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Article

Carbon/nitrogen ratio in soils of silvopastoral systems in the Paraguayan Chaco

Cynthia Carolina Gamarra Lezcano[1*]

Maura Isabel Díaz Lezcano[1]

Mirtha Vera de Ortíz[1]

María del Pilar Galeano[1]

Antero José Nicolás Cabrera Cardús[1]

[1]Facultad de Ciencias Agrarias, Universidad Nacional de Asunción. Campus de San Lorenzo. Paraguay.

[*]Autor por correspondencia, correo-e: cynthiag_011@hotmail.es

Abstract:

The silvopastoral system renders the livestock production more sustainable because the interaction between its components brings benefits to the soil, to the grassland, livestock and trees; furthermore, it enhances the productivity and the diversification of production. To know the characteristics of these systems, a study was carried out in private properties located in the Paraguayan Chaco, where eight permanent plots of 1 ha each were established in which all *Prosopis* spp. (carob) individuals were measured and identified, and samples were drawn from grasslands of subplots located beneath the canopy of the trees and beyond to compare their biomass; soil samples were also obtained under the same conditions, at two different depths —0 to 10 cm and 10 to 30 cm— with the purpose of comparing the content of organic matter and carbon/nitrogen ratio (C/N). The arboreal component consisted of *Prosopis alba* (white carob tree) and *Prosopis nigra* (black carob tree), in association with cultivated grassland composed mostly by *Panicum maximum* cv *Gatton panic* (Gatton Panic), *Digitaria decumbens* (Pangola grass), and *Cenchrus ciliaris* (Buffel grass). The presence of the carob trees influenced the biomass of the grassland, which was more abundant beneath the tree crowns than outside of them. The organic matter in the soil exhibited no significant differences between the conditions of sun and shade, but it differed between depths; in contrast, the C/N ratio did not change under any of the conditions.

Key words: Carbon/Nitrogen ratio, organic carbon, Paraguayan Chaco, organic matter, silvopastoral system, soil.

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Introduction

Land use change for crop expansion and grazing purposes is the main cause of deforestation in Latin America. With the removal of the forest cover, soils are exposed to erosion and can become wastelands in less than 10 years (Steinfeld, 2009).

At the national level, the semi-intensive livestock model was established in the Paraguayan Chaco. As a result of the edaphoclimatic conditions of this region, it is important to manage its resources carefully in order to enhance its productivity; silvopastoral systems are a sustainable exploitation strategy (Laneri 1993; Jobbágy *et al.,* 2011; Bazoberry, 2012).

Because silvopastoral systems provide conditions that allow animal welfare, protect the soil against erosion and compaction and increase its fertility through the cycling and transport of nutrients from the subsoil to the crown and the accumulation of surface organic matter, they contribute to enhance the productivity, the profitability and the sustainability of the exploitation by combining woody species with grassland and livestock production.

The silvopastoral systems of the Paraguayan Chaco include *Prosopis* spp., a major component of the arboreal and shrub structure of the arid and semi-arid zones. It is a legume that is capable of fixating atmospheric nitrogen thanks to the association existing between the bacteria of the *Rhizobium* genus and its roots; this produces a positive impact on the digestibility and the protein content of pasture (Sammartino, 2011).

The speed and the balance between the mineralization and the humidification processes conditioned by the microbial activity in the soil is more important than the total content of organic matter. The speed at which the microorganisms proliferate and the rapidity with which organic matter becomes mineralized are estimated based on the ratio of organic carbon to total nitrogen (Fuentes, 1999).

The C/N ratio is an index of the quality of the organic substratum of the soil. It indicates the rate of nitrogen available to plants. High values imply that the organic matter decomposes slowly, since the microorganisms immobilize nitrogen, so it cannot be used by plants; on the other hand, values between 10 and 14 correspond to a quick mineralization and rupture of tissues, as the microbial activity is stimulated, and there are enough nutrients for both the microorganisms and the plants. Furthermore, the C/N ratio of bacteria and fungi in the soil is less than 15, which means that with low values of C/N the microorganisms will be more efficient in the decomposition of organic matter.

