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Review article

Sistema silvopastoril de cosecha y acarreo como alternativa para la producción ovina sostenible en el trópico húmedo

Harvest and haulage silvopastoral system as an option for sustainable sheep production in the humid tropic

Erika Belem Castillo Linares[1*], María Aurelia López Herrera[2], Alejandra Vélez Izquierdo[3] y Jorge Oliva Hernández[1]

Resumen

En la región del trópico húmedo de México son abundantes las unidades de producción de ovinos a baja escala, en las que es factible incrementar la incorporación de árboles multipropósito con el fin de dar sostenibilidad al sistema de producción. El objetivo de este trabajo consistió en describir el sistema de producción silvopastoril en la modalidad de "cosecha y acarreo de follaje" en el trópico húmedo. Se hizo una comparación de la calidad química y el rendimiento productivo del follaje de algunas leguminosas arbóreas y gramíneas rastreras. Se indican valores sobre la eficiencia de la cosecha manual de follaje y sobre el rendimiento de follaje árbol^{-1}, así como los factores que afectan el rendimiento. También se destacaron algunos metabolitos secundarios que pueden estar presentes en el follaje de los árboles y sus posibles beneficios o perjuicios en la salud y el estado productivo de los ovinos. Además, se revisaron resultados sobre la influencia del consumo de follaje de árboles en diferentes etapas productivas del ovino. Finalmente, se identifican algunos aspectos que se deben de estudiar y cuyos resultados servirán para dar soporte a la sostenibilidad del sistema de producción silvopastoril en la modalidad de "cosecha y acarreo de follaje".

Palabras clave: Alimento, árbol, cerco vivo, follaje, ovinos, trópico húmedo.

Abstract

In the humid tropical region of Mexico, small-scale sheep production flocks are abundant, in which it is feasible to increase the incorporation of multipurpose trees to give sustainability to the production system. The aim of this review work was to describe the silvopastoral production system in "harvest and foliage haulage" modality in the humid tropic. It includes a comparison of the chemical quality and productive performance of foliage of some tree legume and some creeping-type grasses. Are indicated values on manual harvesting efficiency of foliage and tree^{-1} foliage yield, and factors that can affect performance. Are identified the secondary metabolites that may be present in tree foliage and their potential benefits or harms to the health and productive status of sheep. In addition, are reviewed some results on the influence of tree foliage consumption at different production stages of sheep. Finally, are mentioned aspects to be studied, results of which will support the sustainability of the silvopastoral production system "harvest and foliage haulage".

Key words: Food, tree, live fence, foliage, sheep, humid tropic.

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[1]Instituto Nacional de Investigaciones Forestales, Agrícolas y Pecuarias, CIR Golfo Centro, Campo Experimental Huimanguillo. México.
[2]Instituto Nacional de Investigaciones Forestales, Agrícolas y Pecuarias, CIR Sureste, Campo Experimental Mocochá. México.
[3]Instituto Nacional de Investigaciones Forestales, Agrícolas y Pecuarias, Cenid Fisiología. México.
[*]Autor para correspondencia; correo-e: castillo.erika@inifap.gob.mx

Introduction

In the humid tropic region of Mexico, ruminant farming through pastoral-type production systems (PS) contributes to food security by producing meat and milk. These systems mainly use pastures as monoculture, which favors soil degradation. Therefore, it is necessary and important to incorporate trees into the PS in order to give it sustainability and mitigate the environmental damage caused by pastoral PS (Parra-Cortés *et al.,* 2019).

In the state of *Tabasco* there are some cattle ranchers that use trees as part of the living fence and to a lesser extent, also dispersed in the pastures (Grande *et al.,* 2013*;* Maldonado *et al.,* 2013). In the pastoral PS with sheep, the trees are part of the fence and provide shade for the animals (Oliva *et al.*, 2014, 2019).

There are tree species that, in addition to shade, provide foliage as a source of structural carbohydrates and crude protein (CP), which improves the PS sustainability because the natural resources present in the production unit can represent the main food input support (Ayala *et al.,* 2006).

