over time.

11.3.3 Changes in Land Use and Management Practices in the Agroecological Transition Process

11.3.3.1 Land Use

A gradual change in land use was carried out applying conservation tools to increase the connectivity of forest patches and other conservation areas. Since 1997, vegetation cover was increased with the establishment of live fences with *Acacia melanoxylon*, tree corridors, restoration areas, silvopastoral systems with eucalyptus trees (*Eucalyptus globulus*) and iSPS with elderberry (*Sambucus peruviana*) (Fig. 11.3).

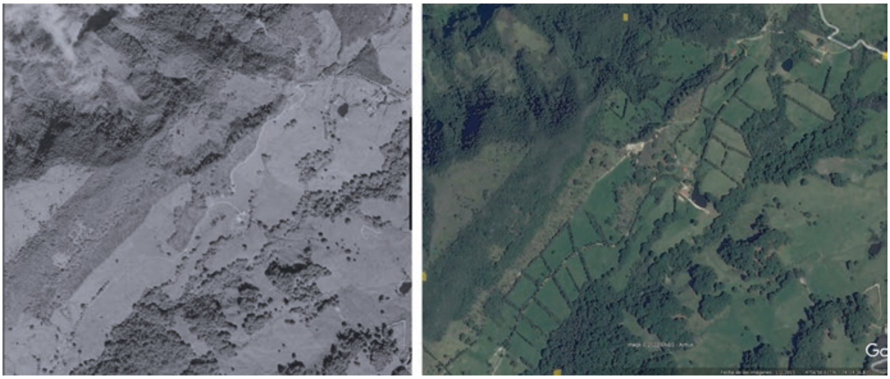

Fig. 11.3 Comparison of land use changes in El Silencio Nature Reserve in images of 1997 (left) and 2021 (right)

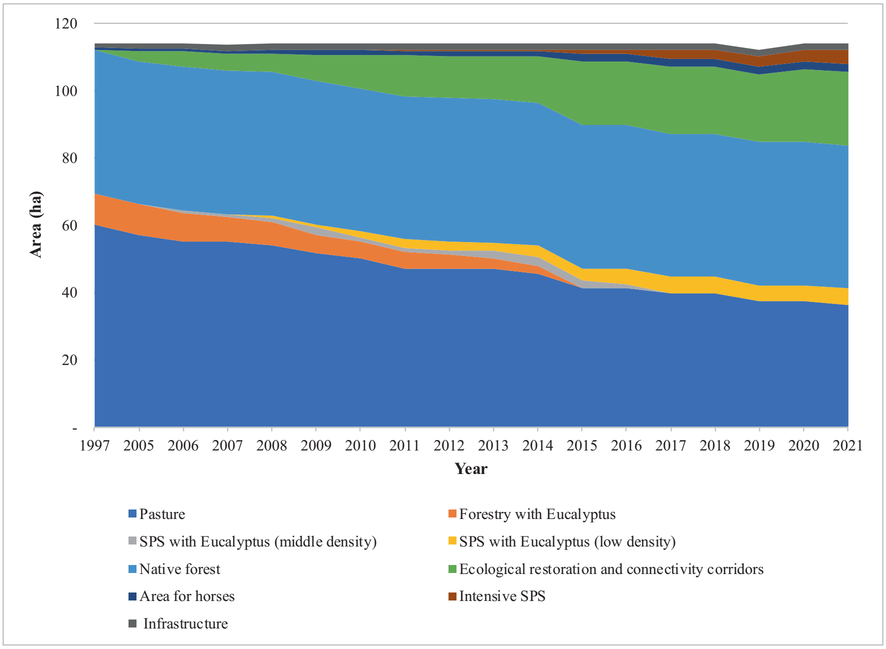

Fig. 11.4 Changes in land use in El Silencio Nature Reserve between 1997 and 2021

Between 2006 and 2021, effective grassland areas were reduced by 30%, and areas dedicated to cattle production by 15%. The native forest increased its area by 50% through plant succession processes and assisted natural regeneration on springs and margins of streams, also through the release of unproductive areas for ecological restoration, as well as the establishment of 5.4 km of live fences, 1.6 km of tree corridors between 5 and 20 m wide (Fig. 11.4). During this period, the total inventory of cattle and the number of milking cows were reduced by 9.47% and 11.90%, respectively, and annual milk production increased by 9.77% (Table 11.1).