The importance of this work lies in the fact that experiences of benefits in the management of this species in silvopastoral systems are scarce and isolated in the Paraguayan Chaco. Research is one of the first approaches to knowledge on soil fertility in silvopastoral systems of Central Chaco.

The objective of this study was to analyze the C/N ratio in soils under silvopastoral systems associated with *Prosopis* spp. of the Central Chaco of Paraguay, and to this end the composition of the grassland and trees within the system were described. The effect of two conditions of solar radiation on the biomass of the grassland was evaluated; the content of organic carbon and nitrogen under two conditions of solar radiation and at two depths was compared; and the rate of decomposition of organic matter was assessed based on the C/N ratio. The hypothesis was that there are significant differences between the C/N ratio in the silvopastoral system under different solar radiation conditions and depths.

Materials and Methods

The study area is located in the *Pirizal*, *Buena Vista* and *Teniente Primero Manuel Irala Fernández* districts of the department of *President Hayes*, and *Filadelfia* and *Loma Plata*, department of *Boquerón*, in the Western Region of Paraguay, located between the parallels 20°05' and 23°48' S and the meridians 62°40' and 59°20' W. It is located 420 km from the city of *Asunción*, bordered on the east with *Alto Paraguay*, to the south by the Eastern Region of the country and on the southwest by the Republic of Argentina. Its natural boundary is the *Pilcomayo* river, which bathes the southern region of the department with tributaries that are non-navigable but important for irrigation. It is an area of open fields with thorny vegetation and prickly pears (DGEEC, 2002).

Its average temperature is 26 °C, with summer rains (December through March) in the form of localized and very intense showers; the highest monthly average precipitation occurs in December (115 mm), and the lowest, in July (15 mm) (Vera *et al.*, 2000; Naumann, 2004).

According to the classification of soils by FAO (1988), in this area there are Luvisols, at a depth between 30 and 70 cm, enriched with clays, having a neutral or slightly alkaline pH; their alkalinity increases with depth; normally they are rich in phosphorus (78 ppm), potassium (1.4 mval 100 g^{-1}) and magnesium (3.1 mval 100 g^{-1}) (Glatzle, 1999).

The work consisted in the determination of the contribution of the carob tree to the soil organic matter based on the analysis of the C/N ratio; for this purpose, eight permanent plots were installed in different properties with paddocks under silvopastoral management. Each plot has a surface area of 1 ha each, in which all the grassland and tree species present were identified, and all carob individuals, from seedlings and trees at the pole stage (from 1 m in height) to adult individuals (DBH>10) and the grassland, were measured.

For the removal of samples of grassland, eight subplots of 1 m × 1 m were established at random within each plot: four under direct influence of the crown of carob trees, and four outside the direct influence of the crown.

For the analysis of soil, four compound samples in each condition (under the influence of the crown of the carob trees and outside it) were extracted at two depths (0 to 10 cm and 10 to 30 cm); they were subsequently bagged, labeled and taken to the *Laboratorio del Área de Suelos y Ordenamiento Territorial de la Facultad de Ciencias Agrarias de la Universidad Nacional de Asunción* (laboratory in the Area of Soil Survey and Land Use Planning of the Faculty of Agricultural Sciences of the National University of *Asunción*) in order to determine the organic carbon content. The results were used to calculate organic matter, the total nitrogen content and the C/N Ratio in order to estimate the fertility of the soil.

Once the plots were installed, it was proceeded to label the present carob trees with metal sheets and to measure their DBH and the DBH or DNH —DBH at 1.30 m from the ground in adult individuals, and DNH in regenerations <10 cm— as well as their total height. The data were recorded in a spreadsheet, and the location of each individual was georeferenced using a Garmin® GPSMAP® 62ac GPS. Table 1 shows the calculations for the woody component.

Table 1. Estimated dasometric variables.

Variable	Formula	References
Basal area (m^2)	$g = (\pi D^2) \div 4$	π = 3.1415
		D = Diameter(m)
Total volume (m3)	$VT = g * h * ff$	*g* = Basal area(m^2)
		h = Height(m)
Total biomass (t ha-1)	$**BT = 0.2733 * (h * D^2)^{0.8379}$	*ff* = Form factor (0.8389)*

* = Form Factor for carob proposed by Quinteros (2001); ** = Allometric equation proposed by Sato *et al*. (2015) for the Dry Chaco.

