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Original article

Environmental services of three silvopastoral systems introduced in the province of Cotopaxi, Ecuador

Servicios ambientales de tres sistemas silvopastoriles introducidos en la provincia de Cotopaxi, Ecuador

Serviços ambientais de três sistemas silvopastoris introduzidos na província de Cotopaxi, Equador

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ABSTRACT

The introduction of silvopastoral systems, due to the environmental services they provide, constitute a viable and adaptable alternative in countries of tropical and subtropical regions of Latin America. The main of the research was to evaluate the influence of silvopastoral systems in the generation of ecosystem and productive services in the experimental and production center of Salache, Latacunga Canton, Cotopaxi province. Three silvopastoral systems with tree and forage species were selected and introduced. The edaphic indicators related to soil fertility, the dry matter content of the grass within the inclusion and the generation of other environmental services of the trees were determined. Descriptive statistical analyzes were applied such as the comparison of silvopastoral systems through ANOVA and Kruskal-Wallis. It was concluded that the introduction of the tree component in silvopastoral systems influences the content of calcium, organic matter and soluble phosphorus. The species that contributes the most to the increase in nutrients in the soil is the *Inga edulis* Mart. followed by *Alnus glutinosa* (L.) Gaertn. Silvopastoral systems proved to be an effective agroecological practice for the accumulation of dry matter, at higher levels than herbaceous species, especially when the Silvopastoral systems was introduced with *Acacia dealbata* Link and *Inga edulis* Mart. These two tree species are the ones that contribute the most to biomass and carbon in the edaphoclimatic conditions of the study area.

Keywords: Tree species; Edaphic properties; Dry materials; Production.

RESUMEN

La introducción de sistemas silvopastoriles, por los servicios ambientales que brinda constituyen una alternativa viable y adaptable en países de regiones tropicales y subtropicales de América Latina. El objetivo de la investigación fue evaluar la influencia de los sistemas silvopastoriles en la generación de servicios ecosistémicos y productivos en el centro experimental y de producción de Salache, Cantón de Latacunga, provincia de Cotopaxi. Se seleccionaron e introdujeron tres sistemas silvopastoriles con especies de arbóreas y forrajeras. Se determinaron los indicadores edáficos relacionados con la fertilidad del suelo, el contenido de materia seca del pasto dentro de la inclusión y la generación de otros servicios ambientales de los árboles. Se aplicaron análisis estadísticos descriptivos como la comparación de los sistemas silvopastoriles mediante ANOVA y Kruskal-Wallis. Se concluyó que la introducción del componente arbóreo en los sistemas silvopastoriles influye en el contenido de calcio, materia orgánica y fósforo soluble. La especie que más contribuye al aumento de los nutrientes en el suelo es el *Inga edulis* Mart. seguido del *Alnus glutinosa (L.)* Gaertn. Los sistemas silvopastoriles demostraron ser una práctica agroecológica efectiva para la acumulación de materia seca, a niveles más altos que las especies herbáceas, especialmente cuando se introdujo el sistema silvopastoril con *Acacia dealbata* Link e *Inga edulis* Mart.; éstas dos especies arbóreas son las que más contribuyen con el aporte de biomasa y el carbono en las condiciones edafoclimáticas del área de estudio.

Palabras clave: Especies arbóreas; Propiedades edáficas; Materia seca; Producción.

RESUMO

A introdução de sistemas silvopastorais, devido aos serviços ambientais que prestam, é uma alternativa viável e adaptável em países das regiões tropicais e subtropicais da América Latina. O objetivo da pesquisa era avaliar a influência dos sistemas silvopastoris na geração de ecossistemas e serviços produtivos no centro experimental e de produção de Salache, Cantão de Latacunga, província de Cotopaxi. Foram selecionados e introduzidos três sistemas silvopastoris com espécies arbóreas e forrageiras. Foram determinados indicadores edáficos relacionados à fertilidade do solo, teor de matéria seca da grama dentro da inclusão e a geração de outros serviços ambientais a partir das árvores. Análises estatísticas descritivas como a comparação de sistemas silvopastorais foram aplicadas usando ANOVA e Kruskal-Wallis. Concluiu-se que a introdução do componente arbóreo nos sistemas silvopastorais influencia o conteúdo de cálcio, matéria orgânica e fósforo solúvel. A espécie que mais contribui para o aumento dos nutrientes do solo é Inga edulis Mart. seguida por *Alnus glutinosa* (L.) Gaertn. Os sistemas silvopastoris provaram ser uma prática agroecológica eficaz para a acumulação de matéria seca em níveis mais elevados do que as espécies herbáceas, especialmente quando o sistema silvopastoris foi introduzido com Acacia dealbata Link e *Inga edulis* Mart; estas duas espécies arbóreas são as mais importantes contribuintes de biomassa e carbono sob as condições edafoclimáticas da área de estudo.

