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Original article

Carbon content in a silvopastoril system of the Paraguayan central Chaco

Contenido de carbono en un sistema silvopastoril del Chaco central paraguayo

Conteúdo de carbono num sistema silvopastoril no Chaco central paraguaio

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ABSTRACT

The objective of this research was to evaluate the carbon content in a plot under silvopastoral management in a period of one year. This study was carried out in the Paraguayan central Chaco, in a permanent plot under silvopastoral system, due to the interest in estimating carbon storage with the use of this management. The methodology consisted in the establishment of a plot in the year 2015 and its revaluation in 2016. Tree species were identified and their diameter (DPA) and height were determined; pasture samples were identified and extracted. Soil samples were taken at two depths: 0-10 cm and 10-30 cm, for physical and chemical analysis. The difference in basal area, volume, total tree biomass and retained carbon were determined. The tree component was composed of 24 specimens of *Prosopis alba*. The basal area, volume, total tree biomass and total tree carbon showed an increase of 0.029 m2 ha^{-1}, 0.101 m3 ha^{-1}, 0.094 t ha^{-1} and 0.047 t C ha^{-1}, between the first and second measurement. The identified pasture was *Digitaria decumbens*, whose difference in total biomass and total carbon presented an increase of 12.02 t ha^{-1} and 6.01 t ha^{-1} during the period analyzed; the difference in accumulated carbon in the soil was -20.09 t ha^{-1}. The carbon balance gave a difference of -13.77 t ha^{-1}.

Keywords: Basal area; Tree biomass; Carbon content; Silvopastural system.

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RESUMEN

El objetivo de esta investigación fue evaluar del contenido de carbono en una parcela bajo manejo silvopastoril en un período de un año. Este trabajo fue realizado en el Chaco central paraguayo, en una parcela permanente bajo sistema silvopastoril, debido al interés en estimar el almacenamiento de carbono con la utilización de este manejo. La metodología consistió en el establecimiento de una parcela en el año 2015 y su revaluación en el 2016. Se identificaron las especies arbóreas y se determinó su diámetro (DPA) y altura; se identificaron y extrajeron muestras de pasturas. Las muestras de suelos fueron tomadas a dos profundidades: de 0-10 cm y de 10-30 cm, para un análisis físico y químico. Se determinó la diferencia del área basal, el volumen, la biomasa arbórea total y el carbono acumulado. El componente arbóreo estaba compuesto por 24 ejemplares de *Prosopis alba*. El área basal, el volumen, la biomasa arbórea total y el carbono arbóreo total presentaron un incremento de 0,029 m^2 ha^{-1}, 0,101 m^3 ha^{-1}, de 0,094 t ha^{-1} y 0,047 t C ha^{-1}, entre la primera y la segunda medición. La pastura identificada fue *Digitaria decumbens*, cuya diferencia de biomasa total y carbono total presentó un incremento de 12,02 t ha^{-1} y 6,01 t ha^{-1} durante el periodo analizado; la diferencia del carbono acumulado en el suelo fue de -20,09 t ha^{-1}. El balance de carbono dio una diferencia de -13,77 t ha^{-1}.

Palabras clave: Área basal; Biomasa arbórea; Contenido de carbono; Sistema silvopastoril.

RESUMO

O objectivo desta investigação era avaliar o conteúdo de carbono numa parcela sob gestão silvopastoril num período de um ano. Este trabalho foi realizado no Chaco central do Paraguai, numa parcela permanente sob o sistema silvopastoril, devido ao interesse em estimar a armazenagem de carbono com a utilização desta gestão. A metodologia consistiu no estabelecimento de uma parcela no ano 2015 e a sua revalorização em 2016. Foram identificadas espécies arbóreas e o seu diâmetro (DPA) e altura foram determinados; foram identificadas e extraídas amostras de pastagens. Foram recolhidas amostras de solo a duas profundidades: 0-10 cm e 10-30 cm, para análises físicas e químicas. A diferença em área basal, volume, biomassa arbórea total e carbono acumulado foram determinados. A componente de árvore era composta por 24 espécimes de Prosopis alba. A área basal, volume, biomassa arbórea total e carbono arbóreo total mostraram um aumento de 0,029 m2 ha^{-1}, 0,101 m3 ha^{-1}, 0,094 t ha^{-1} e 0,047 t C ha^{-1}, entre a primeira e a segunda medição. A pastagem identificada foi. Digitaria decumbens, cuja diferença em biomassa total e carbono total apresentou um aumento de 12,02 t ha^{-1} e 6,01 t ha^{-1} durante o período analisado; a diferença em carbono acumulado no solo foi de -20,09 t ha^{-1}. O balanço de carbono deu uma diferença de -13,77 t ha^{-1}.

