Scientific Paper

Silvopastoral systems: an option for the sustainability of high mountain animal husbandry systems

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Abstract

Objective: To identify the most used tree and shrub species in high mountain silvopastoral systems in the Nariño department as an option for social, environmental and economic reconversion.

Materials and Methods: Two hundred dairy farms were selected based on a non-probabilistic design of intentional sampling. A semi-structured survey was carried out to collect information about the most relevant tree and shrub forage species. A descriptive analysis of the data was carried out using the program SPSS V22.0.

Results: *Acacia melanoxylon* R.Br., *Alnus acuminata* Kunth, *Braccharis latifolia* (R.&P.) Pers. and *Smallanthus pyramidalis* (Triana) H.Rob. were the most representative species in the region. Various silvopastoral designs with functionality for the area were implemented: fodder banks, double-layer live fence, alley pasture, multi-layer live fence for the protection of water sources, contour strips and perimeter hedges. A total of 1 970 actors involved in the milk production chain were trained in the use of silvopastoral systems. A methodology for disseminating knowledge was implemented (field days, training sessions at universities and educational institutions, technical tours, etc.). Among those trained, 40 % were farmers, 50 % were technical assistants, 9 % were university students, 0,5 % were government officials and 0,5 % were extension workers.

Conclusion: The implementation of different silvopastoral designs contributed to technology transfer and knowledge exchange, which encourages the adoption of these systems in high mountain animal husbandry farms belonging to small and medium farmers in the Nariño department.

Keywords: dairy production, production systems, technology transfer

Introduction

In Colombia, dairy cattle husbandry is an important sector of the economy. In high mountain areas 90 % of the farmers are smallholders, those who sustain themselves from animal husbandry activity that contributes to their food security (Mora *et al*., 2017). However, inadequate agricultural practices, in addition to climate variability caused by climate change, have affected the sustainability of these ecosystems. It is predicted that in the next 50 years, agricultural expansion could cause the loss of at least 25 % of the biodiversity that exists in these life zones (Lanz *et al*., 2018; Cardona-Iglesias *et al*., 2020). These production systems have low production efficiency, which increases the excretion of nitrogenous compounds into the environment and the emission of greenhouse gases (GHG), such as methane (CH_4) (Vargas-Martínez *et al*., 2018; Cardona *et al*., 2022). The transition to sustainable systems for high mountain animal husbandry is an immediate need, since these life zones are where the greatest amount of natural resources are produced, such as water, which is a resource used by the population in rural areas and cities (Molina-Benavides and Sánchez-Guerrero, 2017).

High mountain dairy cattle ranching in the Nariño department is one of the most representative agricultural systems in the region and is also one of the five most productive nuclei in Colombia (DNP, 2014). Most farmers in this area have a land surface lower than five hectares (Haller and Branca, 2020), 60 % of the farms have eight cows or less, and 80 % of their areas are planted with Kikuyu grass [*Cenchrus clandestinus* (Hochst. Ex Chiov.) Morrone], which leads to the implementation of forage monocultures that affect biodiversity and nutritional quality (Reyes-Palomino and Cano-Ccoa, 2022). The evident result translates into low milk production, instability in its production and prices, and low profitability, increased by the increases incurred by

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the farmer due to the indiscriminate use of high-cost commercial concentrate feed supplements (Portillo-Lopez *et al*., 2019).

It is necessary to develop research studies in these production systems, so that their results contribute to mitigate the environmental and economic problems generated by specialized dairy cattle ranching. In turn, these results could contribute to solving the problems of forage seasonality. In this context, silvopastoral systems (SPS) are presented as an alternative that can help recover areas degraded by intensive agricultural systems, diversify production, reduce GHG emissions, as well as maximize food production and guarantee nutrient supply (Murgueitio *et al*., 2015).

The objective of this research was to identify the most commonly used tree and shrub species in high mountain silvopastoral systems in the Nariño department, as an option for social, environmental and economic reconversion.