Palavras-chave: Espécies de árvores; Propriedades edáficas; Matéria seca; Produção.

INTRODUCTION

Agricultural activities in the agroecosystem have caused loss of biodiversity due to the decrease in native flora and fauna, the degradation of pastures with a strong ecological repercussion and negative environmental impacts, including the reduction of carbon extraction, erosion of soils among other environmental damage (Pezo, 2019). Trees support sustainable agriculture because, among other aspects, they stabilize soils and climate, regulate water flows, provide shade, represent habitat for pollinators and natural predators of agricultural pests (García *et al*., 2017).

One of the most used technologies in mountain agroecosystems are the silvopastoral systems (SSP); agroforestry modality that combines pastures for livestock with trees and shrubs. These systems fulfill some functions of natural forests because they have permanent vegetation with deep roots that generate ecosystem services such as improved soil properties, contribute to the conservation of biodiversity and increase carbon catch/capture (López *et al.*, 2017).

The introduction of trees in agroecosystems allows an increase in the recycling of nutrients through their root system, which explores greater depth in the soil than grasses; they recover nutrients that have been deepened by leaching processes (Navas *et al*, 2020). These systems can also store between 12 and 228 t of carbon ha^{-1} and, at the same time, their implementation reduces production costs compared to intensive grazing systems (Medina *et al*., 2020).

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MATERIALS AND METHODS

The research was carried out in agroecosystems for milk production located in the Salache Experimental and Academic Center, of the Technical University of Cotopaxi (UTC), Cotopaxi province, between coordinates 01º01'05" south latitude and 78º35'32" west longitude. This climatic zone, located between 2,000 and 3,000 meters above sea level, is defined as a Lower Montane Dry Forest. The average annual temperature is 14.1 ºC and the accumulated rainfall is 579.2 mm. The soils are loamy-sandy in texture.

During the years 2013 and 2016, four treatments were established where a control formed by the traditional grass was evaluated, a mixture of forage species such as: Alfalfa (Medicago *sativa* L.), Annual Ryegrass (Lolium *multiflorum* Lam), Perennial Ryegrass (Lolium *perenne* L.), White Clover (Trifolium *repent* L.), Red clover (Trifolium *pratense* L.); and three SSP where tree species were introduced: *Alnus glutinosa* (L.) Gaertn, *Acacia dealbata* Link. and *Inga edulis* Mart. The experiments were established in plots of approximately 1 ha each. The evaluations were completed.

Soil analysis

For the analysis of the chemical and physical-chemical parameters of the soil, a completely randomized design was used, selecting five exclusions (transects) at random, in each agroecosystem with an average area, per exclusion, of 16 m^2 (Yong *et al.*, 2008). Six exclusion samplings were carried out at a depth of 20 cm with a six-month period between 2013 and 2016. Finally, for laboratory analysis, a total of 10 composite samples of 1 kg were obtained in each system. The determinations were made according to the methods described by the INIAP, (2010).

The pH was determined by the potentiometric method with a soil water ratio of 1:2.5. The organic matter was determined by oxidation with potassium dichromate. The content of assimilable Ca, Mg, K and P was determined according to modified Olsen and the results were expressed in meq /100g of soil. Assimilable P was expressed in mg kg^{-1}. The cation exchange capacity-CEC- (expressed in Meq /100g) was obtained by adding all the exchangeable cations.

Determination of the dry matter content of the grass, under the tree canopy in the inclusion

The measurement of the dry matter content was carried out from the year 2015, two years after the experiment was established until the year 2018. The forage species were common in all the systems and were fundamentally made up of the aforementioned forage herbaceous species.