Palavras-chave: Área basal; Biomassa de árvores; Teor de carbono; Sistema silvopastoril.

INTRODUCTION

Land use change has been increasing in recent times due to the advancement of the agricultural frontier, shifting from forest to planted pasture. This has caused severe problems to the environment, as pastures have been degraded, there has been loss of soil due to erosion, the level of soil fertility has decreased and water pollution has increased.

Silvopastoral systems are a form of land use where trees, shrubs, grasses and animals interact to diversify and optimize production on small lands, from which various products such as wood, fodder and firewood are obtained. These systems are not considered as forests, but they have an important tree component that must be considered for carbon stock estimates (López, 2010).

This system is an alternative that allows to improve the quality of the soil by combining trees, grasses and cattle. The silvopastoral system, besides benefiting the environment, providing organic matter to the soil and capturing carbon dioxide *(CO_2)*, also provides the animal with shade and protection against frost and can contribute to the mitigation of global warming through carbon sequestration and storage, since tree species can retain carbon for a long time, mainly in their wood and soil.

The objective of the present research was to evaluate the carbon content in a plot under silvopastoral system of the Paraguayan central Chaco in a period of one year.

MATERIALS AND METHODS

The research was conducted in a farm under sustainable soil management with silvopasture practices developed in the district of Filadelfia in the department of Boquerón, Western Region of the Republic of Paraguay. The permanent plot is located between the parallels 20°05' and 23°48' South latitude and 62°40' and 59°20' longitude West.

A permanent monitoring plot of 100 x 100 m (10 000 m²) was established in 2015, to be re-evaluated in 2016, and the tree, livestock, pasture and soil components were evaluated.

The trees were marked, georeferenced and measured in diameter (DPA) and total height (ht) of the individuals. In addition, the basal area and volume dasometric variables were calculated and the total biomass and carbon stored in the tree component was estimated, following the following formulas (Equation 1) y (Equation 2).

$$G = \frac{\pi * DPA^2}{4} \qquad (1)$$

Where:

G = basal area (m²)
ð = 3,1416
DAP = Diameter a 1,3 m (cm)

$$V = G * f * ht \qquad (2)$$

Where:

V = tree volume (m³)
G = basal area (m²)
f = shape factor (0,811) for different species in the Chaco (Quinteros, 2001)
ht = height (m)

For the determination of the Total Biomass (TB) of the tree component, the Sato *et al.,* (2015) (Equation 3):

$$BT = 0{,}0609 * (DPA^2 * ht)(DPA^2 * ht)^{0{,}9932} \quad (3)$$

To determine the biomass of the pastures, the pastures present were identified, then eight representative samples were extracted using a 1 m^2 sieve and then dried in an oven at 65 °C until they reached a constant weight; finally, the dry weight was obtained using a scale.

The total biomass, both tree and pasture biomass, was multiplied by 0.5 because the dry matter contains on average 50 % of stored carbon, using the formula according to IPCC, (2006).

The animal component was characterized by determining the type of handling and the load capacity.

The soil variables evaluated were physical properties such as bulk density (using the Metal Cylinder Method) and texture (Bouyucos Method) and chemical properties: pH, phosphorus, nitrogen, organic matter and carbon in the soil.