11.3.3.2 Evolution of Land Use Changes in El Silencio Nature Reserve Between 2006 and 2021, and Their Effects on the Livestock Inventory and Milk Production

Between 2012 and 2016 (intensification of the conventional model) nitrogen fertilizer application increased up to 60 kg/ha/year in each cattle rotation area. However, this amount applied is below what is normally used on specialized dairy farms in the high tropics (Holmann et al. 2003; Carulla and Ortega 2016; Ruiz et al. 2019). In 2015, ENSO (El Niño-Southern Oscillation phenomenon characterized by increased temperatures and drought) became a constraint for nitrogen application due to the lack of soil moisture required for fertilizer assimilation. Due to this and the strategy

Table 11.1 Evolution of land use changes in the El Silencio Natural Reserve between 2006 and 2021, and their effects on the cattle inventory and milk production

	Pasture	Native forest	Forestry	Eucalyptus low density	SPS with eucalyptus	iSPS (hedgerows)	Ecological restoration	Total cattle	Lactating cows	Milk production
Year	Ha							N°		L/year
2006	57.2	42.4	9	0	0	0	4	95	42	198,402
2007	56.6	42.4	9	0	0	0	4	88	38	213,295
2008	54.2	42.4	9	0	1	0	5.4	90	40	241,679
2009	53	42.4	9	0	0	0	7.6	92	39	223,072
2010	53	42.4	0	9	0	0	7.6	93	43	229,658
2011	50.7	42.4	0	8	0	0.3	10.6	91	43	249,909
2012	49	42.4	0	0	5	0.3	15.3	92	43	247,256
2013	49	42.4	0	0	5	0.3	15.3	90	45	293,530
2014	48	42.4	0	0	5	0.3	16.3	92	43	265,545
2015	46	42.4	0	0	5	0	18.6	83	40	223,000
2016	44	42.4	0	1	5	0	19.6	84	34	231,449
2017	42.1	42.4	0	0	5	2.5	20	82	37	242,890
2018	42	42.4	0	0	5	2.6	20	85	40	257,251
2019	41.6	42.4	0	0	5	3	20	81	35	215,344
2020	40.1	42.4	0	0	5	3.5	21	87	37	225,670
2021	39.6	42.4	0	0	5	4	21	86	37	217,792

SPS silvopastoral system, *iSPS* intensive silvopastoral system, *L* litres of milk

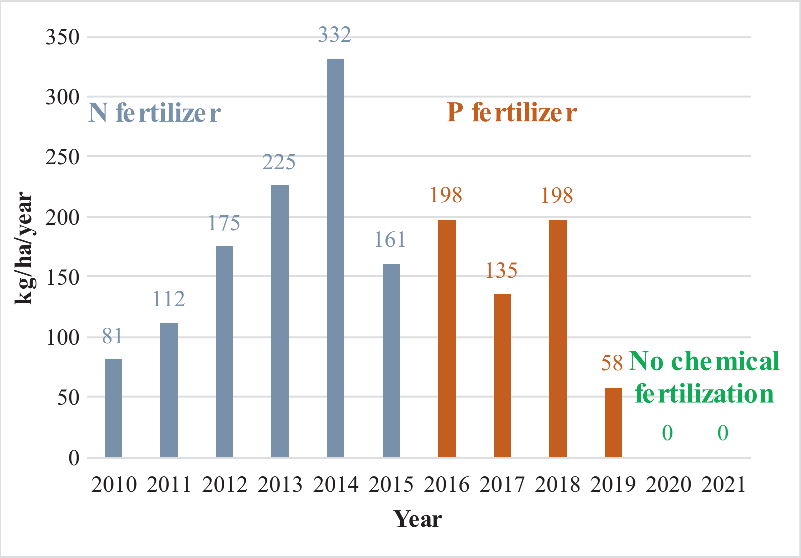

Fig. 11.5 Changes in chemical fertilization with N and P between 2010 and 2021

to reduce chemical insecticide applications to control sucking insects, in 2016 an adjustment was made to fertilization, reducing nitrogen, and increasing the proportion of phosphorus until reaching zero chemical fertilization as of 2020 (Fig. 11.5). It is worth mentioning that since 2010 fertilization with chemical synthesis products was complemented with equine manure compost, between 2010 and 2021 the accumulated application was 1000 m^3 equivalent to 2.3 m^3/ha/year.