For this analysis, a paired sample of one square meter was taken in each of the 5 semi-permanent exclusions, randomly located in each SSP. The cut was made at the beginning of each grazing, the fresh cut mass was weighed to determine the yield. Subsequently, from the total sample an aliquot was extracted. It was weighed and dried in an oven at a temperature of 100ºC for 14 hours, until a constant weight was obtained, and the percentage of DM was determined. These values were expressed in t $ha^{-1}year^{-1.}$ The interval between grazing was 41.6 days.

Determination of carbon ~~sequestration~~ catch/capture by silvopastoral systems

Prior to determining carbon ~~sequestration~~ capture, plant biomass production was determined using the international guide proposed by IPCC (2003) for measuring stored carbon.

Step 1. For the determination of plant biomass, a completely randomized design was used, five random exclusions (16 m^2) were selected in each SSP. The total height of the trees and diameter at 1.30 m height were measured.

The determination of tree biomass was used through allometric formulas according to the equations proposed in Table 1.

Table. 1. - Allometric equations to estimate aboveground biomass (kg dry matter per tree)

Species	Allometric Equation	Forest Type	Font
Alder (A. *glutinosa*)	B= exp (-2.14+2.23* ln (DBH))	Tropical forests of South and Central America.	Acosta *et al.*, 2002; Chavé *et al.* (2005)
Acacia (A. *dealbata*)	BA=0.0673 x (MD x (DBH^2) x height) 0, $^{9\ 76}$	*A. megaloxylon* trees	Chavé *et al.* (2005)
Guabo (Inga *edulis*)	**Log $_{10}$ Biomass = -0.889 + 2,317 (log $_{10}$ dbh)	*I. edulis* forest	Segura *et al.*, (2006)

where: Y = aboveground dry matter, DBH: Diameter at breast height BA: Aerial biomass; DM: Wood density; db: base diameter, DM/tree, h: height.

Step 2. Calculation of tree biomass per hectare (Equation 1).

$$B\ A = (AU /1000) \times (10000/\text{plot area}) \quad (1)$$

Where:
B A = Tree biomass above ground (t DM/ha);
AU = Sum of the tree biomass of all the trees in the plot (kg DM/area of the plot);
Factor 1000 = Conversion of sample units from kg DM/t DM
Factor 10000 = Conversion of the area (m^2) to hectare

Calculation of carbon stocks in tree biomass (Equation 2).

$$ÄC\ B\ A = (BA * FC)\ (ISSP, 2003) \quad (2)$$

Where:
ÄC B A = Amount of carbon in aboveground biomass (t C/ha);
BA = Tree biomass above ground (t DM/ha);
CF = Carbon fraction (t C /t MS). The IPCC standard value for CF = 0.5.

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Determination of production and management indicators in silvopastoral systems

For the evaluation of production, indicators such as: total milk production (L), grazing days, number of grazing cows and liters produced daily per cow L v^{-1} d^{-1} were taken into account. To determine milk production for each SSP, the liters of milk produced 48 hours after the cows entered the SSP were recorded daily until 48 hours after the animals left.

Statistic analysis

Descriptive statistical analyzes were used to compare the means of each silvopastoral system. When the population followed a normal distribution, the arithmetic mean and standard deviation were used; Means were compared using the ANOVA and Tukey tests ($p < 0.05$). In the event that the data followed a distribution other than normal, the median and the interquartile range were used as descriptive statistics. The comparison of the variables was carried out using the non-parametric Kruskal-Walli's test, with multiple comparison in pairs, being more appropriate for this type of population as established by Field (2013). To corroborate the productive results, a Spearman correlation analysis was carried out between milk production and grazing days.

