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Dynamics of carbon storage in forage systems in a livestock farm in Concepción, Paraguay

Dinámica del almacenamiento de carbono en sistemas forrajeros en una finca pecuaria en Concepción, Paraguay

Dinâmica do estoque de carbono em sistemas pastoris para pecuária de corte em Concepción, Paraguay

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Abstract

Although the capacity of plants to store carbon is known, obtaining information about the sequestration potential in the soil and in herbaceous, shrubby and tree biomass in land use systems is essential, even more so in landscapes dominated by livestock. The objective was to study the dynamics of carbon storage in three different forage systems in a livestock farm in Concepción, Paraguay. For this, the carbon level was estimated at different soil depths (0-20, 20-40 and 40-60 cm) and in the herbaceous/shrub biomass in three systems (*Brachiaria brizantha* cv *Marandú, Panicum maximum* cv *Colonial and Leucaena leucocephala* consortium with *colonial*), with an interval of 30 days between the three measurement moments. The results generated from the biomass indicated that the system constituted by the colonial forage consortium with *L. leucocephala*, presented the highest level of carbon (3.73 $t.ha^{-1}$), showing a significant difference in relation to the *B. brizantha* (2.12 $t.ha^{-1}$; $p<0.05$). On the other hand, the initial period showed higher carbon concentration (4.55 $t.ha^{-1}$; $p<0.05$). Likewise, a higher content was found at a depth of 0-20 cm (20.26 $t.ha^{-1}$; $p<0.05$). These results were obtained in a winter process. In this regard, it is important to mention that forage shrubs in systems with pastures constitute a fundamental nutritional resource in winter, in this sense it is recommended to use improved and consortium pasture systems, to increase carbon storage, achieve stable and productive systems, in correspondence with its potentialities.

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Resumen

A pesar de que se conoce la capacidad que tienen los vegetales para almacenar carbono, la obtención de información acerca del potencial de secuestro en el suelo y en la biomasa herbácea, arbustiva y arbórea en los sistemas de uso de tierra, es fundamental, más aún en paisajes dominados por la ganadería. Así, el objetivo fue estudiar la dinámica del almacenamiento de carbono en tres diferentes sistemas forrajeros en una finca pecuaria en Concepción, Paraguay. Para ello, se estimó el nivel de carbono a diferentes profundidades del suelo (0-20, 20-40 y 40-60 cm) y en la biomasa herbácea/arbustiva en tres sistemas (*Brachiaria brizantha* cv *Marandú*, *Panicum* máximum cv *Colonial* y *Leucaena leucocephala* consorciada con *colonial),* con un intervalo de 30 días entre los tres momentos de medición. Los resultados generados en biomasa, indicaron que el sistema constituido por la forrajera colonial consorciada con *L. leucocephala,* presentó el nivel más alto de carbono (3,73 $t.ha^{-1}$), mostrando diferencia significativa en relación a la *B. brizantha* (2,12 $t.ha^{-1}$; $p<0,05$). Por otro lado, el periodo inicial mostró mayor concentración de carbono (4,55 $t.ha^{-1}$; $p<0,05$). Igualmente, se pudo constatar mayor contenido a una profundidad de 0-20 cm (20,26 $t.ha^{-1}$; $p<0,05$). Estos resultados fueron obtenidos en un proceso invernal. Al respecto, es importante mencionar que las arbustivas forrajeras en sistemas con pasturas constituyen un recurso nutricional fundamental en invierno, en ese sentido se recomienda utilizar sistemas de pasturas mejoradas y consorciadas, para aumentar el almacenamiento de carbono, lograr sistemas estables y productivos, en correspondencia con sus potencialidades.

Palabras clave: pasturas, ganadería, biomasa, suelo, almacenamiento de carbono.

Resumo

Embora seja conhecida a capacidade das plantas em armazenar carbono, é essencial obter informações sobre o potencial de sequestro no solo e na biomassa herbácea, arbustiva e arbórea em sistemas de uso da terra, ainda mais em paisagens dominadas pela pecuária. O objetivo foi estudar a dinâmica do armazenamento de carbono em três diferentes sistemas forrageiros em uma fazenda de gado em Concepción, Paraguai. Para isso, o teor de carbono foi estimado em diferentes profundidades do solo (0-20, 20-40 e 40-60 cm) e na biomassa herbácea/arbustiva em três sistemas (*Brachiaria brizantha* cv *Marandú, Panicum maximum* cv *Colonial e Leucaena leucocephala* consórcio com *colonial*), com intervalo de 30 dias entre os três momentos de medição. Os resultados gerados a partir da biomassa indicaram que o sistema constituído pelo consórcio forrageiro colonial com *L. leucocephala*, apresentou o maior teor de carbono (3,73 $t.ha^{-1}$), apresentando diferença significativa em relação ao *B. brizantha* (2,12 $t.ha^{-1}$; $p<0,05$). Por outro lado, o período inicial apresentou maior concentração de carbono (4,55 $t.ha^{-1}$; $p<0,05$). Da mesma forma, um maior teor foi encontrado na profundidade de 0-20 cm (20,26 $t.ha^{-1}$; $p<0,05$). Esses resultados foram obtidos em um processo de inverno. Nesse sentido, é importante mencionar que os arbustos forrageiros em sistemas com pastagens constituem um recurso nutricional fundamental no inverno, neste sentido recomenda-se o uso de sistemas de pastagem melhorados e consorciados, para aumentar o armazenamento de carbono, alcançar sistemas estáveis e produtivos, em correspondência com suas potencialidades.

Palavras-chave: pastagens, pecuária, biomassa, chão, armazenamento de carbono.

