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Original article

Nitrogen content in soils of silvopastoril systems of *Prosopis spp*. from the Paraguayan Central Chaco

Contenido de nitrógeno en suelos de sistemas silvopastoriles de *Prosopis spp.* del Chaco Central paraguayo

Conteúdo nitrogênico em solos de sistemas silvopastoris de *Prosopis spp.* Do Chaco Central paraguaio

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ABSTRACT

Silvopasture allows the diversification of production and the increase of economic, social and environmental benefits for land users, since it is an integrated management of trees, pasture and livestock, which constitutes one of the best options to be implemented in the Paraguayan Chaco, due to livestock and an existing forest structure. This research was carried out in private properties in the Departments of Boquerón and Presidente Hayes, in the Western Region of Paraguay, with the objective of determining the nitrogen content in the soil of silvopastoral systems associated with *Prosopis spp*.

(carob tree). Eight plots of 1.0 ha each were established, in which all the carob trees were measured for the estimation of forest biomass, from samples of pastures under and outside the canopy of the trees where, in addition, soil samples were extracted at depths of 0-10 cm and 10-30 cm to determine the nitrogen content, estimated from soil organic matter. In the forest inventories, individuals of the *Fabaceae* family were identified, followed by the *Apocynaceae*, *Bignonaceae*, *Capparaceae, Rhamnaceae, Sapotaceae* and *Zhygophyllacea* families, with the *Prosopis* genus (carob) being the most abundant, associated with pastures of *Megathyrsus* maximus, *Digitaria decumbens* and *Cenchrus ciliaris* species. It is concluded that there are no significant differences in nitrogen content in the soils of silvopastoral systems between the two conditions of insolation studied, but between the two depths, concentrating in the first 10 centimeters.

Keywords: Carob tree; Forest biomass; Livestock; Organic matter; Pasture.

RESUMEN

La silvopastura permite la diversificación de la producción y el incremento de los beneficios económicos, sociales y ambientales para los usuarios del suelo, pues se trata de un manejo integrado de árboles, pastura y ganado, que constituye una de las mejores opciones para ser implementadas en el Chaco paraguayo, debido a la ganadería y a una estructura forestal existente. Esta investigación se realizó en propiedades privadas de los Departamentos Boquerón y Presidente Hayes, de la Región Occidental de Paraguay, con el objetivo de determinar el contenido de nitrógeno en el suelo de sistemas silvopastoriles asociados a *Prosopis* spp. (algarrobo). Se establecieron ocho parcelas de 1,0 ha cada una, en las cuales se midieron todos los algarrobos para la estimación de biomasa forestal, a partir de muestras de pasturas bajo y fuera de la copa de los árboles donde, además, se extrajeron muestras de suelos a profundidades de 0-10 cm y de 1030 cm para determinar el contenido de nitrógeno, estimado a partir de la materia orgánica del suelo. En los inventarios forestales fueron identificados individuos de la familia Fabaceae, seguidos por las familias Apocynaceae, Bignonaceae, Capparaceae, Rhamnaceae, Sapotaceae y Zhygophyllacea, siendo el género *Prosopis* (algarrobo) el más abundante asociadas con pasturas de las especies de *Megathyrsus maximus*, *Digitaria decumbens* y *Cenchrus ciliaris*. Se concluye que no existen diferencias significativas en cuanto al contenido de nitrógeno en los suelos de sistemas silvopastoriles entre las dos condiciones de insolación estudiadas, pero si entre las dos profundidades concentrándose en los diez primeros centímetros.

Palabras clave: Algarrobo; Biomasa forestal; Ganadería; Materia orgánica; Pastura.

RESUMO

O silvopastura permite a diversificação da produção e o aumento dos benefícios econômicos, sociais e ambientais para os utentes do solo, pois é um manejo integrado de árvores, pastagens e gado que constitui uma das melhores opções a serem implementadas no Chaco Paraguaio, devido à pecuária e a uma estrutura florestal existente. Esta pesquisa foi realizada em propriedades privadas nos departamentos de Boquerón e Presidente Hayes na Região Ocidental do Paraguai, com o objetivo de