RESULTS AND DISCUSSION

The pH values reported in the soils in all the systems are similar, higher than 8, which is considered alkaline according to the scale proposed by the (INIAP, 2010) (Table 2)

Table 2. - Edaphic properties in non-cultivated soils

Silvopastoral systems (n=*160*)		pH (H2O)	AC	mg	K	CIC [1]	MO2	P2O5
			------------- cmol $_c$ kg $^{-1}$	------------			%	mg.kg $^{-1}$
Witness	Half	8.74a	8.35a	4, 71a	0.46b	9,10b	1.29b	12,10b
± SD		0.42	3.13	0.6	0.31	1.69	0.44	5.28
***A. dealbata* Medium**		8.7b	6.85b	3.72c	0.37c	7.81c	0.99c	13.05b
± SD		0.33	2.24	0.88	0.19	1.93	0.45	11.34
***A. glutinosa* Medium**		8.88a	7.76a	4.10b	0.39c	8.81b	1.24b	15.04b
± SD		0.28	1.81	0.93	0.24	1.80	0.47	9.13
***I. edulis* Mean**		8.77a	8.85a	4.66a	0.63a	10.04a	1.60a	34.58a
± SD		0.28	2.58	0.68	0.31	1.83	0.56	19.61

[1] Cation exchange capacity, [2] organic matter, SD standard deviation

These high pH values are due to soil characteristics that are of volcanic origin, and that have evolved in an arid subregion. Another element that may have contributed to the elevation of the pH is the irrigation water that comes from the Cutuchí River sub-basin that carries effluents with contaminated water as a result of the anthropic activities of the sector. Contaminated irrigation water contains total soluble solids that can contribute to an increase in pH (Pereira *et al*., 2017).

The contents of the exchangeable bases calcium, magnesium and potassium showed differences in the SSP that respond to the effect of the growth and development of the tree species on the grasses. It is known that legumes such as *I. edulis*, for instance, can adapt to poorly fertile soils due to their high potential for biological nitrogen fixation, carbon capture and biodiversity conservation, among other benefits (Batista *et al*., 2017).

Ca^{2+} showed values higher than 7.7 meq/100g both in the control and in the *A. glutinosa* and *I. edulis systems*. These values are considered average according to the scale of values proposed by (INIAP, 2010). The contents of these nutrients in the soil vary according to the characteristics of the tree species that in the initial or development stage extract considerable amounts of nutrients that contribute to the reduction of the contents of these elements in the soil. Mg^{2+} and K^{+} had a similar behavior. These values are considered high in both elements and are typical of this kind of soil.

The cation exchange capacity (CEC) had a behavior similar to the content of essential nutrients. The highest value of this indicator was obtained in the *I. edulis* system, followed by the control and *A. glutinosa* with values of 10.04, 9.1 and 8.8 meq100g^{-1} respectively. These values indicate that the introduction of silvopastoral systems, especially *A. glutinosa* and *I. edulis*, contribute to raising or at least maintaining the CEC in agroecosystems. Medina *et al.* (2008), reported that *A. dealbata* and *A. glutinosa* adapt well to poor soils and play the fundamental role of fixing atmospheric nitrogen in a symbiotic way; however, in the *A. dealbata system*, a CEC value of 8 meq100g^{-1} indicated that this species, at least in the initial phase, is the least recommended to contribute to the recovery of soil fertility.

The organic matter content was less than 1.7 % in all the SSP, which is classified as low according to the classification scale of (INIAP, 2010). These soils, due to the nature of their formation process and the erosive processes to which they have been subjected, have a low content of organic matter. However, it can be seen how the system with *I. edulis* shows a tendency to increase this important soil property with a value of 1.6% significantly higher than the rest. This fast-growing species can significantly increase the MO content, specifically in the environment between 1 and 3 m around the trees, depending on the type of soil.

The *I. edulis system* presented soluble phosphorus values of 34.6 mg kg^{-1}, significantly higher than the rest of the systems under study, which did not present significant differences between them. These soils naturally have low phosphorus content. The increase of this element was also reported by Panaifo *et al*., (2021) when introducing an agroforestry system in Valle del Monzón, Peru, obtaining a value of 16.82 mg kg^{-1} much higher than the control. This increase responds to alterations in its biogeochemical cycle, caused by changes in the activity of microorganisms in the rhizosphere, nutrient enrichment and MO.

According to the analysis, the introduction of the different tree species in the SSP caused important changes in the chemical and physical-chemical properties of the soil, fundamentally increasing the CIC, the MO content and soluble phosphorus, as reported by Delgado. *et al.* (2018) who concluded that silvopastoral systems are a good option to increase the chemical fertility of soils; in a study carried out in the Altillanura Plana de la Orinoquia in Colombia.