Materials and Methods

The research was approached from a mixed perspective and was based on the methodological process of Participatory Action Research (PAR) (Sirvent and Rigal, 2012). It is part of the project Improvement of forage supply, optimization of feeding systems and assurance of milk quality and safety in the high tropics of the Nariño department, funded with resources from the General System of Royalties (SGR, for its initials in Spanish). Among the various results shown in this work is the identification of shrub and tree vegetation used for cattle feeding in specialized high mountain dairy systems in Nariño, the implementation and management of SPS and capacity building.

Location. The research was carried out in the dairy basin of the Nariño department (fig. 1), which is made up of the following sub-basins: Pupiales, where the Aldana, Iles, Ipiales and Pupiales municipalities are located; Guachucal, made up of the municipalities of Cumbal, Guachucal, Sapuyes, and Pasto, made up of Pasto and Tangua.

This watershed is located between 2 750 and 3 303 m.a.s.l. in the life zone Lower Montane–Dry Forest (bs-MB) (Holdridge, 1996), with annual mean temperature, rainfall and relative humidity of 13 °C, 967 mm and 75 %, respectively (Bacca-Acosta *et al*., 2020).

Experimental procedure. The research was approached from a mixed perspective and was based on the methodological process of Participatory Action Research (PAR) (Sirvent and Rigal, 2012).

Identification of ligneous species used for cattle feeding in dairy systems. A non-probabilistic purposive sampling design was used. Two hundred cattle dairy farms were selected among the three sub-basins. The following selection criteria were used: a) willingness of the farm owner to participate in the identification process, b) easy access to the farm, c) membership in a milk farmers' association, d) references from other farmers who are leaders in animal husbandry with different actors in the region and who have developed sustainable animal husbandry strategies.

A semi-structured survey was applied, where the following variables were considered: general information about the farm: land area (ha), altitude (meters above sea level), gender (female or male), animal husbandry experience (years), association membership (years), type of tree and shrub species used for animal feeding, and conservation of natural resources soil and water. Based on the collected information, an Excel database was created in which each of the survey components was transcribed by municipality. Subsequently, a descriptive analysis was carried out using SPSS v. 22.0.

Implementation and management of the SPS. Based on the characterization of the functional vegetation, the information available in the local bibliography and the conclusions of the working groups in which cattle ranchers, community associations, government agencies, non-profit organizations, universities and agricultural professionals participated, a silvopastoral showcase was designed and established at AGROSAVIA's Obonuco research center with promising forage tree and shrub species for the high Andean zone of Nariño.

Technology transfer workshops. Since the improvement and implementation of the silvopastoral showcase in 2017 until 2022, activities were carried out to promote the exchange of experiences and knowledge for a diverse public.

Results and Discussion

General characterization of the farms and identification of ligneous species used for cattle feeding. Respondents were classified as small farmers, whose farms had an average area of 7,64 ha and less than ten animals, with a livestock occupation in the farm of 93 % with regards to the total area of their farm. In 30 % of the farms, there was a high participation of women in animal husbandry activities, such as planting and management of plant species for SPS. The farmers had an average of 22 years of experience