For the extraction of the grassland samples, several subplots of 1 m × 1 m were established within each 1 ha plot: four beneath the crowns of the carob trees, 1 m away from the stem, and four outside the direct influence of the crowns of the trees; the total height, root length and fresh weight of the samples taken were then measured and recorded.

The soil samples were bagged, labeled and taken to the laboratory of the Soil and Land Use Planning Area, where they were mixed, screened and prepared; subsequently, the organic carbon content was determined using the Walkley-Black method, in order to calculate the organic matter content, the total nitrogen and the carbon/nitrogen ratio by applying formulas proposed in the literature (Plaster, 2000; Thompson y Troeh 2002; Porta *et al*., 2014). Table 2 presents the variables calculated based on the results of the laboratory analysis.

Table 2. Variables calculated based on the soil analysis.

Variable	Formula	References
O.C ($T.ha^{-1}$)	$C.O = \left(V * Da * CO.(\%)\right)/1000$	
		V = Volume of soil
Organic matter (%)	•$M.O = C.O(\%) * 1.72$	D = Bulk density
Total nitrogen (%)	$^{**}N.T = M.O * 0.05$	$O.C$ = Organic carbon
Total nitrogen(T.ha-1)	$Nt = \left(V * Da * Nt\ (\%)\right)/1000$	$O.M$ = Organic matter
C/N ratio	$C/N = O.C/T.N$	

•=Porta *et al.*, 2014; ** = The nitrogen content is considered to be 5 % of the organic matter content (Plaster, 2000); *** = Bulk density considered: 1 243 kg m^{-3} (0 to 10 cm depth) 1 225 kg m^{-3} (10 to 30 cm depth).

The implemented study was exploratory; it was described as having been applied with the purpose of acquiring knowledge about a scarcely researched topic, obtaining information for a more thorough investigation, and setting priorities for future research (Hernández, 2010).

Results and Discussion

Characterization of the study area

The proper management of the study population requires knowledge of the diametric distribution of the trees of which it consists (Cao, 2004).

In order to make the floristic composition and diameter distribution of the analyzed parcels known, we present below a description of all the trees that exist in the plots, the diametric distribution of the measured individuals, and the grass species registered, as well as a general description of the observed characteristics.

The crowns of the carob trees cover, on average, 13 % of the total surface area of each plot; the spatial distribution of the individuals was random, with a tendency to form clusters with an average distance of 9 m between one another. These data are important because they make it possible to identify the level of influence of the shade provided by the canopy on the other components of the system, such as the soil, the grassland and the livestock.

The diameter classes indicating the distribution of individuals are the following: Class 1: DBH<10; Class 2: 10 to 19 cm DBH; Class 3: 20 to 29 cm; Class 4: 30 to 39. Figure 1 shows the diameter distribution of the 246 measured individuals.

130 individuals (53 %) out of the total number of registered carob trees (245) fall into the category of regeneration, with a DBH<10 cm; the remaining 115 (47 %) had a mean DBH of 16 cm. An average of 31 specimens were measured in each plot.