Evaluation of the dry matter content of the grass in the inclusion in the Silvopastoral Systems

The DM production of pastures is related to varietal characteristics, weather conditions and management. This indicator presented differences in each of the systems (Figure 1).

The best results in this indicator were observed for the *I. edulis* and *A. dealbata systems* with values of 12.2 and 9.3 t ha^{-1} respectively, higher than the control.

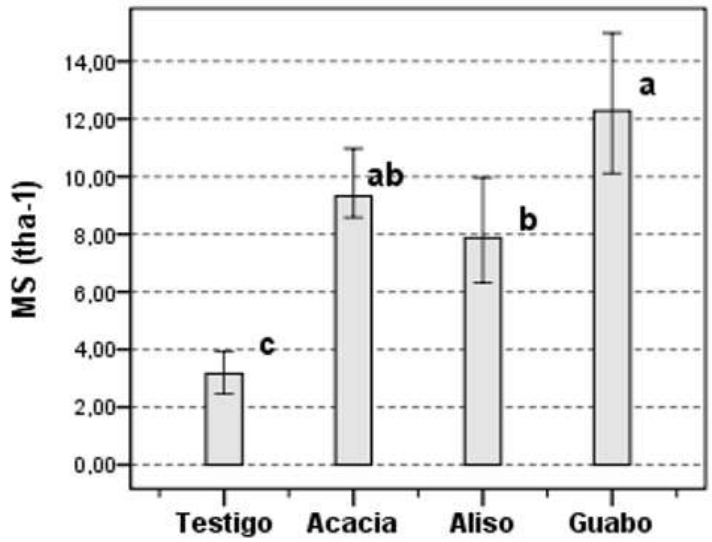

Figure 1. - Dry matter content of silvopastoral systems.The columns indicate the median and the vertical bars confidence intervals for $p < 0.05$

These two tree species fix nitrogen and also intervene in the solubilization of phosphorus (Batista *et al*., 2017), which causes the associated grass to improve its growth and quality, making it in some cases more palatable for animals.

It has been found that the crown of *A. dealbata trees melanoxilum* favor the growth and nutritional quality of mixed meadows of *C. clandestinum and L. perenne* (Navas *et al.*, 2020) as well as *Brachiaria humidicola* (Tomita, 2018). In another study carried out with several tree species, it was shown that the treatment with *A. dealbata* and grasses presented the best indicators in biomass production in the pasture between 0.88 and 1.44 kg DM/m^2 (Apraez *et al*., 2019).

Despite the advantages reported in this study regarding the introduction of SSPs in DM production, Figure 2 shows the DM production trend of the four SSPs in the period between 2015 and 2018 (Figure 2).

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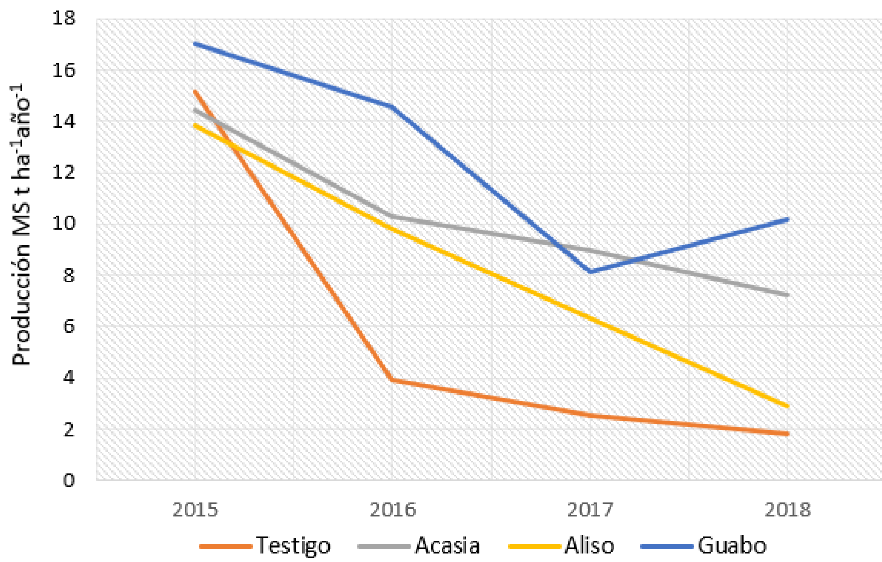