The increase of P in fertilization, the use of horse manure compost and the extension of the pasture resting period, allowed the emergence of other plant species in the padocks (especially creeping legumes, slow-growth grasses, and broadleaf plants) for the nutrient supply to the soil through biological and biochemical routes such as nutrient cycling, solubilization of P immobilized by ions and fixation of atmospheric nitrogen. In addition, these plants also enhanced the supply of forage biomass for the cattle. The botanical composition in the paddocks between 2017 and 2021 presented an increase of leguminous plants from 5% to 17%, highlighting species such as *Trifolium repens* and *Lotus uliginosus* and several weeds of the Asteracea family such as *Taraxacum officinale* and *Acmella sp*; decreasing by 20% the presence of *Cenchrus clandestinus* (main pasture of these milk production systems). Likewise, the proportion of *Lolium sp*. was doubled and the presence of *Holcus lanatus*, a native species of interest for its energetic contribution to the diet of cows in production, was increased (Fig. 11.6).

The reduction in nitrogen and P fertilizer applications, the increase in the diversity of plant species in the paddock and the longer pasture recovery times in the cattle rotation, improved the natural regulation of the grass-sucking insects. These phytophagous insects that include the grass bug (*Collaria scenica, Collaria oleosa*),

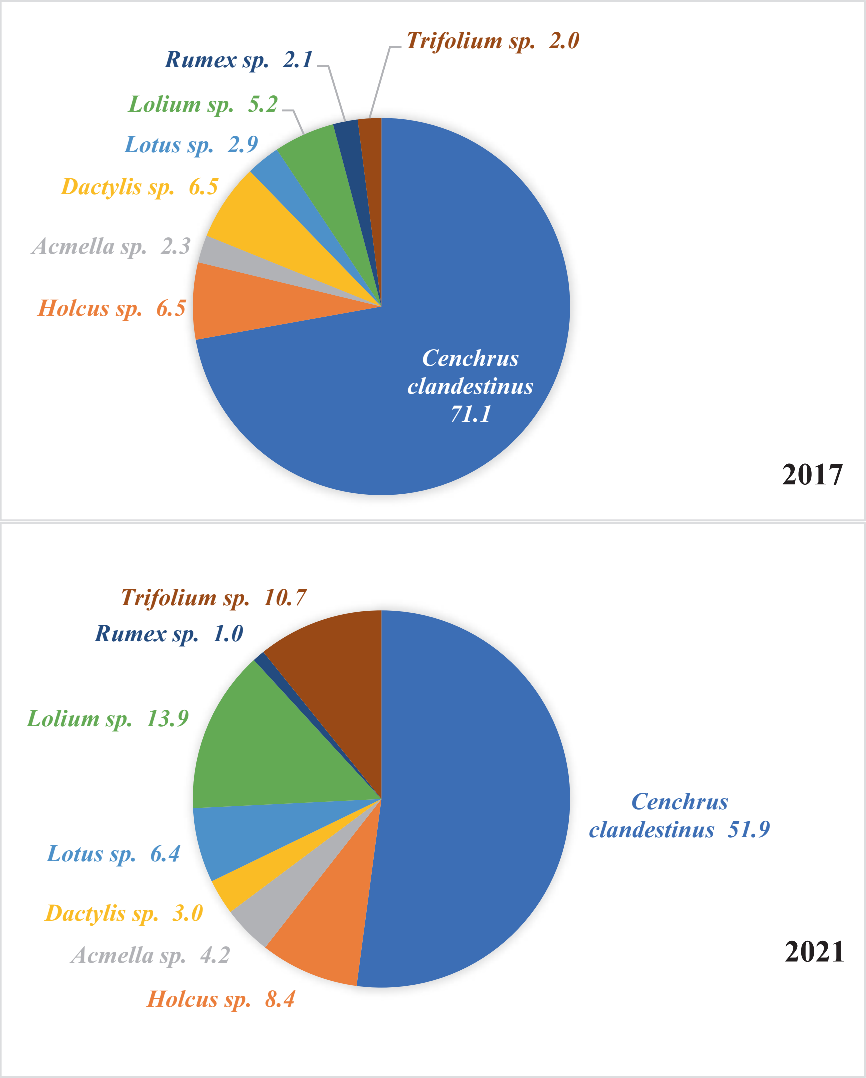

Fig. 11.6 Change in botanical composition (%) of grasslands used for dairy production between (**a**) 2017 and (**b**) 2021 in El Silencio Nature Reserve

the grass sharphooter (*Draeculacephala sp.*) and recently the grass spittlebug (*Zulia carbonaria* and *Mahanarva phantastica*) increase their incidence in monospecies pastures with high fertilizer application (Ochoa et al. 2017). The reduction of their incidence due to agroecological practices, allowed that as of 2018 no synthetic product was applied for their control (Fig. 11.7). Recent evaluations demonstrated cost reductions in insecticide application of up to 75 USD/ha/year (Lopera-Marín et al. 2020a). Also, the labor required was redirected to other activities within the