Sheep production in the pastoral PS in the humid tropics of Mexico is limited by the variability in the quantity and nutritional quality of the pastures (Enríquez *et al.,* 2011). To this should be added that the voluntary consumption of pastures does not allow animals to meet their nutrient requirements to express their productive potential. A silvopastoral type PS can optimize the handling and feeding of sheep. However, it is necessary for producers to value the potential benefits that trees bring to the PS and to be willing to invest capital and labor for their management.

Silvopastoral PS promotes the conservation of soils and the environment. Trees offer direct advantages to grazing animals, by generating refuge areas, protection against direct solar radiation and rain, and the foliage of some arboreal legumes such as *Leucaena leucocephala* (Lam.) de Wit, who represents an alternative to supplement their diet (Villanueva-Partida *et al.,* 2019).

Foliage harvest can be accomplished through the following variants of the silvopastoral PS: harvesting and carrying of the foliage and browsing of the trees

(Candelaria-Martínez *et al.,* 2017; Oliva *et al.,* 2019). In any of the variants of the silvopastoral PS there is limited information on its productive, economic, environmental and sustainability indicators; therefore, this work aims to describe silvopastoral PS for sheep production in the "harvest and foliage haulage" modality of trees in the humid tropics.

Silvopastoral PS for sheep production

The presence of trees can coexist in the grazing ruminants area, which gives rise to a great diversity of variants of the silvopastoral PS, among which the trees stand out as a windbreak curtain, as a living fence, scattered in the grasslands, protein banks, and forming alleys in grazing areas. In some cases, PS can have as its primary product the production of wood and fruit, and raise animals as a secondary product when using the plantation areas for grazing (Maldonado *et al.,* 2013). When the primary product of the PS is sheep, the variants of the silvopastoral PS that may have the greatest opportunity to be implemented are the harvesting and hauling of tree foliage and browsing trees in alleys (Candelaria-Martínez *et al*., 2017; Oliva *et al.,* 2019; Villanueva-Partida *et al*., 2019;). The small size and low weight of hair breed sheep, compared to a bovine, are advantages for them to be integrated into a silvopastoral PS, because their trampling during grazing causes less soil compaction and it is easier to supplement their dry matter (DM) requirements with tree foliage (Daniel and Couto, 1999; Hernández-Espinoza *et al.,* 2020a; Hernández-Espinoza *et al.,* 2020b).

Grazing requires fences to control grazing areas, in the absence of the shepherd as a component of the PS. The fence can be made with different materials, among which stand out the arboreal individuals of forage species that function as "live posts" in combination with barbed wire or energized threads, which together constitute the living fence, which represents a better economic option, regarding dead wood and concrete posts (Torres *et al.,* 2008).

Use of tree foliage as a food supplement

The foliage of some trees in the living fence can be used as a food supplement for sheep during the productive stages with high nutrient demand, such as the last third of gestation and lactation in breeding ewe, and the beginning of the post-weaning phase (Oliva *et al*., 2014). The foliage of forage trees can also serve as a food supplement for grazing sheep in circumstances of low biomass availability in the pasture; the former situation occurs more frequently in the dry and hurricane seasons that occur in *Tabasco*. During drought, due to a lower production of DM ha^{-1} and greater lignification of the pastures. During the hurricanes, sheep cannot access the pastures for two reasons: soaked or flooded meadows and due to a feeding behavior typical of sheep that avoid grazing when the rain is intense and continuous (Oliva *et al.,* 2013).

The chemical composition of the foliage allows us to suggest including it in the sheep's diet, as a protein ingredient and contributor of structural carbohydrates (Ayala *et al.,* 2006; Grande, 2010; Hernández-Espinoza *et al.,* 2020a; Hernández-Espinoza *et al.,* 2020b). However, it must have high palatability and a minimum presence of toxic substances for animals (Rochfort *et al.,* 2008; Pagare *et al.,* 2015).