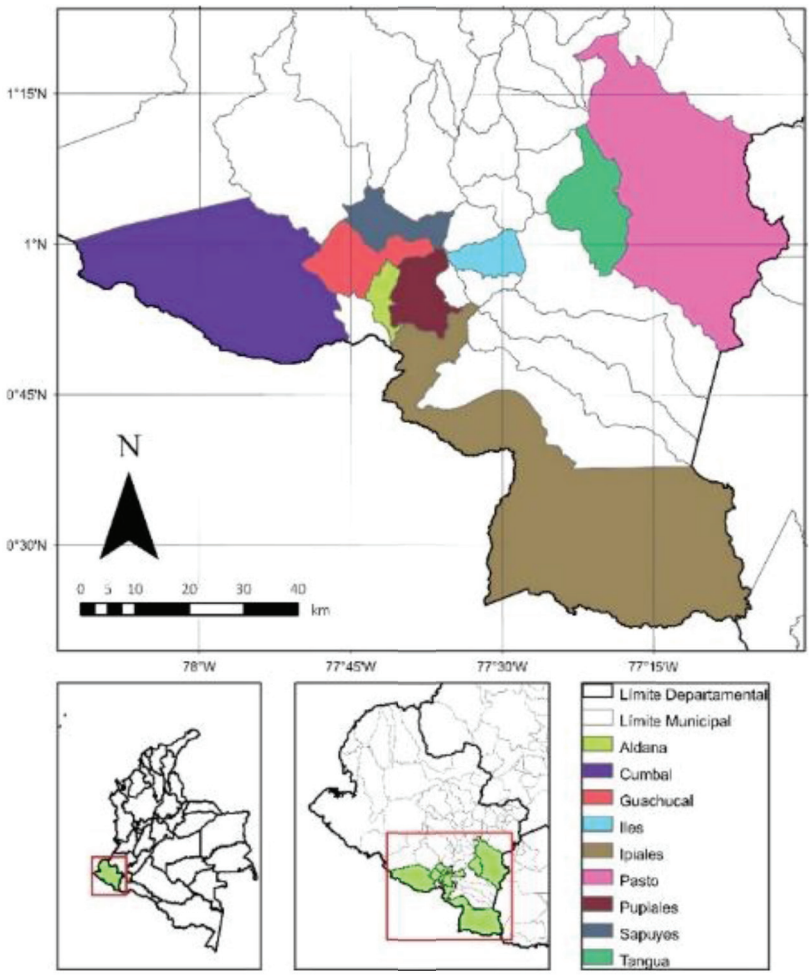

Figure 1. Location of the municipalities selected for the characterization of tree and shrub species present in the high mountain dairy sub-basins of the Nariño department.

in animal husbandry activities and eight years in working initiatives in livestock projects with different actors in the territory. Eighty-one percent of the farmers had shrub or tree species in their farms, used in silvopastoral arrangements: windbreaks (80 %), live fences (70 %), scattered trees (60 %) and forage banks (10 %) with poorly defined management and use. The average occupation of the SPS represents 6 % of the total area of the characterized farms.

When the surveys were applied, the percentage of perceived use of the different ligneous species by farmers in the high mountain SPS allowed the identification of the most commonly used species in cattle, sheep and guinea pig feeding. These species were: *Acacia melanoxylon* R.Br. (blackwood acacia), *Alnus acuminata* Kunth, *Sambucus peruviana* Kunth, *Sambucus nigra* subsp. peruviana (Kunth) Bolli, *Smallanthus pyramidalis* (Triana) H.Rob., *Braccharis latifolia* (R.&P.) Pers. and *Sambucus nigra* L. (table 1).

In the high tropics of the Nariño department there are few studies on SPS (Navia *et al*., 2017). Muñoz *et al*. (2014) consider that, in Colombia, animal husbandry agroforestry in high mountain regions has been established and managed empirically through the use of traditional technologies. However, these have contributed to improving the biological, physical and chemical properties of the soil, regulating the water regime and fixing nitrogen in the soil. This makes them a climate change mitigation and adaptation strategy in the context of global warming (Murgueitio *et al*., 2015).

Table 1. Tree and shrub forage species most used in high mountain silvopastoral systems in the Nariño department.