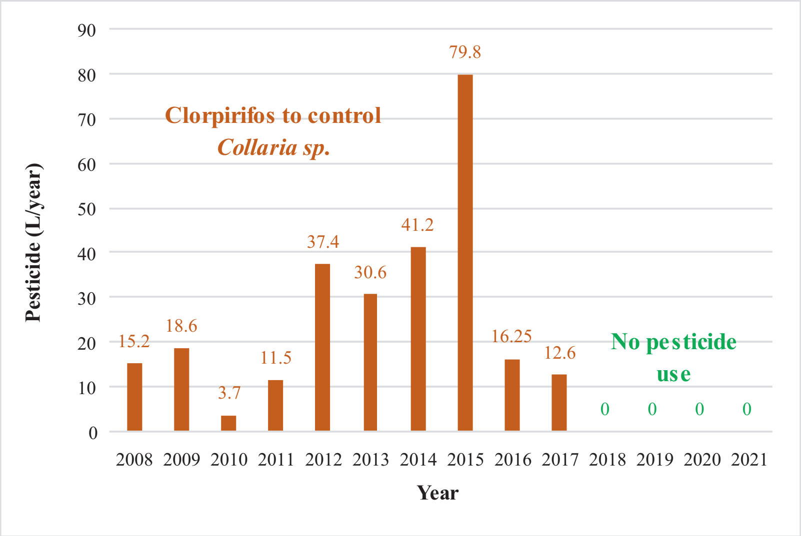

Fig. 11.7 Amount (L) of insecticides used between 2008 and 2021 for the control of grass-sucking insects in El Silencio Nature Reserve

production system, avoiding the exposure of people to toxic substances and improving their quality of life.

11.3.3.3 Paddock Rotation and Supplementation of Cows in Production

The division of pastures with fences increased the number of paddocks from 10 to more than 40, with an average area of one (1.0) ha each. Cattle groups increased from three to five, being categorized by age, physiological and productive stages: lactating cows, calves, heifers, prepartum cows and non-lactating dairy herd. This management allowed offering fresh forage through grazing strips to all groups twice a day. The management involved the use of electric fences to guarantee the occupation and rest periods of each grazing area, in addition to the livestock water supply network, which always offered fresh, good quality water.

Initially, the rotation of paddocks with one day occupation per strip was carried out with a maximum of 60 days of rest (return of the cattle), however, in the dry season it was reduced to 30 days, affecting the physical structure of the soil and its forage production capacity. With the increase in the number of paddocks, group management, agroecological management of grass-sucking insects, increased plant diversity, and the incorporation of SPS, pasture rest was extended to 90 days (in the dry season it is reduced to 60 days).

The supplementation of cattle with grain from balanced feed (concentrate) is one of the main practices of the conventional model of milk production in the high tropics. However, with the incorporation of ISPS with fodder hedges and fodder banks, concentrate supplementation has been reduced (without the use of balanced feed in rearing females up to 5 months of age, and cows close to calving). Currently, the farm has 3.5 km of *Sambucus peruviana* forage hedges with approximately 20,000 plants. According to green forage production evaluations, each plant produces in average 2.5 kg three times per year. This is a forage that has been used on the farm to supplement all livestock groups, replacing concentrate for calves and heifers, and eliminating the purchase of silage (corn silage and other forages) in times of drought or high rainfall.

The effect of replacing 35% of commercial concentrated feed by leaves and green stems of *Sambucus peruviana* on the production and chemical quality of milk was evaluated by Durana et al. (2022). A significant difference ($p < 0.05$) of 4% in milk production was found in favor of the control diet treatment (commercial concentrate), but there was no significant difference between treatments in the variables related to compositional quality of the milk. When comparing the economic surpluses of each diet, it was identified that replacing 35% of the balanced feed with forages increased the gross income from milk sales by 14% (Durana et al. 2022).

11.3.3.4 Input Reduction

As mentioned above, the agroecological transition process in the farm has resulted in a reduction in the use of the main external inputs such as chemical fertilizers, insecticides and other toxic substances that were eliminated in the productive process and replaced by organic fertilizers (Table 11.2). The use of antiparasitic

Table 11.2 Changes in the use of external inputs in the milk production system in the different stages of management between 2008 and 2021 in the El Silencio Nature Reserve

Stage	Year	Insecticide (L)	Chemical fertilizer (kg)	Organic fertilizer (m^3)
Conventional low intensive management	2008	15	4280	0
	2009	18.6	4300	25
	2010	3.7	4320	108
	2011	11.5	5680	70
Intensification in the use of external inputs	2012	37.4	8940	188
	2013	30.6	11,520	0
	2014	41.2	16,680	70
	2015	79.8	8780	99
	2016	16.25	11,000	75
Agroecological transition	2017	12.6	7300	10
	2018	2	7980	3
	2019	0	2600	201
	2020	0	0	79
	2021	0	0	126

products, antibiotics and hormones also decreased, and the spread of insecticides against the hematophagous horn fly (*Haematobia irritans*), was also discontinued.