determinar o teor de nitrogênio no solo de sistemas silvopastoris associados a *Prosopis spp.* (alfarrobo). Foram estabelecidas oito parcelas de 1,0 ha cada, nas quais todas as alfarrobeiras foram medidas para a estimativa da biomassa florestal, a partir de amostras de pastagens sob e fora da copa das árvores onde, além disso, foram extraídas amostras de solo em profundidades de 0-10 cm e 10-30 cm para determinar o teor de nitrogênio, estimado a partir da matéria orgânica do solo. Nos inventários florestais foram identificados indivíduos da família Fabaceae, seguidos pelas famílias Apocynaceae, Bignonaceae, Capparaceae, Rhamnaceae, Sapotaceae e Zhygophyllacea, sendo o gênero *Prosopis* (alfarroba) o mais abundante associado às pastagens das espécies *Megathyrsus maximus, Digitaria decumbens* e *Cenchrus ciliaris*. Conclui-se que não há diferenças significativas no teor de nitrogênio nos solos dos sistemas silvopastoris entre as duas condições de insolação estudadas, mas entre as duas profundidades, concentrando-se nos primeiros 10 centímetros.

Palavras-chave: Alfarrobo; Biomassa florestal; Gado; Matéria orgânica; Pastagem.

INTRODUCTION

In Paraguay, meat production more than doubled between 2005 and 2016, driven by productivity growth, which increased by 70 percent during this period. The expansion of soybean production in the eastern region after 2006 displaced cattle to the western Chaco region. In this new environment, the adoption of high-yielding tropical pasture varieties, together with improved animal genetics, were the main factors behind the increase in productivity. Challenges for future development are those related to the environment, as future expansion of production will continue on forest lands in the Chaco region (Nin-Pratt *et al*., 2019).

Silvopastoral systems can reverse rangeland degradation processes; they increase the physical protection of the soil and contribute to the recovery of fertility with the intervention of legumin which fix nitrogen to the soil and trees with pivot roots that take advantage of the deep layers and recycle nutrients; however, they require good management for the trees and shrubs to last, as well as their use in animal feed (Alons 2011; Lam 2016). Through the symbiotic association between forage legumes and bacteria of the genus *Rhizobium*, it is possible to improve the nitrogen content and the development of the associated grass, the bacteria of this genus are present in natural conditions when the strains are present in the soil (Bueno and Camargo 2015).

Nitrogen fixation performed in this symbiosis is another positive effect of silvopastoral systems on soil fertility, in addition to providing an economic benefit for the producer by reducing the use of nitrogen fertilizers (Hristov *et al.*, 2013). On average, fixation is estimated at 200 kg N ha^{-1} yr^{-1} in the tropics (Camacaro *et al.,* 2004), an amount that depends on the type and proportion of the legume in the pasture, the *Rhyzobium* strains involved, sowing density, soil fertility and climatic variations (Vargas *et al*., 2013).

Nitrogen is, after water, the most limiting nutrient for plant productivity in arid and semiarid zones. In natural form, nitrogen is found in the atmosphere as a gas, in a reservoir unavailable to plants, so in order to use it, plants need to establish symbiosis

with some species of bacteria, which allows them to contribute nitrogen to the soil in arid zones (Celaya and Castellanos 2011).

Some trees such as *Prosopis* contribute large ecological inputs, due to their ability to recover deforested areas and conserve soil moisture in forested areas in good conditions (Rojas 2007). Taking into account the above, the objective was to determine the nitrogen content in the soil in a silvopastoral system associated with *Prosopis spp*.

MATERIALS AND METHODS

Study area

The work was carried out in the localities of Pirizal, Buena Vista, Loma Plata and Filadelfia in the Departments of Boquerón and Presidente Hayes, located at coordinates 22° 35' 6.5'' S and 59° 44' 33.9'' W, more than 430 km from the city of Asunción.

Eight permanent plots were randomly established in different properties, with pastures under silvopastoral management (Figure 1). The work consisted of determining the nitrogen supply to the soil through the analysis of organic matter.