Types of grasses and trees in a silvopastoral PS with sheep

The grasses that are associated with silvopastoral management in *Tabasco* must undergo grazing control, in order to offer a pasture with greater digestibility. However, there are some grasses that are not easily consumed by sheep, such as *Paspalum fasciculatum* Willd. ex Flüggé, *Paspalum plicatulum* Michx. and *Paspalum virgatum* L.; others, such as *Brachiaria eminii* (Mez) Robyns, damage the health status of sheep and are lethal for young lambs, so they should be prevented from being part of the PS (Enríquez *et al*., 2011). The trees suitable for use in the living fence of a silvopastoral PS must produce foliage with forage characteristics, that is, it should be easily consumed by sheep in their different productive stages (Table 1).

Table 1. Chemical composition and production of DM (t) hectare^{-1} year^{-1} of some grasses and tree foliage used in the fences for the management of grazing sheep.

Type of species	**Chemical composition**				**Performance**	**Source**
	ME (Mcal kg DM^{-1})	**CP (%)**	**NDF (%)**	**ADF (%)**	**t MS hectare^{1} year^{-1}**	
Creeping grass						
Cynodon plectostachyus Plig.	1.90	8.0	81.4	--.-	10.8	1, 2
Cutting grass						
Cenchrus purpureus (Schumach.) Morrone	2.1	10.2	60	40.3	66.9	3, 4
Arboreal Legume						
Erythrina americana Mill.	1.6	17.3	52.9	37.2	16.4	1, 5, 6
Gliricidia sepium (Jacq.) Walp.	2.3	19.7	44.2	30.2	19.0	1, 6
Non-Legume shrub						
Guazuma ulmifolia Lam.	2.2	10.6	55.9	38.2	25.3	1, 6
Morus alba L.	2.7	18.4	48.5	23.1	22.4	1, 6, 7

Source: Based on the data from 1) Ayala *et al*. (2006); 2) Enríquez *et al*. (2011); 3) Cerdas y Vallejos (2010); 4) Hinojosa *et al*. (2014); 5) Hernández-Espinoza *et al*. (2020b); 6) Meléndez (2003); 7) Pino-Moreno *et al*. (2014). ME = Metabolizable energy; DM = Dry matter; CP = crude protein; NDF= Neutral detergent fiber; ADF= Acid detergent fiber.

Differences in the nutrient content and yield of tree foliage, with respect to grasses

The leaves of some trees have a higher CP content; lower content of structural carbohydrates and a DM yield ha^{-1} year^{-1}, similar or higher than that of creeping grasses. However, the DM ha^{-1} year^{-1} yield of cut grasses far exceeds that of creeping grasses and tree foliage. In addition, the foliage yield of the trees (DM ha^{-1} year^{-1}) may be higher than that of some creeping grasses, a circumstance that favors their adoption in pastoral PS (Table 1).

Differences in nutrient content between tree foliage and commercial sheep feed

Commercial sheep feed has a variable CP content (12 to 19 %) and can be similar to that of tree foliage (Table 1). Regarding the content of ME (Mcal kg of DM), it is expected that this will be higher than that of the tree foliage because cereal grain is used in its preparation. Some advantages of commercial feed are the acceptance of its consumption by sheep, ease of storage and handling. Among the disadvantages, they incur higher production costs in the food sector when purchasing it and the short shelf life (less than two months). Regarding the foliage of trees, sheep consume it easily, both green and dry; and it can be available all year round. Once dry, the foliage can be stored for no more than a month, when there is high humidity (Hernández-Espinoza *et al*., 2020b).