11.3.4 Sustainability Indicators

The effect of the different management practices was measured with technical, economic, and environmental indicators by applying the conceptual framework proposed by Giampietro and Mayumi (2000). Economic variables were measured from 2006 to 2021, and environmental variables from 2010 to 2021.

11.3.4.1 Technical and Economic Viability of the Production System

The technical and economic viability of the system was defined by productivity, cost efficiency and profitability variables (Table 11.3). Costs were established with constant 2021 prices for labor, pasture maintenance expenses, milking, external inputs, electricity, veterinary services and medicines, artificial insemination, pesticides, and transportation with actual farm values.

Productivity per hectare increased in the agroecological transition stage (between 2017 and 2021) when compared with the conventional management stage (between 2006 and 2011), but it was lower than the productivity per hectare during the conventional intensification period (between 2012 and 2016) (Fig. 11.8). However, milk yields were maintained with agroecological production above 6000 L/cow/year, with a more stable behavior in the production per animal and close to what is recommended for organic milk production based on forage resources (5000 L/cow/year) as suggested by Dietl et al. (2009). In terms of milk chemical quality, fat content increased by 5% and protein by 10% between 2008 and 2022. However, these increments were not proportionally reflected in the price per liter due to external factors.

Cost efficiency is related to the number of cows milked and the weight of fixed costs, especially labor costs. Between 2020 and 2021 there was a reduction in cattle inventory affecting this indicator, although it remained at competitive values in the international market (below 0.28 USD considering the analysis with constant prices of 2021 and the value of the currency at 4000 COP) (Carulla and Ortega 2016). It is important to highlight that labor presented a higher share of costs in the initial management and in the agroecological transition periods compared to the intensification stage with external inputs (Fig. 11.9). This indicates that the resources for milk production went to the workers and not to commercial inputs, most of which are imported. However, in the cost structure remains that of commercial concentrate for milking cows, still representing 33% of total costs in 2021.

Profitability depends on production levels, costs, and milk prices. The latter showed higher values between 2008 and 2012. Between 2012 and 2015, in the years of greater intensification with external inputs, profitability was reduced, despite

Table 11.3 Technical and economic feasibility indicators in El Silencio Nature Reserve between 2006 and 2021

Stage	Year	Milk production	Cost efficiency		Profitability	
		L/year	Cost/L (COP) (C)	(USD)	Price/L (B)	(B-C)/C (%)[a]
Conventional low intensive management	2006	198,402	1029	0.26	1371	33
	2007	213,295	993	0.25	1376	39
	2008	241,679	1038	0.26	1538	48
	2009	223,072	1136	0.28	1479	30
	2010	229,658	1056	0.26	1411	34
	2011	249,909	1091	0.27	1410	29
Intensification in the use of external inputs	2012	247,256	1121	0.28	1397	25
	2013	293,530	1086	0.27	1273	17
	2014	265,545	1094	0.27	1296	18
	2015	223,000	1178	0.29	1290	10
	2016	231,449	1132	0.28	1397	23
Agroecological transition	2017	242,890	1073	0.27	1389	29
	2018	257,251	983	0.25	1281	30
	2019	215,344	1084	0.27	1279	18
	2020	225,670	990	0.25	1343	36
	2021	217,792	1054	0.26	1383	31

C cost, *B* benefit

[a] **(B-C)/C (%):** Profitability (B/C) is calculated as the surplus (benefits minus costs) over costs. It is calculated in the unit of a liter of milk with the benefits as the price of milk, which is the value that comes in from the sale of milk, and the costs, considering the cost of producing a liter of milk. The percentage resulting from dividing the surplus per liter (price per liter minus cost per liter) by the cost per liter, represents the percentage of profit over the investment (labor, inputs, electricity, transportation, among others) in the production process

high production levels. This was aggravated by the drought of 2015 due to ENSO. Although in 2019 there was an internal crisis that affected profitability, this was recovered for 2020 and 2021.