Eight soil samples were taken, at two depths: 0-10 cm and 10-30 cm, totaling 16 samples. The amount of organic carbon (CO) and organic matter (MO) of each sample was determined by the method of Walkley and Black, according to Tedesco *et al*. (1985) using the following formula (Equation 4).

$$\%\ CO = \%\ MO \div 1{,}72 \quad (4)$$

Phosphorus was determined by the Bray and Kurtz Method, according to Tedesco *et al*., (1985). The total nitrogen content in the soil was determined by the following formula (Equation 5)

$$\%\ N = \%\ MO\ *\ 0{,}05 \quad (5)$$

(Plaster 2000)

To determine the carbon accumulated in the system, all the deposits (tree, herbaceous and soil carbon) were added together and to establish the carbon storage, the difference in the deposits between the years studied was determined.

RESULTS AND DISCUSSION

Characterization of the plot

The plot studied was intended for a silvopastoral system for meat production, under a rotating regime and variable allocation. It was installed in November 2015, and was under a closed regime, without the presence of animals, while in the remeasurement of the plot in October 2016, the paddock had a load of animals.

The bovine breeds found in this plot were: Santa Gertrudis, Hereford and Brangus, with a load capacity of one livestock unit per hectare, consisting of calves and heifers.

The results obtained are close to the values reported by Alvarenga *et al.*, (1998), who under similar conditions in the central Paraguayan Chaco reported an animal load of 0.70 livestock unit/ha.

Griffith's research (2016) reported an animal load of 1.01 livestock unit per hectare in the paddocks under study in the central Paraguayan Chaco. As for the characterization of the floristic composition of the studied plot, the tree individuals present were identified, being *Prosopis alba* the only species found.

A total of 24 individuals of the species *Prosopis alba* were recorded in the plot, with an average diameter of 4.9 cm, the average height was 2.5 m and an average distance of 12 meters between each tree; in addition, individuals belonging to the category of saplings and bole-stem with a diameter of between 2.4 and 9 cm were inventoried. Table 1 shows the floristic listings of the renewals recorded in the first measurement and the second shows a loss of 11 individuals corresponding to the renewals recorded in the first measurement, leaving only the *Prosopis alba*.

In the first measurement the presence of saplings and grasslands of *Aspidosperma quebracho-blanco* and *Cercidium praecox* was recorded, which were not found in the second measurement presumably by mechanical removal; it was also verified the presence of *Sorghum vulgare* distributed over the entire surface, during the second measurement.

Associated with the *Prosopis alba*, the *Digitaria decumbens* (pangola) pasture was identified; the height of this herbaceous component in the plot varied from 40 to 60 cm, between the first and the second measurement (Table 1).

Table 1. - Floristic composition of the permanent plot under a silvopastoral system, Chaco central, Paraguay

Family	Specie	Common name
Apocynaceae	*Aspidosperma quebracho-blanco* Schltdl.	quebracho blanco
Fabaceae	*Prosopis alba* (Griseb.)	algarrobo blanco
Fabaceae	*Cercidium praecox* (Ruiz y Pav.)	verde olivo

According to Griffith (2016), in his study to estimate the carbon content in three components (tree, pasture and soil) of a silvopastoral system in the Paraguayan Chaco, trees of the species *P. alba* were found in the study plots, with an average height of 5.6 m per individual and a total volume of 0.438 m^3 ha^{-1} and the pastures found in the plots were *Gatton panic* and *Digitaria decumbens*, with an average height of 12.5 cm.

According to Gamarra (2016), in his study analyzing the carbon/nitrogen ratio in soils of silvopastoral systems in the Paraguayan Chaco, a total of 31 tree individuals per hectare were recorded, of which 53 % had a diameter of less than 10 cm and the remaining individuals (47 %) had an average diameter of 16 cm.

Carbon in the arboreal component

Basal area

The basal area showed a difference of 0.029 m^2 ha^{-1} between the first and second measurement. The Table 2 shows the total basal area per hectare of each measurement (Table 2).

Table 2. - Basal area in hectares of the permanent plot under a silvopastoral system, Chaco central, Paraguay

	Specie	Total basal area (m^2 ha^{-1})
Measurement 1	*Prosopis alba*	0,022
Measurement 2	*Prosopis alba*	0,051
Difference	***Prosopis alba***	**0,029**

Gamarra (2016) mentions that the average basal area was 0.34 m^2 ha^{-1}, as well as Leguizamón (2016) that in his study of carbon content estimation in the central Chaco the basal area obtained an average of 0.3 m^2 ha^1.