On the other hand, other nutritional components (for example, ammonium chloride) and ionophores (for example, lasolacid sodium) are added to commercial food, which are not found in tree foliage. However, the disadvantages of tree foliage in relation to this aspect can be reduced by using foliage with high acceptance by sheep (*Morus alba* L., *Gliricidia sepium* (Jacq.) Walp., *Erythrina americana* Mill.), with high value protein and low content of neutral detergent fiber (Benavides, 1999; Ku *et al*., 1999; Hernández-Espinoza *et al*., 2020a; Hernández-Espinoza *et al*., 2020b). The aforementioned can be optimized with a control in the regrowth age (90 days), in order to obtain a foliage with a higher protein value and DM degradability, with respect to a foliage of trees with a regrowth age greater than the 90 days or without control in the regrowth age (Hernández-Espinoza *et al*., 2020a; Hernández-Espinoza *et al*., 2020b).

An additional option consists of supplying sheep with the difference in metabolizable energy between commercial feed and tree foliage, for which an ingredient with a high starch content is used, for example, *Musa paradisiaca* L. (Benavides, 1999). Choosing tree species with high acceptance by sheep, having control of the regrowth age of tree foliage and providing sheep with an energy supplement represent alternatives that can promote a greater and better use of forage trees.

Foliage consumption and productive efficiency of sheep

The use and level of inclusion of tree legume foliage in the diet of sheep in a silvopastoral PS is subject to the number and physical characteristics of the trees in the living fence, as well as the number and productive stages of the sheep in the unit of production. In the growth stage it has been suggested that the inclusion of *G. sepium* and *Erythrina variegata* L. should not be higher than 30 % of the diet, because at that level the digestibility of the diet and voluntary consumption are not affected (Ku *et al.,* 1999; Best *et al*., 2017). However, other studies indicate that the foliage of *E. poeppigiana* (Walp.) O. F. Cook can be used as the sole food source in growing sheep and that of *E. americana* in adult sheep without gestation and lactation, thus a positive weight gain is registered, which can be increased if energy ingredients with regional availability are added to the diet, such as *M. paradisiaca* and *Dioscorea* spp., and energy ingredients of conventional use in the industry that produces animal feed from farm, for example, *Sorghum bicolor* (L.) Moench grain (Benavides, 1999; Hernández-Espinosa *et al.,* 2020b).

In growing lambs fed with *E. poeppigiana*, energy supplementation with *M. paradisiaca* (1.1 % of live weight) allowed an increase in daily weight gain by 51 % compared to the control group, 112 g *vs* 74 g, respectively. However, economic studies are required to know the cost-benefit relationship of supplementation with *M. paradisiaca* (Benavides, 1999). In contrast, Grande (2010) describes a negative weight change in growing sheep when they fed on *Cenchrus purpureus* (Schumach.) Morrone grass and *Erythrina* spp. foliage. Probably, both the grass and the arboreal legume used in the study had a high variation in nutritional quality and regrowth age, which had a negative impact on the productive response of the animals.

Lactation is the stage in which the sheep has the highest consumption of DM on day^{-1}. Studies have been carried out with foliage of *Leucaena leucocephala* (Lam.) de Wit and *G. sepium* as a food supplement (Yzaguirre and Combellas, 2002; Pérez *et al*., 2017), from which it was concluded that both foliages can be used as part of the diet, because the productive efficiency of the ewe and its litter is not affected with respect to a control diet. *L. leucocephala* was included in up to 35 % of the diet; while *G. sepium* was supplied in two forms: dry and milled *ad libitum* plus *Cynodon nlemfuensis* Vanderyst hay; and green (3 kg animal^{-1} day^{-1}) plus *C. nlemfuensis* hay.

In works carried out in *Yucatán,* México, with reproductive rams that were supplemented in their diet with *Hibiscus rosa-sinensis* L., *Moringa oleifera* Lam. and *Trichanthera gigantea* (Bonpl.) Nees, seminal quality measured through concentration, volume, acrosome integrity and mitochondrial activity of sperm is not affected. However, the type of motility and viability of the sperm membranes are influenced by the type of foliage used (Maza *et al*., 2015; Ramírez-Bautista *et al*., 2020). Further research is required in the humid tropical region of Mexico to know the influence of the foliage of arboreal legumes, supplied continuously, on the fertility in a group of sheep. Studies are also necessary on the pre-weaning and pregnancy growth stages to establish the percentage of inclusion in the diet that allows obtaining a productive efficiency similar or superior to a conventional diet.