With the agroecological transition, production was maintained, profitability increased compared to the intensification stage with external inputs, and costs were reduced while labor participation in them increased and milk quality improved. Similarly, milk production was maintained despite the effects of ENSO, low rainfall in 2019, some sanitary problems in the herd between 2020 and 2021, and the increase in chemical fertilizer prices in 2021. The information of loss of profitability in milk production is a nationwide phenomenon caused by the rise in input and labor costs and the low increase in milk prices (FEDEGAN 2022), where the most affected producers were those with models of high dependence on imported inputs.

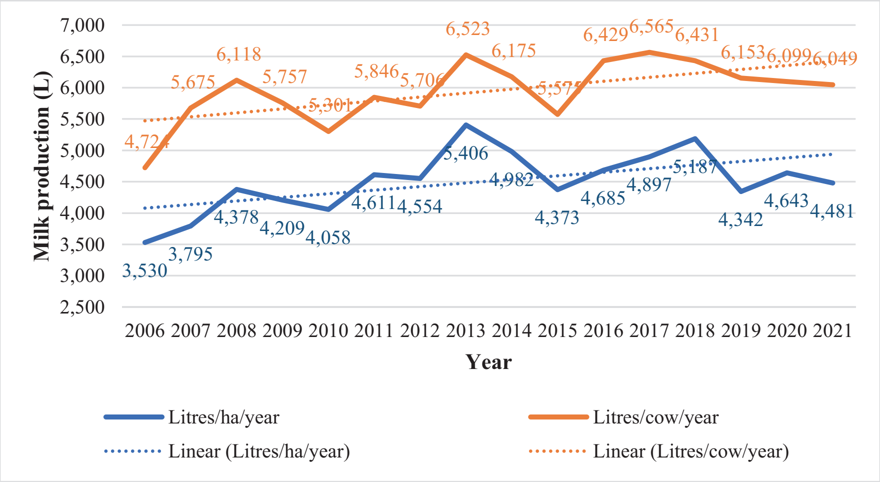

Fig. 11.8 Annual productivity per animal and per hectare between 2006 and 2021 in El Silencio Nature Reserve

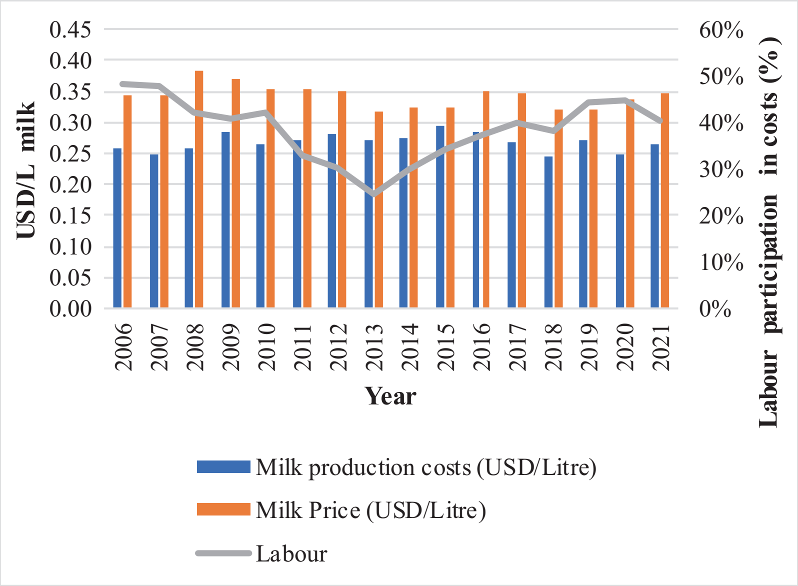

Fig. 11.9 Costs and prices per L of milk and labor participation between 2006 and 2021 in El Silencio Natural Reserve

11.3.4.2 Environmental Feasibility of the Production System

Environmental feasibility is another condition for the sustainability of the systems that implies efficiency in the use of natural resources and in the emission of pollutants. In this case, non-renewable energies (NRE) that enter the system through external inputs, fuels and electricity are compared. Likewise, nitrogen input through chemical fertilizers and balanced feed is also analyzed in terms of utilization efficiency. The conversion values correspond to the NRE used in the manufacture and transport of external inputs (Table 11.4). The formula of Energy Output (EO) in meat and milk over Energy Input (EI) in external inputs and energy sources (EO/EI), reflects the efficiency in the use of NRE coming from these inputs in the system, with the highest values showing greater efficiency in the transition process from the conventional model to agroecological production.

As for the efficiency in the use of NRE from external inputs, it was lower during the intensification stage and higher during the agroecological transition. Commercial concentrate is one of the NRE sources that continues to be used, considering that they cause dependency and increase production costs, but maintain production. However, *Sambucus peruviana* forage, according to the results of research in milk production, will begin to replace the milk cows balanced feed (Durana et al. 2022).