Stratum	Family	Scientific name	Common name	Type of use	Use perception by farmers, %
Tree	Leguminosae	*A. melanoxylon*	Blackwood acacia	Live fences Browsing Shade Firewood	74,0
	Betulaceae	*A. acuminata*	Andean alder	Live fences Browsing Shade Firewood	47,5
	Myrtaceae	*Eucalyptus globulus* Labill.	Southern blue gum	Live fences Timber Shade	42,1
	Cupressaceae	*Cupressus lusitanica* Mill	Cypress	Live barriers Timber Shade	22,0
	Meliaceae	*Cedrela montana* Moritz ex Turcz.	Andean cedar	Live fences Timber Shade	9,0
Shrub	Asteraceae	*Braccharis latifolia* Ruiz & Pav.	Chilca	Live fences Live barriers Ruminant feeding	51,0
	Leguminosae	*Ulex europaeus* L.	Common gorse	Live fences Live barriers Ruminant feeding	33,0
	Euphorbiaceae	*Sapium* sp Jacq	Milktrees	Live fences	27,0
	Boraginaceae	*Cordia rhopaloides* (H.B.K.)	Mote	Live fences	26,0
	Asteraceae	*S. pyramidalis*	Pyramidal yacon	Cut and carry, fence	23,0
	Adoxaceae	*S. nigra*	Common elderberry	Cut and carry, fence	22,0
	Adoxaceae	*Sambucus nigra* subsp. peruviana (Kunth) bolli	Elder	Cut and carry, fence	22,0

All attempts to transfer knowledge, considering local wisdom, are important to promote sustainable animal husbandry, especially considering that the productivity of the system is influenced by climate variability (Escobar-Pachajoa *et al*., 2019, Quiñones-Chillambo *et al*., 2020). Encouraging the use of ligneous forage species, adapted to the edaphoclimatic conditions of the region, such as those mentioned above, constitutes an appropriate nutritional strategy in animal husbandry systems to cope with forage seasonality and increase milk production and quality (Guatusmal-Gelpud *et al*., 2020). It is also an alternative for mitigation and adaptation of high mountain animal husbandry systems to climate change (Bacca-Acosta *et al*., 2022).

Regarding this research, Navia *et al*. (2017) observed that the tree species *S. nigra*, *Acacia mangium* Willd., *Salix humboldtiana* Willd. and *A. acuminata* are used as live fences and occasionally for animal feeding. Obtaining timber is what motivates the use of these tree species in high mountain cattle ranches (Muñoz *et al*., 2014). From them, posts are obtained to renew fences and they constitute an alternative economic source when firewood is marketed. Therefore, it is also necessary to promote research on non-timber forest products, as well as payments for environmental services (PES).

Silvopastoral showcase. SPS integrate perennial ligneous plants, mainly with forage potential, with pastures, in different types of arrangements with animals (Montagnini, 2015). They are considered

a sustainable option with high forage and nutrient availability (Sotelo-Cabrera *et al*., 2017). Similarly, different forage species can be used in these systems, which can be part of the various silvopastoral arrangements (live fences, alley pastures, protein bank, among others). These species have been shown to have higher nutritional values than grasses, which are the ones commonly used in animal husbandry systems (Buitrago-Guillen *et al*., 2018).

Based on the previously described information, the following silvopastoral arrangements were established in order to provide field experiences, generate knowledge exchange and promote the adoption of these sustainable systems for the area.

Fodder banks. Several forage banks were established using native forage species (*S. nigra*, *S. nigra* subsp *peruviana* (Kunth) bolli, *Physalis peruviana* L., *S. pyramidalis* and *Tithonia diversifolia* (Hemsl.) A Gray).

The following management issues are detailed for each of the established species: 1) planting frame of *T. diversifolia*, *S. nigra*, *S. peruviana* (1 x 1 m) and *S. pyramidalis* (3 x 3 m); cutting age of *T. diversifolia* (80 days), *S. nigra* (90 days), *S. peruviana* (1 x 1 m) and *S. pyramidalis* (3 x 3 m). *S. nigra* (90 days), *S. peruviana* (75 days) and *S. pyramidalis* (70 days); 3) annual yield (dry matter) of *T. diversifolia* (35,5 t/ha), *S. nigra* (14,4 t/ha), *S. peruviana* (0,56 t/ha) and *S. pyramidalis* (0,76 t/ha). The purpose of this arrangement was to diversify the forage supply of the cattle herd (fig. 2A).