Presence of secondary metabolites in tree foliage

Plants produce secondary metabolites that favor their adaptation and survival. Although they differ qualitatively and quantitatively between plants, their presence represents a defense mechanism to protect themselves from herbivorous organisms (Pagare *et al*., 2015). Therefore, it is important to know the type and concentration of secondary metabolites in alternative foliage with potential use in feeding small ruminants.

Some secondary metabolites present in the foliage of tree legumes can be seen in Table 2. Their type and concentration depends on the tree species, age of regrowth of the plant and environmental conditions (Grande, 2010; Pérez, 2019; Hernández-Espinosa *et al.,* 2020a). Therefore, the potential benefits or harm of consuming foliage with this type of metabolites may be limited by the variation in their quality and quantity (Hernández-Espinosa *et al.,* 2020b).

Table 2. Presence of some secondary compounds in *Gliricidia sepium* (Jacq.) Walp. and *Erythrina* spp.* foliage.

Arboreal legume	Type of secondary metabolites						Source
	Alkaloids	Steroids	Flavonoids	Saponins	Tannins	Cyanogenic glycosides	
Erythrina spp.*	+	ND	ND	--	++	--	1
Gliricidia sepium	+	ND	ND	++	++	--	1
Gliricidia sepium, regrowth age 90 days	++	++	+++	--	+	ND	2

Source: based on the data from 1) Grande (2010); 2) Pérez (2019).

*Results of three species; ND = Not determined; +++ = High presence; ++ = Notable; + = Light; -- = Absence.

The consumption of plants with a high concentration of secondary metabolites affects the palatability of the foliage and the population of ruminal microorganisms, and reduces voluntary foraging, the digestibility of DM and protein (Rochfort *et al*. 2008). But it can be favorable, as is the case with condensed tannins, since they have nematicidal properties and the ability to bind to proteins, thereby protecting them from ruminal degradation, and leaving amino acids available in the intestine (Naumann *et al*., 2017).

The condensed tannins in foliage of tree legumes have a negative impact on the microorganisms that live in the rumen, particularly the methanogenic ones, and reduce the production of CH_4. This gas is continuously eliminated through the ruminant's eructation, so its reduction represents an advantage since it is considered one of the gases with greenhouse effect (Piñeiro-Vázquez *et al.,* 2015). However, given the variation in the content of condensed tannins in the foliage of tree legumes, according to the species, regrowth age and climatic conditions (Pérez, 2019; Hernández-Espinosa *et al*., 2020a), the impact of its consumption on the emission of CH_4 when it is used in the diet of sheep continuously and with different inclusion level is unknown, as could occur in a silvopastoral PS with “harvest and foliage haulage”.

PS silvopastoral modality "harvest and foliage haulage" as a food generator for sheep production

The “harvest and foliage haulage” modality consists on implementing the use of trees in the living fence of the PS, in order to harvest the foliage to be offered to the sheep (Hernández-Espinoza *et al.,* 2020b). The manual harvesting of tree foliage can be done in two ways: harvesting and hauling the foliage to offer in the manger, and cutting the branches with foliage and offering it to the sheep in the meadow. It should be noted that manual foliage harvesting, present in this variant of the PS, involves a cost of labor (García and Oliva, 2012). In addition, it must be considered that mechanical harvesting is not possible because there is no machinery for this purpose. However, the use of arboreal foliage can give sustainability to the ovine PS.

A favorable scenario for this PS modality implies using a high density of trees for every 100 linear m of living fence (1 m distance between trees), in order to have foliage most of the year and promote shade for the animals. However, to avoid limiting the growth of grasses and stimulate that of shade plants around the trees (vines), it is convenient to apply controlled and staggered pruning (Meléndez, 2003; Oliva *et al*., 2014). It is also necessary to consider that the yield and harvest efficiency are influenced by the diameter of the tree, the height and distance between the trees, the time of year, the age of the regrowth and the harvesting technician (Meléndez, 2003; Ramos-Trejo *et al*., 2016; Oliva and López, 2017; Oliva *et al*., 2019).