Total volume

The difference in tree volume recorded an average of 0.101 m^3 ha^{-1} between the two measurements. The Table 3 shows the average plot volume per hectare (Table 3).

Table 3. - Total volume of the permanent plot under a silvopastoral system, Chaco central, Paraguay

	Specie	Total volume (m^3 ha^{-1})
Measurement 1	*Prosopis alba*	0,032
Measurement 2	*Prosopis alba*	0,133
Difference	***Prosopis alba***	**0,101**

Griffith (2016) conducted a study to estimate the carbon content of the three components (arboreal, pasture and soil) in the central Chaco, in which he obtained an average total volume of *Prosopis spp*. of 0.438 m^3 ha^{-1}, while Gamarra (2016) in similar conditions obtained an average total volume of 1,59 m^3 ha^{-1}.

Total arboreal biomass

The difference in total biomass estimates between the measurements made in 2015 and 2016 was 0.094 t ha^{-1} in the plot, due to the increase in both diameter and height of each of the individuals inventoried. The Table 4 shows the total average biomass (Table 4).

Table 4. - Total biomass in the permanent plot under a silvopastoral system, Chaco central, Paraguay

	Specie	**Biomass (t ha^{-1})**
Measurement 1	*Prosopis alba*	0,031
Measurement 2	*Prosopis alba*	0,125
Difference	***Prosopis alba***	**0,094**

The total biomass values estimated in this research are similar to those reported by Brítez (2015) in a study on an integrated production system carried out in the Paraguayan Chaco, where the accumulated biomass was 0.07 t ha^{-1}, while Leguizamón (2016) in his study estimating carbon content in the central Chaco, reports that the average total biomass was 2.3 t ha^{1}.

Total arboreal carbon retained

To consider carbon storage in forest biomass it is assumed that living trees contain approximately 50 % carbon. Therefore, it is suggested to use the factor of 0.5 to transform the biomass to carbon (Mac Dicken, 1997). The difference between the estimates of total tree carbon in the plot was 0.047 t C ha^{-1}. The Table 5 shows the estimated tree carbon in each of the measurements and the difference between them (Table 5).

Table 5. - Total carbon in the tree component in the permanent plot under a silvopastoral system Chaco central, Paraguay

	Specie	**Total carbon (t ha^{-1})**
Measurement 1	*Prosopis alba*	0,015
Measurement 2	*Prosopis alba*	0,062
Difference	***Prosopis alba***	**0,047**

Leguizamón (2016) obtained an average of 2 t ha^{-1} of total biomass of *Prosopis spp*. and the carbon equivalent yielded an average of 153 t ha^{-1}. Griffith (2016) comments in his study to estimate the carbon content in the three components (tree, pasture and soil) in the central Chaco, which obtained an average of 36.72 t ha^{-1} and the carbon equivalent yielded an average of 134,65 t ha^{-1}.

Carbon in pasture

The Table 6 shows that, in the first measurement, the total herbaceous biomass was 610 kg ha^{-1}, where the pasture coverage was 50 % of the plot's soil, with the height of the pasture being between 20 and 30 cm, with no other type of herbaceous fodder supply being recorded. In the second measurement, a total of 12,630 kg ha^{-1} was recorded, where the coverage was 100 % of the soil, with the height of the pasture being 40 and 60 cm. In addition, the presence of *Sorgum spp*. with an average height of 2 m.

The estimate of the difference in herbaceous biomass was 12,020 kg ha^{-1} between one year and the next. This can be attributed to the fact that in the first measurement the plot was closed and in the second measurement it was noted that the biomass presented a higher value, evidencing the soil preparation (plowing, subsoiling and harrowing), noting the increase in fresh matter from the pasture.

Total carbon storage difference in pasture was estimated at 6.01 t ha^{-1} between the years 2015 and 2016 (Table 6).