The energy efficiency decreased during the period with higher intensification and increased to in the years with agroecological production. These values were above

Table 11.4 Environmental feasibility of the production system from energy efficiency, N efficiency and GHG emissions through external inputs between 2010 and 2021 in El Silencio Nature Reserve

Stage	Year	Energy efficiency		N inputs efficiency		Emissions	
		EO/EI	MJ/kg FPCM	NI/NO	g N/kg FPCM	Productive area	Whole farm
						CO2eq/ha/year	
Conventional low intensive management	2010	1.26	2.57	0.53	10.9	771	383
	2011	1.22	2.64	0.46	11.9	917	455
Intensification in the use of external inputs	2012	1.00	3.22	0.39	14.1	1182	587
	2013	1.07	2.99	0.27	16.8	1323	657
	2014	0.88	3.63	0.22	23.0	1474	732
	2015	0.73	4.49	0.34	17.6	1355	673
	2016	0.93	3.44	0.45	12.8	1095	543
Agroecological transition	2017	1.09	2.94	0.49	11.3	969	481
	2018	1.28	2.45	0.60	8.5	868	431
	2019	1.23	2.62	0.96	6.8	664	330
	2020	1.43	2.24	1.07	5.6	614	305
	2021	1.45	2.21	1.14	5.3	579	287

EO energy output (in meat and milk), *EI* energy input in external inputs, fuel, and electricity, *NI* N input in fertilizers and feed, *NO* N Output in milk and meat, *MJ* Mega Juoles, *FPCM* fat and protein corrected milk, *CO2eq* carbon dioxide equivalents, *ha* hectares those found in conventional specialized dairies in cold climates in Colombia that are between 0.51 and 0.73 for medium and high intensification systems (Benavides Patiño 2016). The same is reflected in the index of quantity of non-renewable energy used to produce 1 kg of milk (MJ/kg FPCM). In the agroecological intensification stage (between 2017 and 2021) this value was on average lower than that of organic farms supplementing with grain and reporting an index of 2.6 MJ/kg FPCM but was higher than in the organic production farm without supplementation with an index of 2 MJ/kg FPCM (Rotz et al. 2020).

Regarding nitrogen entering the system through chemical fertilizers and feed, efficiency is measured by the ratio of N Input (NI) over N Output (NO) (NI/NO) which represents the units of synthetic nitrogen required to produce one unit of N contained in milk protein. This index increased with the intensive use of fertilizers and was subsequently reduced with the introduction of SPS and agroecological management. Likewise, the amount of nitrogen used from fertilizers and concentrates per kg of milk produced was reduced in the agroecological production stage with values below 6 g N/kg FPCM (Fig. 11.10). Studies in dairies in Costa Rica and the United States reported averages of 16.95 gN/kg milk and between 22 and 24 g N/kg milk produced, respectively (Jiménez-Castro and Elizondo-Salazar 2014).

The overall analysis of this case study of the El Silencio Nature Reserve shows the evolution of milk production and its economic and environmental effects through the three stages described above. Agroecological intensification stands out for maintaining high productive and financial indexes while significantly reducing the negative environmental externalities of the high external input model. Table 11.5 summarizes the transition of the farm according to agroecological principles, agroecological practices and the results achieved:

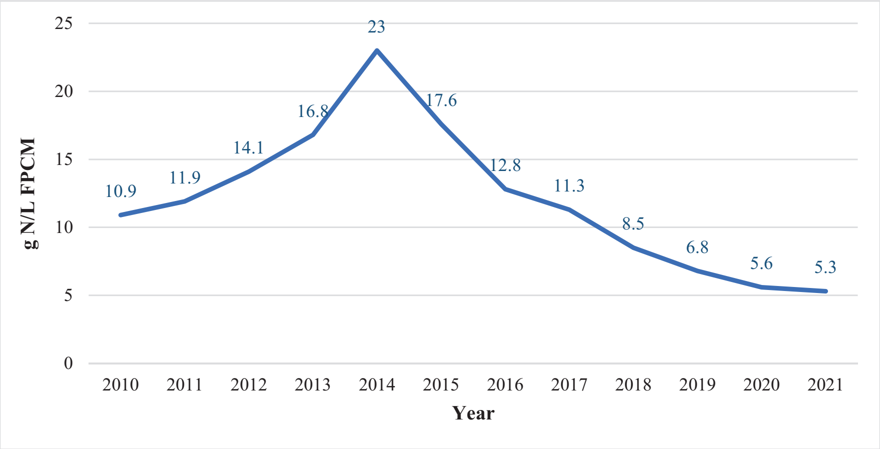

Fig. 11.10 Nitrogen from fertilizers and concentrates per kg of FPCM in El Silencio Nature Reserve over time