Investment in the silvopastoral PS "harvest and foliage haulage" is expected to pay off in the long term. Due to the perennial component (s), it is estimated to have a horizon of at least 10 years. Under a controlled and staggered pruning scheme, *G. sepium* and *E. americana* trees produce foliage all year round. However, it should be considered that they are deciduous species, and when they are not exposed to continuous pruning at controlled intervals throughout the year, the highest foliage production is recorded in the rains and the lowest during the drought (Meléndez, 2003). The controlled pruning of trees with foliage hauling, although it is a tough activity, can be easily implemented in herds located in the tropical region that have less than 30 sheep, where the producer carries out the task, since, if not thus the costs in the PS are increased. Also, this system can be used with herds that require a food supplement produced on the same farm in order to cover part of the DM and CP requirements of animals that are in stables for short periods, for example, recently lambing ewes, sick animals and stabled lactating lambs (García and Oliva, 2012; Hernández-Espinoza *et al.,* 2020a; Hernández-Espinoza *et al*., 2020b).

Management of the forestry component

In the "foliage harvest and haulage", the amount of foliage that will be provided to each group of animals can be accurately determined. However, it is necessary to establish a program of controlled and staggered pruning in advance, as well as enough trees to have foliage available all year round. A 90- day interval between pruning allows to achieve a balance between foliage yield, its nutritional quality and its ease of harvest (Meléndez, 2003; García and Oliva, 2012; Oliva and López, 2017).

The convenience of establishing shade-tolerant grasses (for example, *Panicum maximum* CV. Likoni) should be evaluated in those areas that need planting, since the type of selected grass should be easily consumed and without damaging the health of sheep (Pentón, 2000).

G. sepium and *E. americana* are examples of tree legumes suitable for use in fences as providers of foliage in a silvopastoral PS. In *E. americana* trees without a history of pruning (with an average age of seven years), it is possible to harvest 7.6 kg of fresh foliage per hour and in *G. sepium* without a history of pruning as well (with an average age of nine years), 6.9 kg . It is important to indicate that the efficiency in the manual harvest of foliage of *E. americana* increases between 14 and 36 % when the trees are pruned at intervals of 90 days. The production kg foliage tree^{-1}, the harvesting efficiency (DM kg hour^{-1}), the cost of the day (MX $ hour^{-1}) and the content of CP in foliage are elements that contribute to determine the value of foliage CP kilogram and its opportunity to add it as food supplement (García and Oliva, 2012; Oliva and López, 2017; Oliva *et al.,* 2019).

The tree^{-1} foliage yield is related to the diameter of the tree and the time of year. In *E. americana*, with a regrowth age of 90 days and a diameter at the breast height (DBH) of 0.08 m, 0.308 kg of DM tree^{-1} are produced (Oliva and López, 2017), a foliage amount that exceeds 15 % of the DM requirements of three ewes (non-pregnant and non-lactating offspring) with 30 kg of live weight (LW), which means having 90 trees (planted at 1 m distance) to continuously supplement 15 % of the DM that these sheep potentially consume.

Efficiency in the manual harvest of *E. americana* in one hour and with trees without a history of pruning is 1.7 kg of dry foliage; this quantity can cover 15 % of the DM needs of at least 15 sheep with 30 kg of live weight. In the previous scenario and from a foliage harvest efficiency of 1.7 kg DM h^{-1} and 0.308 kg of dry foliage tree^{-1}, it results 5.5 trees day^{-1}, that is, 495 trees are necessary to complement 15 % of DM potentially consumed by 15 sheep.