Double stratum live fence. The species *A. acuminata*, *T. diversifolia*, *S. nigra*, *S. peruviana* were established with a separation of 1 m between rows and 1 m between furrows. The purpose of this arrangement was to minimize environmental temperature variation, due to the impact of winds, which can have a negative effect on pastures and animals (fig. 2B).

Pasture in alleys. Two areas of 2 800 m^2 each were established. Of these areas, each was divided into 13 strips, 12 m wide x 20 m long, delimited by two lines of shrub species (*T. diversifolia* and *S. nigra*), planted at a distance of 1 x 1 m between plants. The establishment time of these species was 210 days. In addition to the strips delimited by the lines of *T. diversifolia* and *S. nigra*, tree tomato was planted at a distance of 3 x 3 m between plants in the central area between these two lines. To mark the area destined for browsing, three lines of tree species were established. These tree species are *A. acuminata*, *Morella pubescens* (Humb. & Bonpl. ex Willd.) Wilbur. and *Andesanthus lepidotus* (Humb. & Bonpl.) P.J.F.Guim. & Michelang. with a 3 x 3 m

Figure 2. Silvopastoral arrangements - A) fodder banks - B) double-layer live fence - C) pasture in alleys - D) multi-layer live fence for protection of water sources.

planting frame. The browsing height was established at 1,20 m. The purpose of this arrangement was to improve the forage supply and allow browsing on the established species (fig. 2C).

Multistratum living fence for the protection of water sources. Different tree and shrub strata were established according to the growth habit of the plants. In the tree stratum, several species were used, including *A. acuminata*, *Salix babylonica* L, *Quercus humboldtii* Bonpl. and *Cedrela*. These species were planted at a distance of 20 to 40 m between plants. In the shrub layer, several species were used, such as *Sambucus nigra*, *Tibouchina lepidota* Bonpl, *Smallanthus pyramidalis* and *Oreopanax floribundum* Kunth. These species were planted at a distance of 1,5 and 2,5 m between plants. The purpose of this arrangement was to protect, regulate and improve the flow of water sources, as well as to improve the edaphic conditions of the system and provide a suitable microclimate for the development of forage species and shaded grazing (fig. 2D).

Contour strips. *A. acuminata* species were established for the tree layer, *T. diversifolia*, *S. nigra* as forage shrubs and *C. clandestinus* as grassland, implemented in contour according to the contour lines of the terrain and interspersed between them. The distance between plants was 5 x 5 m for *A. acuminata*, and 1,5 x 1,5 m for *T. diversifolia* and *S nigra*. The purpose of this arrangement was to diversify the forage supply and improve the biological, physical and chemical properties of the soil.

Perimeter hedges. The species *S. nigra*, *T. diversifolia* and *A. acuminata* were established in an intercalated linear distribution. The distance between the tree species was 10 x 10 m and for the forage shrubs of low stratum it was 1,5 x 1,5 m. The purpose of this arrangement was to delimit the plots with a live fence, improve the availability and diversity of forage and conserve the soil.

Technology transfer. The results of the activity of technology transfer field days are relevant because of the type of participatory processes they involve, as they allow improving learning styles (Rodriguez-Espinosa *et al*., 2017). In a general sense, traditional technology transfer models are associated with educational institutions, decentralized or private organizations, where field days are basically established. In these a farmer assimilates implemented technologies, and then he/she does not have the clarity of how to establish or implement them in their farms.

A strategy was established to encourage the adoption of technologies with two-way transfer methodologies, by showing real indicators of production costs and the most appropriate adoption system, according to the conditions of each farm.

Thus, the establishment of representative SPS modules led to the training of 1 970 beneficiaries between 2017 and 2022, with the use of methodologies for the dissemination of information: field days, training days at universities and educational institutions, technical tours, among others. Among those trained, 40% were farmers, 50 % technical assistants, 9 % university students, 0,5 % government officials and 0,5 % extension workers (fig. 3).