Figure 2. - Production of dry matter for the SSP between the years 2015 and 2018

A trend towards a decrease in DM production was evidenced in all SSPs, however, in the case of the system with *I. edulis* this trend is more marked between 2016 and 2017, with a slight recovery observed in 2018. The rest of the SSPs maintain this trend, being the control the one that shows the most marked decrease in this parameter, followed by *A. glutinosa*. This is due to the low recovery capacity of the control based on a forage mixture based on grasses and herbaceous legumes, together with the low capacity of these systems to recycle soil nutrients. Mejia *et al*. (2017) argued that dry matter production in pastures such as kikuyo (P. *clandestinum*) relies heavily on soil fertility and moisture to express good yield. That is why the *I. edulis* system, with the greatest contributions to soil fertility, propitiates a greater production of dry matter from the pasture.

Evaluation of tree biomass in the SSP

The study of biomass production is shown in table 3, being the systems with *A. dealbata* and *I. edulis* the ones with the highest contribution with values of 28.05 t DM ha^{-1} and 27.49 t DM ha^{-1} respectively (Table 3).

Table 3. - Production of tree biomass and stored carbon in the silvopastoral systems studied

SSP	Biomasa (t MS ha^{-1})	Carbono (t ha^{-1})
A. dealbata	28,05	14,03
A. glutinosa	4,80	2,40
I. edulis	27,49	13,75
Total	60,34	30,18

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According to Batista *et al.* (2017) *A. dealbata* is a nitrogen-fixing species; and also has a strong interaction with mycorrhizal fungi arbuscular (HMA, acronym in Spanish). These circumstances determine a higher biomass productivity. According to Echevarría *et al.* (2019) properly managed SSP in tropical America can present a high availability of edible biomass, greater than 30 t DM ha^{-1} year^{-1}. Biomass production in the case of the system with *A. glutinosa* was 4.8 t DM ha^{-1} lower than the rest of the systems. This reduction could be due to the fact that this species grows more slowly and adapts to highly eroded soils in semi-arid regions, as is the case in this study, which limits biomass production, especially in the first 5 years of establishment.

In relation to carbon storage, the results were similar to biomass accumulation, with the systems with *A. dealbata* and *I. edulis* showing the best results, with values of 14.03 t ha^{-1} and 13.75 t ha^{-1} respectively. These results are similar to the mean carbon storage values of SSPs based on *I. edulis* and other promising species (23.1 ± 4.1 t ha^{-1}) reported by Hernández *et al*. (2021); who demonstrated in a cocoa- *A. dealbata* SAF higher indicators of carbon accumulation are achieved than with other timber species.

These values are higher than the values presented by exclusively short-lived agricultural systems, which demonstrates the importance of establishing agroforestry systems for carbon recovery in areas previously disturbed by slash and burn and used for agriculture.

Evaluation of milk production in silvopastoral systems

Another of the essential benefits of SSP is the increase in milk production, not only due to the increase and diversification of DM production in the agroecosystem, but also because the reduction of heat stress and the improvement of comfort in the animal, they allow to increase the consumption in the grassland, which has a positive impact on the productive results.

In this study, the introduction of the SSP had a slight effect on milk production and other productive indicators except in the case of the system with *I. edulis* (Table 4).

Table 4. - Indicators of milk production in different Silvopastoral systems

Cultivo	Prod. leche (*litros ha^{-1} año^{-1}*)	Días pastoreo	T.P./día	N.V.P.	L/V/d	UBA* ha^{-1} año^{-1}	L ha^{-1} día^{-1}	Costo leche (USD L^{-1})*
Testigo	7902,7 b	45,0 b	175,6	13,5	13,0	3,5	45,4	0,362
A. dealbata	7930,0 b	44,3 b	178,9	13,4	13,3	3,4	45,4	0,352
A. glutinosa	8216,3 b	47,3 b	173,6	13,4	13,0	3,6	47,5	0,332
I. edulis	13495,0 a	71,7 a	172,2	13,4	12,9	5,5	71,4	0,235

Equal letters in the same column indicate significant differences for *p* -0.05. *Includes the years from 2014 to 2016. UBA-animal load in adult bovine units.