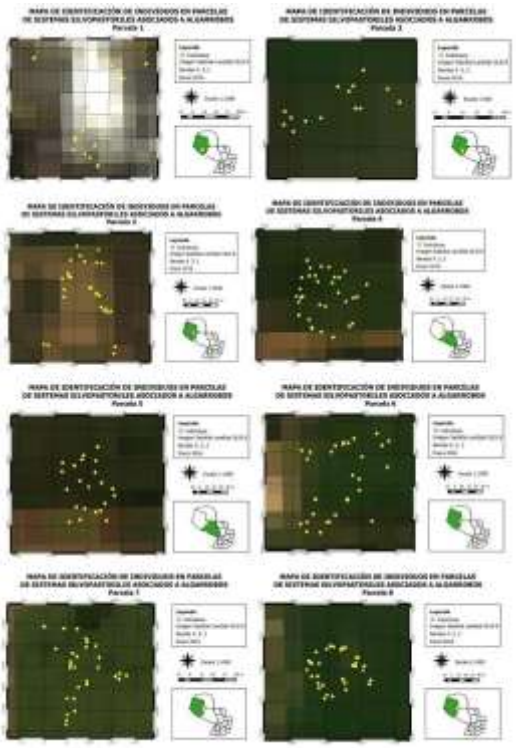

Figure 1. - Distribution of *Prosopis spp*. in the permanent monitoring plots

The eight permanent plots were represented by an area of 1.0 ha each, in which all tree and pasture species present were identified and all carob individuals were measured and recorded, from seedlings and saplings to adult trees. The variables measured were:

- DAC (root collar diameter): diameter measured at the root collar of the plant, in (cm).
- $D_{1.30}$ (diameter of the tree at 1.30 m height in (cm).
- Total height: height of the tree from the ground to the apex in (m). Basal area: sum of cross sections of individuals measured at DBH m from the ground, expressed in (m^2).
- Total volume: amount of wood estimated in (m^3).
- Total biomass: weight of organic matter above and below the soil, expressed in ($t\ ha^{-1}$).

The following equations were applied to determine basal area, total volume and tree biomass, respectively (Equation 1); (Equation 2) and (Equation 3).

$$G = n\ x\ DAP^2/4 \quad (1)$$

$$V = FxGxh \quad (2)$$

$$BT = 0{,}2733X(DAP^2 x\ altura\ total)^{0.8379} \quad (3)$$

(Sato *et al.*, 2015)

Meanwhile, for the extraction of pasture samples, eight subplots of 1.0 m^2 were established within each experimental unit (plot). These were randomly distributed, under direct influence of the carob tree canopy (4) and in areas outside the direct influence of the carob tree canopy (4). The variables measured were:

- Total height: length of the pasture from root to apex in (cm). Root length: length measured from root collar to coppice in (cm). Fresh weight: weight at the moment the pasture was extracted in (g). Dry weight: weight of the pasture after oven drying in (g).
- Biomass: total mass of the pasture, represented by its dry weight expressed in t ha-1.

For the determination of biomass in the pasture, samples were extracted from the established plots through a wooden frame of 1 m^2, thus obtaining the fresh weight in the field. Eight subplots were randomly distributed: four under the direct influence of the carob tree canopy and four subplots in areas outside the direct influence of the carob tree canopy. The samples were taken to the Wood Technology Laboratory of the Faculty of Agricultural Sciences.

For soil analysis, four composite samples were extracted under each condition (under the influence of the carob tree canopy and outside the influence of the carob tree canopy) and at two depths (from 0 to 10 cm and from 10 to 30 cm) and analyzed in the Soil and

Land Management Area laboratory for the determination of organic matter. The organic matter content was determined using the Walkley and Black wet method, and these results were used to calculate the total nitrogen content (Equation 4).

$$N\ (\%): M.O\ (\%) * 0{,}05 \quad (4)$$ (Plaster, 2000)

RESULTS AND DISCUSSION

Floristic composition and diametric classification of tree individuals

The species found in the 8 plots sampled belong to the categories of brinzal, latizal and trees; as can be seen, individuals of the *Fabaceae* family predominate, followed by the *Apocynaceae, Bignonaceae, Capparaceae, Rhamnaceae, Sapotaceae* and *Zhygophyllacea* families.

Rossi (2014) mentioned that the vegetation corresponds to a deciduous xerophytic forest, composed of three strata, arboreal, shrub and herbaceous-grassy, in original forest conditions, trees dominate, and there is a moderate to low presence of shrubs and the lower stratum corresponds to an abundant and rich community of grasses. Among the main species of the arboreal stratum, the most important genera of the Arid and Semiarid Chaco Region of Argentina are *Schinopsis*, *Aspidosperma*, *Prosopis*, *Caesalpinia* and *Bulnesia*.