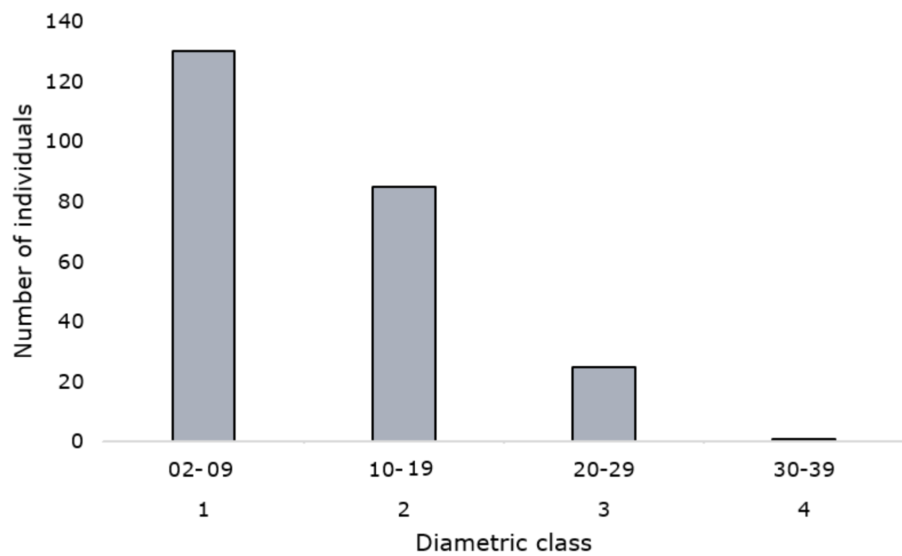

Figure 1. Diametric distribution of all the measured carob trees. Central Chaco (December 2015).

As Glatzle (2004) has stated, allowing the establishment of carob tree (*Prosopis alba* Griseb., *P. nigra* Hieron. or *Prosopis kuntzei* Harms) regenerations with a density of 20 to 50 trees per hectare in degraded grasslands may bring ecological benefits, since the greater accumulation of organic matter beneath their crowns helps increase the yield of the grasslands for the livestock.

Basal area. De Arruda Veiga (1984) points out that knowledge of the basal area of a population is crucial for estimating the volume and determining the density of the population. In this regard, at the time of the measurement, the installed plots had an average of 31 individuals of *Prosopis* spp. per hectare, particularly of the *Prosopis alba* species (white carob tree), followed by *Prosopis nigra* (black carob). Figure 2 shows the values of basal area, with an average of 0.34 m^2 ha^{-1}; plot 6 had the minimum value, of 0.02 m^2 ha^{-1}, and plot 5 had the maximum value, which was 0.64 m^2 ha^{-1}. Furthermore, this figure depicts the average basal area of the carob trees per hectare.

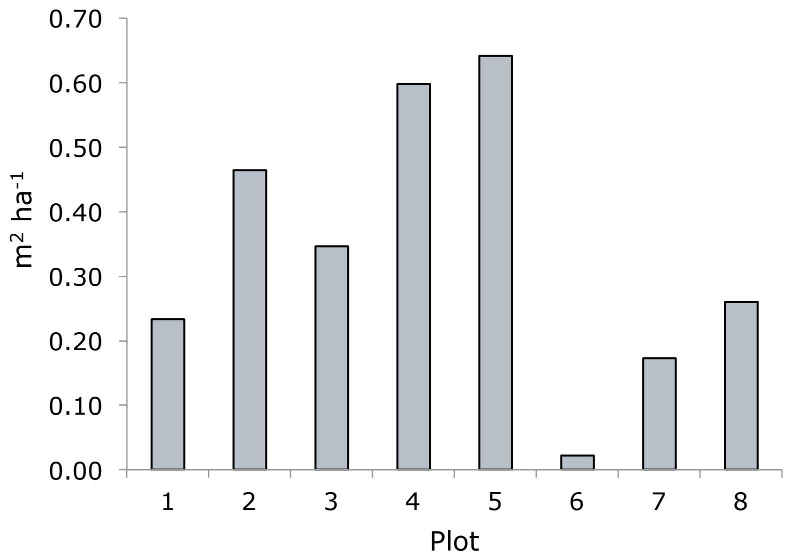

Figure 2. Average basal area of the carob trees per hectare. Central Chaco (December 2015).

35 trees were measured in plot 6; they were all regenerations, with a mean DNH of 2.6 cm. On the other hand, the 30 individuals of plot 5 had a mean DBH of 16 cm, i.e. they were all adult trees.

Senilliani and Navall (2005) estimated similar values in a plantation of *Prosopis alba* trees aged 4.5 years, with a density of 555 trees per hectare and a basal area of 0.7 m^2 ha^{-1}.

Kees *et al*. (2015) cite higher values in the Argentinean Chaco, in a silvopastoral system consisting of a plantation of carob trees, with a density of 150 trees per hectare, associated with *Panicum maximum* Jacq. The mean basal area of the trees of this species aged 10 years was 5.62 m^2 ha^{-1}, and that of the trees aged 14 years was 8.07 m^2 ha^{-1}.