Table 6. - Biomass and total carbon in pasture in the permanent plot under a silvopastoral system, Chaco central, Paraguay

	Specie	Total biomass (t ha^{-1})	Total Carbono (t ha^{-1})
Measurement 1	*Digitaria decumbens*	0,61	0,305
Measurement 2	*Digitaria decumbens*	12,63	6,315
Difference	*Digitaria decumbens*	12,02	6,01

Leguizamón (2016) obtained for the genus *Prosopis*, total biomass and carbon values of 0.61 t ha^{-1} and 0.305 t ha^{-1}, respectively.

Physical and chemical properties of soil

Apparent soil density and texture

Apparent density results recorded an average of 1490 kg m^{-3} at depths of 0-10 cm, and 10-30 cm an average of 1433 kg m^{-3} was recognized, which according to Fuentes (1999) is associated with sandy soils.

The soil texture analyzed at the sampling depths was sandy-clay loam and sandy-clay soil. Gamarra *et al.*, (2018) show that soil density was 1 240 kg m^{-3} and 1 250 kg m^{-3} for depths of 0-10 cm and 10-30 cm, respectively, in their research related to

the carbon/nitrogen ratio in soils of silvopastoral systems in the Paraguayan Chaco, whose soil sampling was recorded in the area of this study.

One effect of grazing is an increase in the apparent density of the soil due to the trampling of the animals, and this must be taken into account when giving the grass a chance to rest and recover (Kunst *et al*., 2015).

Determination of pH

In the two depths, 0-10 cm and 10-30 cm, the pH was neutral and slightly acidic, averaging 6.62 and 6.8 respectively. Similar results were reported by Griffith (2016) who recorded pH values of 6.2 to 6.4 in his study of carbon content in a silvopastoral system in the central Chaco, Paraguay.

According to Thompson and Troeh (2015), the optimal soil pH is between 6.0 and 7.5 since all nutrients are reasonably accessible, and pH values between 6.5 and 7.5 are usually the best in terms of phosphorus availability.

Determination of organic matter, phosphorus, organic carbon and total nitrogen in the soil

The Table 7 shows the values of organic matter, phosphorus, organic carbon and total nitrogen in the soil (Table 7).

Table 7. - Values of organic matter, phosphorus, organic carbon and nitrogen in the plot under sustainable management in the town of Filadelfia Chaco, Paraguay

Sample	Sample depth	Organic matter (%)	Phosphorus (mg kg^{-1})	COS (%)	COS (t C ha^{-1})	N (%)	N (kg ha^{-1})
1	0-10 cm	1,73	82,78	0,8	11,2	0,08	1 120
2	0-10 cm	0,35	118,42	0,2	2,8	0,01	140
Average	0-10 cm	1,04	100,6	0,5	7	0,045	630
3	10-30 cm	1,38	63,62	0,8	11,2	0,06	840
4	10-30 cm	1,38	50,97	1	14	0,06	840
Average	10-30 cm	1,38	57,295	0,9	12,6	0,06	840

The organic matter obtained was low, the phosphorus content was high and the total nitrogen stored in the soil at all depths was low, according to the values established by Criollo (2013).

The results obtained in this research coincide with the results of similar research carried out in the South American Gran Chaco by Ledesma (1995), Griffith (2016) and Díaz Lezcano *et al.,* (2017) According to Ledesma (1995), in a study of the soil in an agricultural experimental station in Colonia Benitez, province of the Argentinean Chaco, the laboratory results show 63.6 ppm of phosphorus at a depth of 0-23 cm, which indicates a high content of phosphorus in a soil with neutral and slightly acidic pH levels. According to Griffith (2016), the organic matter obtained in this investigation in a silvopastoral system in the central Chaco was 0.72 %, and

according to the chemical analysis it presented a high Mg content, as well as K and Al, while Ca was at a medium level.

According to Gamarra *et al*., (2018), in their work on carbon: nitrogen in soils of silvopastoral systems in the Central Chaco, the estimated organic carbon content in the soil, outside the direct influence of the canopy of the carob tree in the first 30 cm of the soil, was 34.03 t ha^{-1} (0-10 cm): 18.60 t ha^{-1} and 10-30 cm: 15.43 t ha^{-1}); under the influence of the crown was 44.84 t ha^{-1} (0-10 cm: 24.48 t ha^{-1} and 10-30 cm: 20.36 t ha^{-1}), considering a soil bulk density of 1 240 kg cm cm^{-3} and 1 250 kg cm cm^{-3} for the depths of 0-10 cm and 10-30 cm, respectively. According to Gamarra (2016), in a study carried out in a plot in silvopastoral system, the total nitrogen content was on average 0.12 % (1 516,85 kg ha^{-1}).