The most abundant species was *Prosopis alba* Griseb. with 160 individuals (64.8 %), followed by *Prosopis nigra* (Griseb.) *Hieron*. with 77 individuals (31.2 %), the scarcest species were: *Prosopis* kuntzei Harms, with 6 individuals (2.41 %) and *Prosopis rojasiana* with 4 individuals (1.60 %).

Martín *et al*., (2014) in a study on tree density in semiarid grasslands, under two situations of silvopastoral use carried out in Argentina, found 168 individuals in total per plot of one hectare each, where the most abundant was *Aspidosperma* quebracho with 53 individuals, followed by *P*. *nigra* with 34 individuals and *P. alba* with 23 individuals per hectare, the scarcest species was *Schinopsis* quebracho colorado with 10 individuals, all this referring to situation B) 570 hectare pasture with 23 years of extensive cattle management and controlled logging (only extraction of dry, deformed and/or aged specimens).

The distribution of the 247 carob individuals in the eight plots classified 134 individuals in Class I: $D_{1,30}$ < 10 cm, 93 individuals in Class II: 10.1 to 20 cm, 18 individuals in Class III: 20.1 to 30 cm and only 2 individuals in Class IV: 30.1 to 40 cm. This shows that, in practice, all the plots were composed of regenerating individuals in which there was a greater abundance of P. alba (Figure 2).

Figure 2. - Diametric distribution of the total number of individuals in the 8 plots

In a study of dasometric parameters of plantations of *P. alba* in the irrigated area of the Province of Santiago del Estero, Argentina, where data were collected in five plots, each with a density of 48 trees, with different ages and distances, it was concluded that the average growth values of DAC (2.1 ± 0.2 cm yr^{-1}) and IMA (1.8 ± 0.1 cm yr^{-1}) are provisional and indicative (Senilliani and Navall 2006).

Basal area and total volume

An average basal area of 0.34 m^2 ha^{-1} was obtained, with an average minimum value of 0.02 m^2 ha^{-1} found in plot 6, made up entirely of regenerating black locust trees, with an average diameter at neck height of 2.66 cm; and a maximum average value of 0.64 m^2 ha^{-1} found in plot 5 made up entirely of white carob, with a diameter at breast height of 16.05 cm, which means that in this plot the individuals occupy a larger cross-sectional area compared to the other plots (Figure 3).

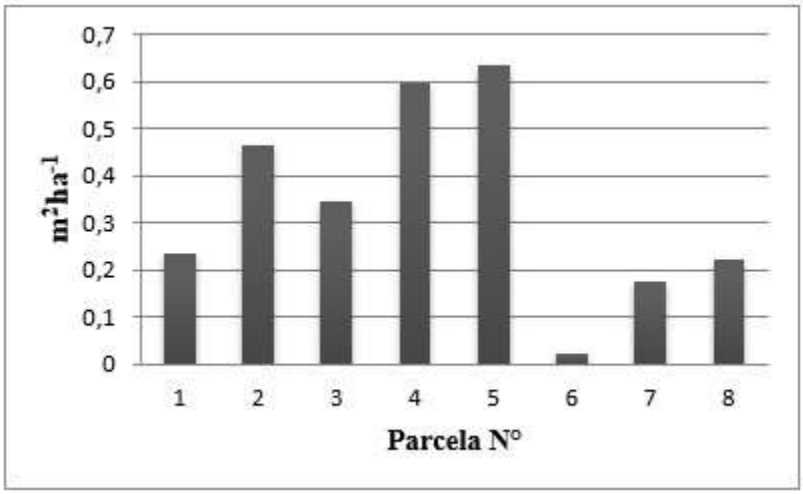

Figure 3. - Average basal area of *Prosopis spp.* per hectare

In a study on dasometric parameters of *Prosopis alba* plantations in the Province of Santiago del Estero, where data were taken in five plots, with a density of 48 trees each, with different ages and distances, it was concluded that plot 4 reached the maximum values of 19.3 m^2 ha^{-1} and the minimum values in plot 1 with 1.2 m^2 ha^{-1} (Senilliani and Navall 2006).