Volume. It is important to know the volume of timber produced in grasslands, forests or plantations in order to acquire technical knowledge on the development of individuals and in order for the producers to learn how much timber that can be obtained from these sources and marketed (Ordóñez *et al.*, 2012).

The average estimated volume in the study plots was 1.59 m^3 ha^{-1}; the maximum value was obtained in plot 2, made up in its entirety of white carob individuals, with a mean DBH of 13.15 cm, a height of 6 m and a volume of 2.75 m^3 ha^{-1}; the minimum value, 0.035 m^3 ha^{-1}, was estimated in plot 6, formed by regenerations of black carob, with a DBH of 2.66 cm and an average height of 1.76 m (Figure 3).

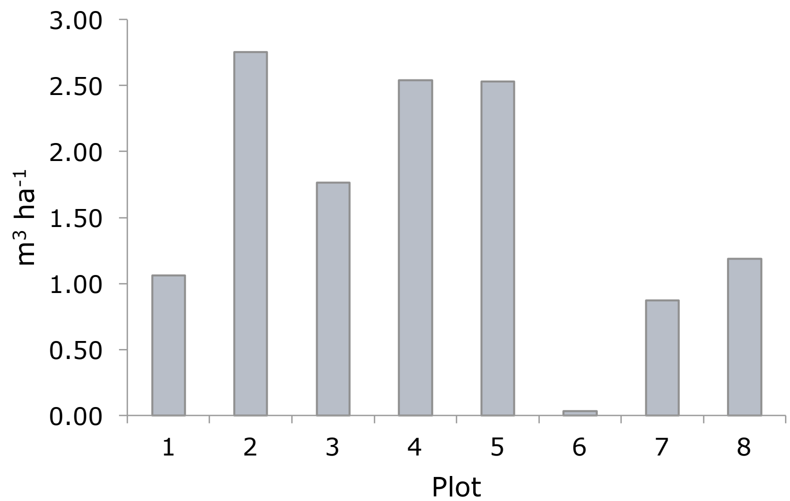

Figure 3. Volume of carob trees per hectare. Central Chaco (December 2015).

In an assessment of silvopastoral systems with three carob tree species (*Prosopis nigra*, *Prosopis affinis* Spreng. and *Prosopis vinalillo* Stuck.) implemented on a of 125 m × 80 m plot at the *Maroma* ranch, in the *Presidente Hayes* Department of the Humid Chaco, the calculated volume averaged 2.79m^3 ha^{-1} (Arano y De Egea, 2014).

Total biomass of the tree stratum. The aboveground biomass includes everything that is above the ground, such as the stem, the branches and the leaves (Yepes *et al*., 2011). Thus, the average biomass of the tree component of the system was 2 t ha^{-1} (Figure 4), a value higher than the reported by Ibrahim *et al.* (2007), less than 30 individuals present per hectare, in tress with DBH ≥5.

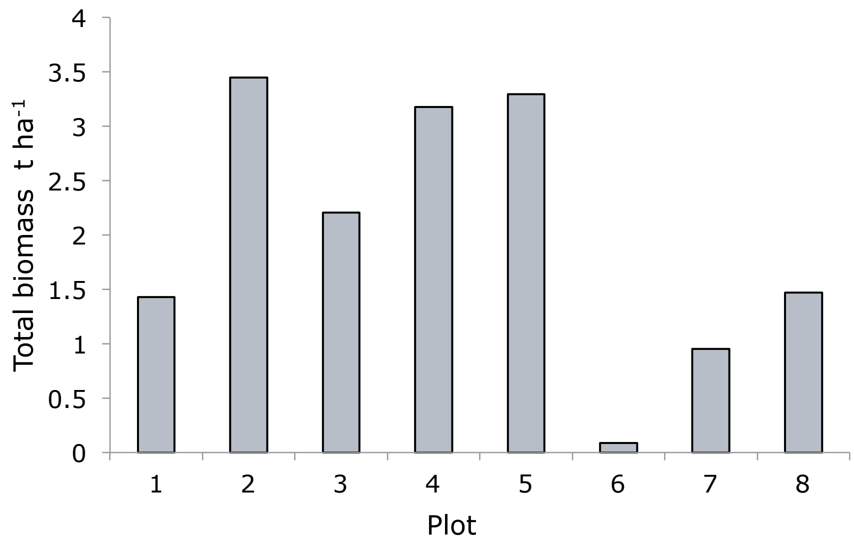

Figure 4. Total biomass of the arboreal component. Central Chaco (2015).