Another aspect that must be considered is that foliage management during pruning and harvesting practices implies risky situations for the producer, due to the presence of insects in the trees. For example, *Polybia occidentalis* Olivier, 1791 wasp combs are common in *G. sepium* and *E. americana*. In *E. americana*, in addition, you can find combs of the wasp *Polistes instabilis* Saussure, 1853 and the native bee *Trigona corvina* Cockerell, 1913. The latter is characterized by the absence of a stinger, so it does not represent any problem for the integrity of the harvester, but it causes annoyance when harvesting the leaves due to the fact that it flies in groups around the producer's head. In addition, both *G. sepium* and *E. americana* inhabit caterpillars with branching hairs (*Automeris* i*llustris* Walker, 1855) that manage to go unnoticed when they blend in with the leaves of the trees. Accidental skin contact with the villi of the caterpillar causes itching and shooting pain on the skin, so it is important to check the branches to be harvested beforehand and try to wear leather gloves.

Carbon sequestration in silvopastoral PS

Silvopastoral PS help mitigate climate change by removing carbon from the atmosphere through trees and retaining it for a long time, mainly in wood. In the modality "harvest and foliage haulage" at 90 -day intervals there would be four harvests of branches per year; however, it is necessary to study its efficiency to capture carbon, as it is an environmental service that could be remunerated. However, it must be regulated and measured (Andrade and Ibrahim, 2003).

The management of the trees under this modality does not allow to produce wood for firewood due to the young age of the branches that are not suitable for that purpose. However, it is feasible to leave some trees without pruning and encourage the development of branches for wood and vegetative material (rods).

Aspects to be studied in the "harvest and haulage" modality

The silvopastoral PS have been attributed productive, social, economic and environmental advantages. However, the benefits and their impact must be measurable in order to support the sustainability of the PS.

In family-type production units with a reduced sheep inventory, in which it is convenient to use the "harvest and foliage haulage" modality, it is necessary to generate sustainability indicators in the silvopastoral PS, as well as to determine the measurement methodology, the baseline and the status in the silvopastoral PS.

In regard to soil, it is necessary to know the changes in its compaction and chemical composition over time, as well as its ability to restore degraded soil areas, if any. In relation to trees, their useful life should be assessed when they are subjected to a controlled pruning program, and their response to organic fertilization with manure from the same production unit. Regarding animals, the quantity and quality of meat products produced per breeding female, herd and hectare under silvopastoral PS and their contribution to reducing CH_4 emissions must be specified. In the economic aspect, it is important to define the economic performance of the silvopastoral PS sheep in general, and the cost structure in particular, as well as the cost of establishing and maintaining and / or sustaining the PS. In the environmental topic, it is necessary to determine the number of trees per ha^{-1} and the carbon sequestration capacity. Finally, it is necessary to know the social aspect, such as the degree of conviction and perception that the producer has of his PS regarding the reproduction of living conditions through the use of family labor, the development of capacities in the handling of sheep in the silvopastoral PS, the contribution of a meat product with a possible differential quality and a PS with less polluting capacity.

Conclusions

The silvopastoral production system in the "harvest and foliage haulage" modality represents a possible option to give sustainability to sheep production in small-scale production units. The foliage harvest of arboreal legumes at 90-day intervals allows to have a food supplement with a higher value in CP, in regard to that of a grass, throughout the year. However, the cost of the harvest (not yet specified) and its management to offer it in manger can limit this modality, so it is convenient to adopt it in production units with family labor to avoid costs in wages. The presence of secondary metabolites in the foliage does not affect the productive efficiency of sheep when it is offered as a food supplement. However, its long-term benefits need to be studied when used continuously. There are still no sustainability indicators for the “harvest and foliage haulage” modality in small-scale production units, so they will have to be generated, in order to increase their participation in the productive environment and base a possible economic gratification on the part from government authorities to production units that generate environmental benefits, measured through a reduction in CH_4 emissions and an increase in carbon sequestration.

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Conflict of interests

The authors declare no conflict of interests.

Contribution by author

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