With regards to the low participation of extension workers in the project "Improvement of forage supply, optimization of feeding systems and assurance of milk quality and safety in the high tropics of the Nariño department", it is important to note that the project focused on two levels of participation: a direct level, composed of cattle ranchers and technical assistants, and an indirect one, where the participants were supposed to be animal husbandry extension workers. According to the perceptions obtained in the various technology transfer workshops, it was found that animal hsbandry extensionism in this department is a component that is little worked on by the different actors in the dairy chain, which contributed to their low participation in the various training workshops.

As has been shown, SPS are considered an option for the restoration of degraded high mountain landscapes (Bacca-Acosta *et al*., 2022). However, the adoption of this type of technology has been minimal, due to the lack of spaces for technology transfer and linkage, where the different actors associated with the dairy value chain can prove the advantages of this system. The lack of knowledge in the use and exploitation of the agricultural unit is also added (Navia *et al*., 2017).

Conclusion

The implementation of various silvopastoral designs contributed to the transfer of technologies and the exchange of knowledge, which encourages the adoption of these systems in high mountain animal husbandry farms of small and medium farmers in the Nariño department.

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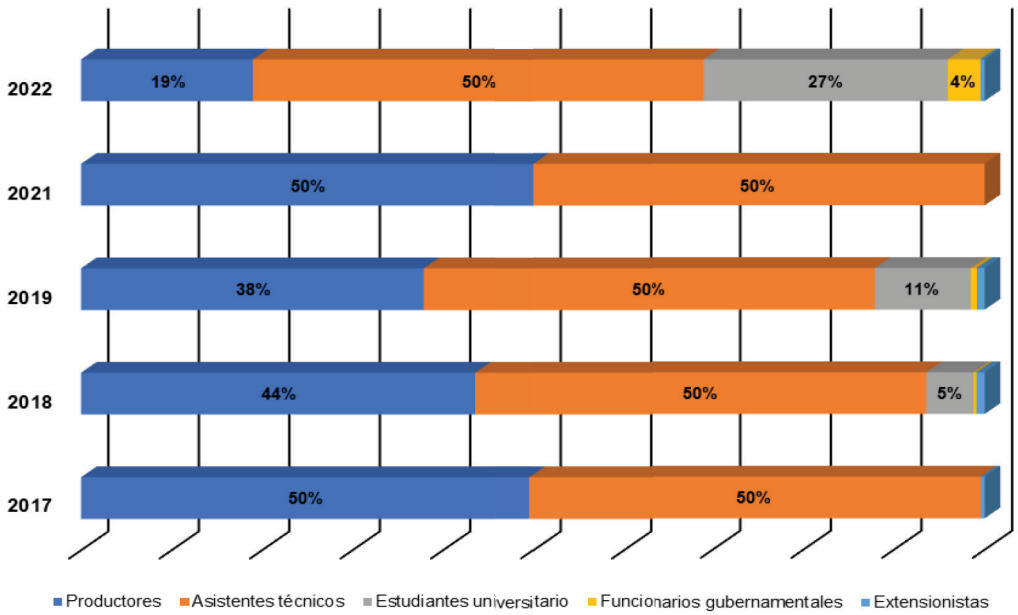

Figure 3. Capacity building in SPS for high mountain animal husbandry..

optimization of feeding systems and assurance of milk quality and safety in the high tropics of the Nariño department", executed with resources from the General System of Royalties (SGR, for its initials in Spanish).

Conflict of interests

The authors declare that there is no conflict of interest among them.

Authors' contribution

- Jose Libardo Lerma-Lasso. Execution of the research, writing of the original draft and data analysis.
- Pedro Pablo Bacca-Acosta. Execution of the research, writing of the original draft and data analysis.
- Bayron Giovanny Obando-Enríquez. Execution of the research, writing of the original draft and data analysis.
- Edwin Castro-Rincón. Methodology design, manuscript writing, revising and editing.
- Juan Leonardo Cardona-Iglesias. Design of the methodology, manuscript writing, revision and editing.

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