Grassland biomass

The values varied according to the degree of exposure to solar radiation; this refers to the canopy cover of the carob trees.

The grasslands most frequently identified in the plots were *Gatton panic*, Pangola and Buffel; stargrass and Urochloa grass were found in a lower proportion.

The carob trees influenced the development of the biomass of the grassland, as there were significant differences between the samples drawn beneath the carob tree canopy and those drawn outside of the crown, according to a comparison carried out using the Student t test method with data from plots that were not paired, at a confidence level of 95 %.

Thus, the biomass of the grassland located outside the projection of the carob tree crown had an average value of 0.46 t ha^{-1}; on the other hand, the mean biomass of the grassland beneath the crown amounts to 1.65 t ha^{-1} (Figure 5).

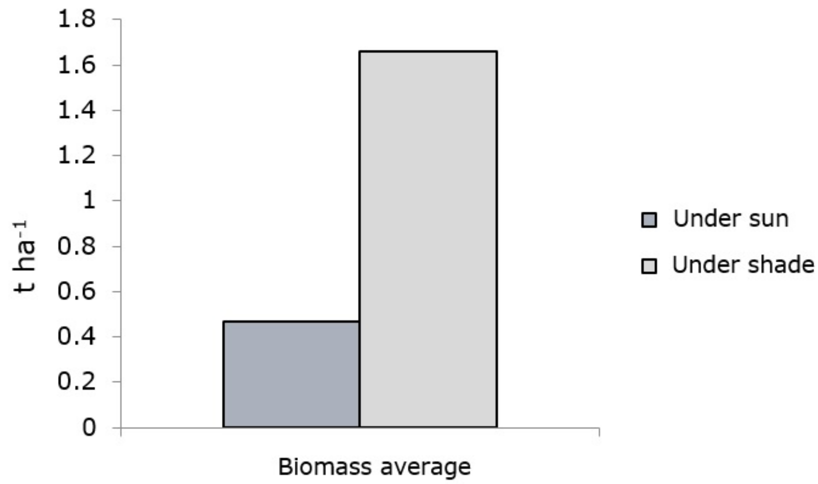

Figure 5. Average grassland biomass under two different conditions of solar radiation. Central Chaco (December 2015).

Valle *et al*. (2004) cite higher values (3.5 t ha^{-1}) for the biomass of 3.5 month old Buffel grass associated with *Gliricidia sepium* (Jacq.) Kunth (a tree species belonging to the *Leguminosae* family) on a 500 m^2 plot located in *Miacatlán*, *Morelos*, Mexico.

Ibrahim *et al*. (2001) stated that *Panicum maximum* had a higher content of biomass (2.98 t ha^{-1}) when associated with *Erythrina poeppigiana* (Walp.) O.F.M. Cook, compared to 2.07 t ha^{-1} of biomass produced by grasslands associated with woody species.

Chemical properties of the soil

Organic matter content. The organic matter is made up of the remains of animals and plants (of fallen leaves, dead logs, tree roots or herbs and crop residues) in various degrees of decay and fulfills important functions; furthermore, it is an indicator of the quality of soil because it conditions its physical, chemical and biological properties (Plaster, 2000; Porta *et al.*, 2014).

The organic matter content of the soil in the studied plots did not show significant differences between sun and shade, but the differences are significant when the sampling depths are compared (Student t test at a confidence level of 95 %). Figure 6 shows the average biomass under the two solar radiation conditions.