An average volume of 1.57 m^3 ha^{-1} was determined. Plot 6 had the lowest average value of 0.03 m^3 ha^{-1}, consisting entirely of regenerating black locust trees, with an average height of 1.77 m; and the highest value was found in plot 2 with an average value of 2.75 m^3 ha^{-1} consisting entirely of white locust trees, with an average height of 6.60 m, where a higher percentage of wood to be harvested could be found (Figure 4).

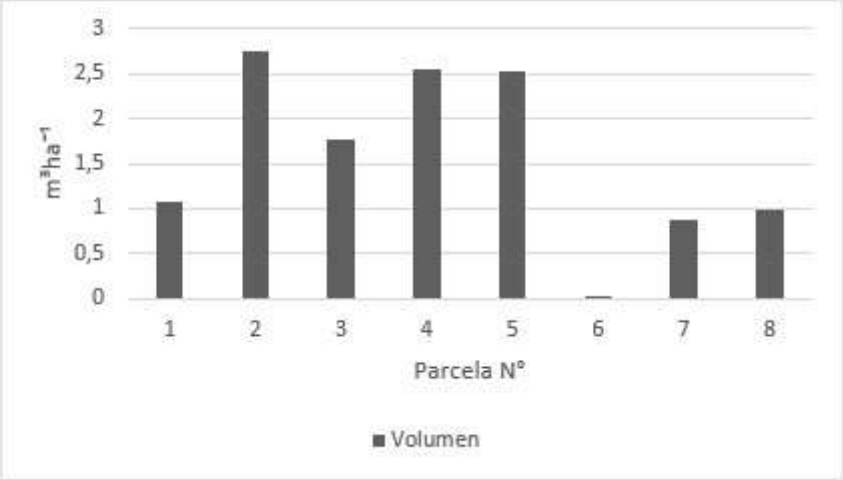

Figure 4. - Volume of *Prosopis spp*. per hectare

Similar values were reported by Gaillard de Benítez (1994) in his publication on functions for estimating the commercial volume of trees in four species of the dry Chaco forest. Values were available for 126 trees for *Schinopsis* quebracho-colorado, 120 for *Aspidosperma* quebracho-blanco, 58 for *Prosopis nigra* and 49 for *Zizyphus* mistol. These results showed that black locust has an average total volume of 0.15 m^3.

Tree biomass and pasture biomass

The average estimated tree biomass was 0.78 t ha^{-1}, being plot 2 with the maximum average value of 1.3 t ha^{-1}, and plot 6 with the lowest average value of 0.04 tha^{-1} this can be attributed to the fact that the individuals belonging to this plot presented the smallest diameter and height with respect to the other plots. The tree biomass averages are shown in Figure 5 (Figure 5).

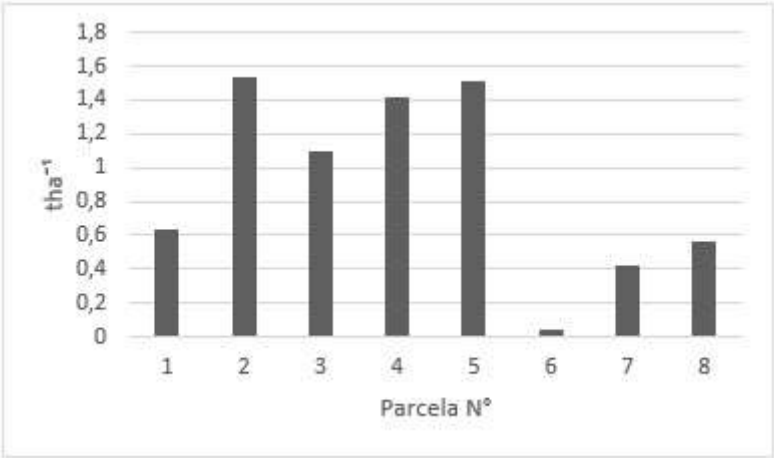

Figure 5. - Average total biomass of *Prosopis spp*. per hectare

The most frequently found pastures were gatton panic (*Megathyrsus maximus*), pangola (*Digitaria decumbens*) and buffel (*Cenchrus ciliaris*). Heterogeneity was observed in the distribution of the pastures, which varied in a range of 3.28 t ha^{-1} as maximum value and 0.60 t ha^{-1} as minimum value, this for the shaded condition; while under sun the range is 0.72 t ha^{-1} as maximum and 0.32 t ha^{-1} as minimum value.