Soil carbon storage

The Table 8 shows a difference in COS of -1.2 % in the first 10 cm of depth, and from 10 to 30 cm a difference of 0.17 %, with a total loss of 20.09 t ha^{-1} from 0 to 30 cm. Other factors to be considered are the emission of methane gas from bovine deposition and the sanitation of animals with deworming agents, which can alter the speed of decomposition of the feces, as well as the microflora of their contact surface on the ground. The use of heavy machinery also influenced the preparation of the site for the sowing of grass, where there was a change in the structure of the soil (Table 8).

Table 8. - Soil carbon content of a plot under silvopastoral system in the central Chaco, Paraguay

Measurement	MO %	MO %	COS %	COS %	COS (t ha^{-1})	COS (t ha^{-1})	COS (t ha^{-1})
	0-10 cm	10-30 cm	0-10 cm	10-30 cm	0-10 cm	10-30 cm	0-30cm
2015	2,93	1,26	1,7	0,73	21,15	18,54	39,69
2016	1,04	1,38	0,5	0,9	7	12,6	19,6
	-1,89	0,12	-1,2	0,17	-14,15	-5,94	-20,09

The difference obtained between the plot remedies reports a loss of COS in the first 30 centimeters of soil, indicating that there was more emission than uptake of this compound. The present estimate of organic carbon, which could be considered early, indicates losses in the greenhouse gas balance, which could constitute a diagnosis of the farm in order to later seek corrective alternatives for cultural management.

The values reported in this study show a negative balance in silvopastoral systems for meat production, which differ from those presented by Messa (2003), Moreno and Lara (2003), who reveal a positive carbon balance in intensive silvopastoral systems, in Venezuela and Colombia, respectively.

According to Messa (2009), another important factor to be considered in this type of study is the variability of the characteristics of the soils under study, as well as the origin of the soil (formative processes), management history, use and current management, which influence the behavior of organic carbon in the soil.

Moreno and Lara (2003) point out that the soil is a more dynamic and unstable natural body than it appears and therefore continuous research into its processes is justified, in order to better understand its role in the carbon cycle.

Carbon storage in a silvopastoral system

The grazing system used did not prove to be effective in capturing CO_2 from the environment during a one-year monitoring period under a meat production regime with site preparation for planted pastures. Table 9 shows the result of carbon storage in the three components studied, giving a value -13,77 t C ha^{-1} (Table 9).

Table 9. - Carbon storage in the three components of the Silvopastoral System (SSP) monitored in the central Chaco, Paraguay

Measurement	Carbon in tree vegetation (t C ha^{-1})	Carbon in Pasture (t C ha^{-1})	Carbon in soil (t C ha^{-1})	Carbono SSP (t C ha^{-1})
2015	0,01	0,03	39,69	39,73
2016	0,06	6,3	19,6	25,96
Difference	**0,05**	**6,27**	**-20,09**	**-13,77**

According to Messa (2009), greenhouse gas emissions from bovines, such as methane and nitrous oxide emissions from enteric fermentation of ruminants, are affected by factors such as: breed of animal, physiological status, health status, composition of animal diet, quality of feed processing, feed management, ruminant excreta management and environmental conditions, factors that influence digestive processes and determine the balance of their final carbon emission products.

The silvopastoral system composed of *Prosopis alba* associated with *Digitaria decumbens* showed a slight increase in basal area, volume, tree biomass, total carbon and arboreal component carbon between the two assessments made, despite the decrease in tree individuals at the study site.

In the pasture component, total biomass, total carbon and carbon equivalent showed an increase in the second measurement which could be attributed to resting in the pasture.

As for the total carbon balance, in the silvopastoral system a loss of 13.77 t ha^{-1} of organic carbon was recorded, which indicates that there was more emission than capture of this compound in the period studied.

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