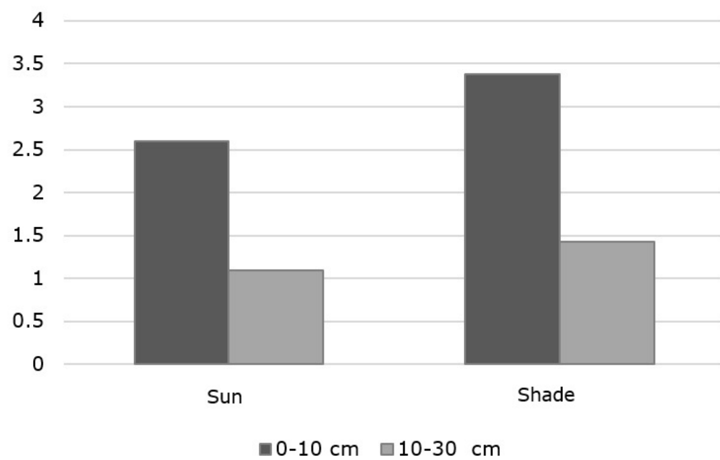

Figure 6. Average organic matter content as a percentage under two different solar radiation conditions and at two different depths in silvopastoral systems of Central Chaco (2015).

Samples drawn beneath the shade of trees, in the first 10 cm of ground, had the highest average value —3.38 %. This percentage is interpreted as a high content of organic matter. Under the sun, the value was 2.6 % in the first 10 cm, an indication that the organic matter content diminished under the sun. The values were also lower at a depth of 10-30 cm, *i.e.* 1.09 % in the sun and 1.43 % under the shade. As the depth increased, the organic matter content decreased to medium and low levels.

This coincides with the description by Thompson and Throeh (2013), according to whom the organic matter covers the surface of the ground, then decays and is mixed and incorporated to the first 5-15 cm of mineral soil thanks to the action of the mesofauna that lives at these depths.

Glatzle (1999) cites an organic matter content of 3.3 % beneath the carob tree crowns, and of 2.4 % in areas without a cover of carob trees in a study carried out in the Central Chaco of Paraguay.

Organic carbon. The soil is a great reservoir of carbon, its concentration has high variations, even within small areas, due to the heterogeneity of soils, the climatic conditions and the geomorphic elements (Yepes *et al.*, 2014).

The total organic carbon content was determined in the laboratory using the Walkley-Black method; the percentage value was extrapolated to kilograms and tons, considering a soil bulk density of 1.24 g cm^{-3} and 1.25 g cm^{-3} at the depths of 0 to 10 cm and 10-30 cm, respectively. Table 3 shows the average values found under different conditions.

Table 3. Total organic carbon content.

	Total Organic Carbon			
	Sun 0-10 cm	Shade 0-10 cm	Sun 10-30 cm	Shade 10-30 cm
O.C (%)	1.5	1.97	0.63	0.83125
O.C (t ha^{-1})	18.6	24.4871	15.435	20.365625

The total content of soil organic carbon in the first 30 cm was 44.85 t ha^{-1} under the direct influence of the carob tree crown, and 34.03 t ha^{-1} outside it.

Lok *et al*. (2013) reported similar values in a silvopastoral system with *Panicum maximum* and *Leucaena leucocephala* (Lam.) de Wit aged 8 years, with an organic carbon content of 38.8 t ha^{-1} in the first 35 cm of ground.

Total nitrogen. Nitrogen is the main element that provides organic matter for plant growth; it is considered to be a primary macronutrient because it is used in large quantities by plants and is not always available in the soil in sufficient quantities to allow them a better growth (Plaster, 2000).

The nitrogen content was estimated taking into account that the content of this element amounts to 5 % of the organic matter. Table 4 presents the average values found under each condition.

Table 4. Total nitrogen soil contents. Central Chaco (2015).

Total Nitrogen				
	Sun 0-10 cm	Shade 0-10 cm	Sun 10-30 cm	Shade 10-30 cm
N (%)	0.129	0.163	0.0547	0.071
N (t ha^{-1})	1.603	2.033	1.34	1.75

The total nitrogen content in the first 10 cm of soil outside the influence of the carob tree crown was 1.6 t ha^{-1}; 2.03 t ha^{-1} under its shade, and 1.34 t ha^{-1} and 1.75 t ha^{-1} at a depth of 10 to 30 cm under the sun and shade, respectively.