Table 11.5 Summary of the transition of El Silencio Nature Reserve according to agroecological principles, agroecological practices and results achieved

Agroecological principle	Practices implemented	Observed results
Improved biomass recycling and nutrient cycling.	Reduction of nitrogen applications. Application of vermicompost, microorganisms and rocks instead of chemical fertilizer. Application of biochar. Windbreaks and live fences. Fodder hedges. More native forests and more connectivity between forest fragments.	Improved working conditions by replacing some activities such as irrigation, chemical fertilization, and pesticide application with manual and specific activities in the SPS. Increased production of fodder biomass. Increased forage quality. Moderate stocking rate is maintained. Increased functional biodiversity. Milk production is maintained. Improved compositional quality of milk (more protein and total solids). Reduction of external inputs with elimination of chemical fertilizers and reduction of feeds Reduction of production costs (10–15%). Total elimination of the use of chemical pesticides in pastures. Reduction of erosion. Increased water retention in the soil with less irrigation demand. Increased welfare and comfort of livestock. Greater resilience in very wet or dry seasons. Milk demand for ecological products.
Improved functional biodiversity	Application of vermicompost, microorganisms and rocks instead of chemical fertilizer. Application of biochar. Windbreaks and live fences. Fodder hedges. More native forests and greater connectivity between forest fragments. Introduction of leguminous plants in grasslands No control of weeds in grasslands Reduction of endoparasite treatments and elimination of Ivermectin's.	
Increased biomass production, more organic matter, and increased soil biological activity.	Longer pasture rotation (longer resting periods). Application of vermicompost, microorganisms and rocks instead of chemical fertilizers. Application of biochar. Windbreaks and live fences. Fodder hedges. More native forests and more connectivity between forest fragments. Reduction of endoparasite treatments and suspension in the use of Ivermectin's.	
Increased conservation and regeneration of soil, water, and agricultural biodiversity.	Longer pasture rotation (longer resting periods). Application of vermicompost, microorganisms and rocks instead of chemical fertilizer. Use of biochar. Windbreaks and live fences. Fodder hedges. More native forests and more connectivity between forest fragments.	
Diversification of species and genetic resources in the agroecosystem in time and space and at the landscape scale.	Mixed pastures of grasses, legumes, and shrubs. Windbreaks and live fences. Fodder hedges. More native forests and more connectivity between forest fragments.	
Increased biological interactions and synergies among components of agricultural biological diversity.	Mixed pastures of grasses, legumes, and shrubs. Windbreaks and live fences. Fodder hedges. More native forests and more connectivity between forest fragments.	

11.4 Conclusions

The case study of the El Silencio Natural Reserve demonstrated the approach to sustainability in milk production in the high-altitude tropics with good levels of productivity and profitability while achieving a better compositional quality of milk. It also allowed the release livestock areas for the conservation of native forests, along with the establishment of other biodiversity conservation tools.

The case study shows that productive and environmental conversion with agroecological processes in sustainable livestock models requires the implementation of simultaneous actions, generating synergies and reducing the use of external inputs. With the increase in prices, profitability is better compared to the model of intensification with external inputs since the increase in chemical fertilizers cost does not affect the system's economy. Less dependence on external inputs contributes to reduce production costs, and to distribute the benefits among the people working in the farm, while the enriched agroecological base increases and sustains production levels, improving product quality. This would give the possibility of obtaining added value for its characteristics, traceability, and environmental benefits, as well as the opportunity to access new markets (organic, sustainable, agroecological and others) and be more competitive.

The incorporation of SPS in agroecological transition processes allows for greater efficiency in the use of non-renewable energy and nitrogen from external inputs, as well as lower GHG emission levels. Despite the inherent demand of more complex management and the conditions of high Andean slopes or mountain areas, it is shown that these are a sustainable option for livestock intensification due to its economic viability, its environmental feasibility, and its concordance with social objectives like social welfare, biodiversity conservation and environmental services.

A comprehensive understanding of the system based on a set of indicators of different dimensions, such as those presented in the case study, can lead to better decision making and the development of instruments to promote the conversion to a more sustainable model within a rural landscape. Agroecological intensification with SPS is part of a necessary process of energy transition, climate change mitigation and biodiversity conservation in rural landscapes.

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