It is shown that there were significant differences between the samples extracted under the canopy of the carob trees and outside the canopy of the carob trees; therefore, it can be said that *Prosopis spp*. have a positive influence on the development of the pasture. This can be observed in Figure 6, where the highest biomass concentration in pasture was under shade with 3 t ha^{-1} considering fresh weight and 1.81 t ha^{-1} of dry matter; and the lowest biomass concentration was under sun with 2.02 t ha^{-1} (fresh weight) and 0.46 t ha^{-1} (dry matter) (Figure 6).

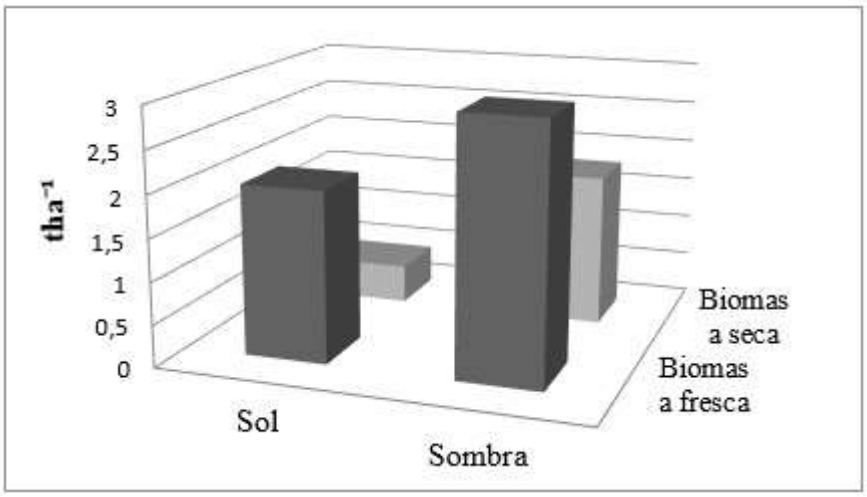

Figure 6.- Average pasture biomass under two conditions of insolation

In an investigation conducted by Obispo *et al.,* (2008), on the effect of tree shade density on biomass production and quality of guinea grass (*Panicum maximun*) in four paddocks, where tree crown densities and their respective shadows were determined as (high >30 %; medium between 20-30 %; low <10 % and no shade), it was concluded that the biomass production and quality of *P. maximum* is affected by the level of shading, with a maximum value of 14.32 t ha^{-1} with no shade and a minimum value of 8.859 t ha^{-1} with high shade levels; 10.01 t ha^{-1} with medium shade levels and 14.046 t ha^{-1} with low shade levels.

Soil organic matter

It was determined that soil organic matter content did not show significant differences between sun and shade conditions, but the differences were significant when the sampling depths of 0-10 cm and 10-30 cm were compared in each condition, under shade and under sun. The average organic matter content in percent at two depths and under two sunlight conditions is presented in Figure 7.

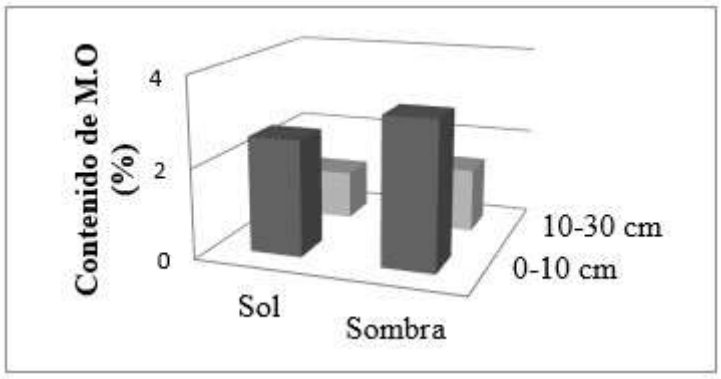

Figure 7. - Average in percentage of organic matter content at two depths and under two sunlight conditions

As can be seen in Figure 7, the highest organic matter content is presented in the first centimeters of the soil from 0-10 cm; with 3.27 % under shade and 2.58 % under sun, decreasing as the depth increases to 10-30 cm, with 1.43 % under shade and 1.09 % under sun; therefore, it can be argued that under the influence of the carob tree canopies a higher organic matter content is located and in the first centimeters of the soil.