Silberman *et al*. (2015) reported a similar nitrogen content in the first 15 cm of ground covered with *Gatton panic* (0.828 t ha^{-1}), and a higher value (4.14 t ha^{-1}) in a silvopastoral system based on its association with *Ziziphus mistol* Griseb. (Mistol) (22 to 27 trees ha^{-1}) with *Gatton panic*, in a study carried out in *Santiago del Estero*, in the arid Chaco of Argentina.

Carbon/Nitrogen Ratio. The organic matter of the plots presented values of 11.8 and 12.07 in soils outside the direct influence of the carob tree crowns, at a depth of 0 to 10 cm and 10-30 cm, respectively; as for the ground under the influence of the carob trees, a value of 11.6 in the first 10 cm, and of 11.67 at a depth of 10 to 30 cm.

No significant differences were obtained in paired plots through the Student t test (with a confidence interval of 95 %) between conditions of sun and shade or for different depths. The calculated value indicates that, according to the description of the organic matter by Porta *et al*. (2014), the organic matter is stable when the value of the C/N ratio is 10 to 14 (Figure 7).

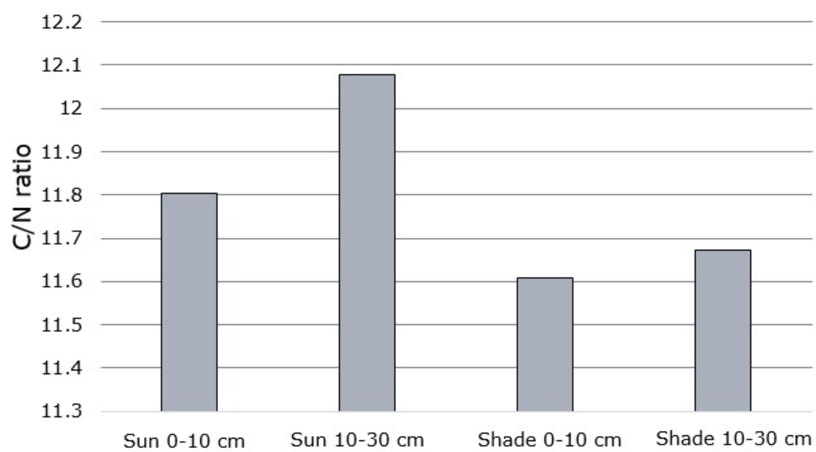

Figure 7. C/N ratio in the plots at two different depths and under two different conditions of solar radiation. Central Chaco (2015).

A C/N ratio is between 10 and 14 favors the proliferation of microorganisms that bring about the decay of organic matter, because it provides them with sufficient carbon to use as a source of energy and with enough nitrogen to synthesize their proteins, and stimulates the mineralization of the nitrogen made available to the plant components of the system.

These results are consistent with the records of East and Felker (1993), for the C/N ratio, of 12 to 14, beneath *Prosopis glandulosa* Torr. var. *glandulosa* in the open land; the first result can be attributed to the increase in microbial activity that led to an increased release of nitrates.

According to González (2009), there were no significant differences in the C/N ratio between silvopastoral systems and natural grasslands located in the province of Chimborazo, Ecuador; the ratio was 11.6 and 11.3, respectively.

Conclusions

The value of the C/N ratio indicates a good mineralization rate, as this proportion stimulates the proliferation of microorganisms that mineralize the organic matter, and therefore, the nutrients made are available for pasture and for the arboreal component of the system.

The conditions of solar radiation and depth do not cause variations in the decay of organic matter, for the C/N ratio did not present significant differences, its average in the first 10 cm of ground outside the influence of the carob tree crown being 11.8; 12.07 in the same condition at a depth of 10 to 30 cm, and 11.63 in the first 10 cm, or 11.7 at a depth of 10 to 30 cm, under the influence of the carob tree crown.

These values prove that the organic matter decays at a medium rate under all the conditions analyzed; therefore, we reject the proposed hypothesis.

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Conflict of interest

The authors declare no conflict of interests.

Contribution by author

Cynthia Carolina Gamarra Lezcano and Maura Isabel Díaz Lezcano: field work, analysis of results and drafting of the manuscript; Mirtha Vera de Ortíz and María del Pilar Galeano: analysis of results and discussion; Antero José Nicolás Cabrera Cardús: logistical support and field work.