In the SSP with *I. edulis*, the best behavior was recorded, in milk production, 13495.0-liter ha^{-1} $year^{-1}$ and 71.7 grazing days. In addition, in this system a stocking rate of 5.5 UBA ha^{-1} $year^{-1}$ was supported. The rest of the SSP had a similar production between them, with 7902.7, 7930.0- and 8216.3-liters ha^{-1} for the control, *A. dealbata* and *A. glutinosa,* respectively.

This result is contradictory since the inclusion of tree species such as *A. dealbata* and *A. glutinosa* allow to achieve productive increases between 20 and 40%, compared to systems based on forage species as is the case of the control. In the case of *A. glutinosa,* this similarity could be due to the fact that it is a slow-growing species in arid soils with low humidity, so the positive effect on the forage mixture that grows in the paddock is longer-term. Therefore, in the establishment stage, the tree does not favor the uniform development of the forage species, predominating one over the other due to competition. In this study, kikuyu grass (*P. clandestinum*) prevailed over the rest of the species. The introduction of the SSPs influences the chemical-morphological composition of the forages, determines the palatability and the nutritional value for cattle, for which they influence on the quantity and quality of the food consumed (Tomita, 2018).

The rest of the productive results, such as milk production per cow per day, for example, were similar for all systems (Table 4). Sometimes the introduction of a SSP compared to the traditional grazing system, does not allow differences in milk production by individuals to be appreciated, however, when comparing production per hectare, differences are found, as reported by Barragan *et al.* 2019, not finding tangible increases in individual milk production or quality in dairy SSPs in Colombia.

In the case of the system with *I. edulis*, a productive result of 13495.0 was obtained liters ha^{-1} significantly higher than the rest of the studied systems. The previous result corresponds to the dry matter production of the pastures in this system, where *I. edulis* presented the best results and greater stability over time (Figures 1 and 2).

The best indicator of grazing days was observed in the *I. edulis system* with 71.7 (Table 4); because in this system there is a greater availability and quality of the grass produced, which translates into a longer grazing time of the lots. To corroborate the previous result, a correlation analysis was carried out between milk production and grazing days, where a high positive correlation was obtained between both indicators with a coefficient of 0.886, reaffirming the importance of the availability of pastures in the productive results and its impact on the increase in milk production.

Another of the favorable indicators in the investigation was the cost of production, which in all the SSPs was similar to the control (Table 4). Although in traditional, pasture-based dairy systems, the total cost of production is lower, productivity also decreases, causing a reduction in net benefit, when compared to SSP. These results are similar to those obtained in a study carried out by Pérez *et al*. (2019) in SSP with *A. glutinosa* and *A. dealbata* with values of 0.38 USD and 0.35 USD, respectively.

The *I. edulis* system presented the lowest cost (0,235 USD L^{-1}) and the highest profitability, due to the increase in stocking rate and consequently in milk production. The adoption of SSP and the gradual elimination of agrochemical inputs, allows to reduce the cost of milk production, increase its quality and price (Lopera *et al.* 2015).

CONCLUSIONS

The introduction of the tree component in the studied silvopastoral systems improves the physical-chemical and chemical properties of the soil, fundamentally in the content of calcium, organic matter and soluble phosphorus. The species that contributes the most to the increase in nutrients in the soil is *I. edulis* followed by *Alnus glutinous*.

The introduction of silvopastoral systems proves to be an effective agroecological practice for the increase and stability over time of dry matter production, in the edaphoclimatic conditions of the study area, due to its contribution of biomass and carbon at levels higher than the herbaceous species, especially when *I. edulis* and *A. dealbata are used*.

Among the silvopastoral systems evaluated, *I. edulis* is the only one where it is possible to obtain significant increases in total milk production, due to the increase in the number of grazing days; production costs are similar in all systems.

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