Similar values were exposed by Serrano *et al*., (2015), in a study of forage biomass production under different densities of tree cover associated with pasture in Colombia; who classified tree cover in five classes of < 20 %, > 20 %, 20 to 40 %, 40 to 60 %, 60 to 80 % and >80 % in 19 plots, in which they determined the organic matter content in the soil, resulting that in plot 4 with tree cover between 60 - 80 % was the highest, with 1, 3 %, while plot 5 with tree cover between 80 and 100 % presented the lowest value with 0.3 % for organic matter, attributing the low values of organic matter in soils with tree cover higher than 80 %, possibly explained by the type of soil texture present in these plots.

Total soil nitrogen

The total nitrogen content of the soil did not show significant differences between sun and shade conditions, but the differences were significant when the sampling depths of 0-10 cm and 10-30 cm were compared in each condition, under shade and under sun. Figure 8 shows the average values of nitrogen content by calculation (Figure 8).

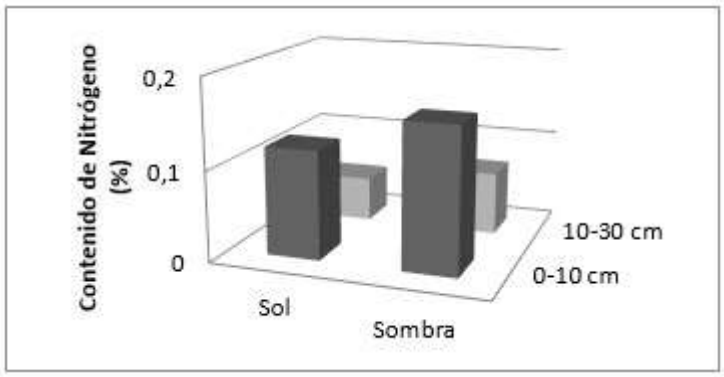

Figure 8. - Total nitrogen content in the soil

As in the organic matter content; the highest nitrogen content was in the first centimeters of the soil from 0-10 cm; with 0.16 % under shade and 0.12 % under sun, decreasing as the depth increased to 10-30 cm, with 0.07 % under shade and 0.05 % under sun; therefore, it can be explained that under the influence of the carob tree canopies a higher nitrogen content is located in the first centimeters of the soil.

The minimum value was 0.03 % in plot 3 and 0.29 % as maximum value in plot 4, this for the shaded condition, while for the sunny condition the minimum value was 0.02 % in plot 7 and 0.20 % as maximum value in plot 8.

Similar results were obtained by Díaz Lezcano *et al*., (2020) under similar conditions in the Central Paraguayan Chaco, accumulating low levels of both organic matter and total nitrogen content in the soil.

These results coincide with those presented by Mahecha (2002) in a study on N, P and C contents at different soil depths, in a silvopastoral system (SSP) of *Cynodon plectostachyus* (star grass) + *Leucaena leucocephala* (*Leucaena*) + *Prosopis juriflora* and in monoculture of *C. plectostachyus* carried out in Colombia, obtaining similar values in terms of the percentage of nitrogen content, with the maximum content for the silvopastoral system with 0.22 % at a depth of 20-30 cm and the minimum value is from 10 to 20 cm depth with 0.11 %; while the maximum value in the monoculture system is from 20 to 30 cm depth with 0.12 % and the minimum value at a depth of 10 to 20 cm with 0.06 %.

According to Carranza and Ledesma (2005) the individuals of *Prosopis spp. leguminous* trees can establish symbiotic relationships with bacteria of the genus *Rhizobium,* capable of fixing atmospheric nitrogen. These authors refer to evaluations made in the northern hemisphere, with *P. glandulosa,* where it was estimated that 60% of the total N in the first 30 cm of soil came from atmospheric fixation.

CONCLUSIONS

The results of the present investigation allow us to conclude that the nitrogen content in the first ten centimeters was higher than in the lower levels and that there were no significant differences between the conditions under and outside the canopy of carob trees in the soil of silvopastoral systems of the Central Paraguayan Chaco.

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Authors' contribution:

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