Introduction

In Latin America, one of the main changes in land use has been the deforestation of forests to establish pastures for livestock, and currently, pasture areas continue to increase. The main components of carbon (C) storage in land use are soil organic carbon (SOC) and aboveground soil biomass. Despite the recognition of the potential of both forests and agroforestry systems to store C, there is still a lack of information on soil and tree biomass sequestration in livestock landscapes in Latin America.

In this context, livestock activities have a significant impact on the environment, producing 9% of carbon dioxide (CO_2) emissions of anthropogenic origin, where the livestock sector, in general, is considered responsible for 18% of greenhouse gas (GHG) emissions measured in CO_2 equivalents, in addition to emitting 37% of methane (CH_4) and 65% of nitrous oxide (N_2O) (González *et al*., 2015). In this regard, Camero-Rey (2020), points out the questioning of livestock production, both for its effect on the soil and its contribution to the increase in GEI emissions. According to Lara (2019), livestock intensification has favored economic and social development; however, inadequate management of pastures and animals has led the agricultural sector to have a negative impact on the environment. In view of this, silvopastural practices have played a key role in contributing to the recovery of degraded soils in tropical regions, in addition to being a production alternative that promotes the mitigation of the effects on the environment.

In Paraguay, the livestock activities are quite active; therefore, it is important to monitor C levels in soil and herbaceous and tree biomass. Thus, the objective of this work consisted to study the dynamics of C storage, in three different forage systems and in the soil at different depths, in a livestock farm in the department of Concepción, Paraguay.

Materials and methods

Study area

The study was carried out on a private livestock farm with rotational grazing, of 410 hectares (ha) in the locality of Capitán Giménez, district of Horqueta, Department of Concepción, Paraguay (figure 1). The facility is located to the north of the Oriental region (parallels 22º 00' and 23º 30' south latitude and, meridians 58º 00' and 56º 11' west longitude), locality of Capitán Giménez, district of Horqueta, Department of Concepción, Paraguay. The area exhibits heterogeneous topography, being the center and north, low and flat, with extensive grasslands for grazing alternated with wooded sectors (Instituto Nacional de Estadísticas [INE], 2002).

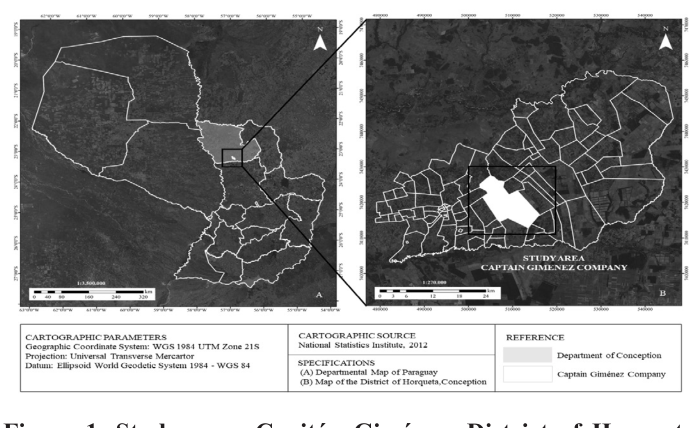

Figure 1. Study area, Capitán Giménez. District of Horqueta, Paraguay.

Procedure

The field operation was carried out in three moments (1, 2, and 3) with an interval of 30 days between them, during a characteristic winter period (between June and September). The parameter of interest consisted of the C concentration measured in tons per hectare ($t.ha^{-1}$), at different soil depths (0-20, 20-40, and 40-60 centimeter (cm)) and the herbaceous/shrub biomass in three direct grazing systems formed by: (1) only *Brachiaria brizantha cv Marandú*, (2) only *Panicum maximun cv. Colonial* and (3) the consortium defined as the combination of *Colonial* with *Leucaena leucocephala*. It is important to point out, that the grazing area constituted by these systems, had a month of rest of the animal load at the beginning of the analysis, taking into account that in the case of mentioned grasses, they are tropical perennials, and in winter, they are given a grazing rest. The units or plots were of the nested type, where the limits given the matrix unit considered independently for each system (75 x 15 meters (m)) concentrated three subplots (25 x 15 m). The sampling areas were marked with wooden stakes so that the same points were measured in subsequent samplings.

Herbaceous and shrub plant biomass

Herbaceous plant biomass was collected using a 1 square meter (m^2) frame. Biomass sampling was performed randomly, establishing a transept diagonally to each matrix plot, joining 2 opposite vertices. Subsequently, all the biomass was cut at 15 cm from the ground, within the area delimited by the square. After, they were placed in coded bags; the fresh weight was determined (electronic balance, ACS-C, Tokyo, Japan) and finally, they were dried in an oven (UN30, Memmert, Germany) at a temperature of 105°C (48 hours). The dry matter (MS) was multiplied by 0.5 to estimate the C content (Intergovernmental Panel on Climate Change [IPCC], 2003.

Regarding shrub biomass, 15 trees were randomly selected within the matrix plot (75 x 15 m) and the technique of targeted sampling was applied to the most tender sections (leaves and twigs, simulating the harvesting by the animal and its incidence on C dynamics) of each tree. Green matter (MV) and MS were determined, whose value was multiplied by 0.5 to estimate the C content (IPCC, 2003).

Five repetitions were considered (biomass samples) for each system, at each time of evaluation. For the estimation of total biomass (BT) the equation: $BT=0.112 \times (pw \times DAP^2 \times H)^{0{,}916}$ was used, which includes the diameter at breast height (DAP), wood density (pw), and, height (H) (Chavé *et al.*, 2005).

Soil samples

The soil was extracted by opening mini-trial pits. Three composite samples were taken at each of the three depths (0-20, 20-40, and 40-60 cm), in each system, totaling 27 sample units in each period. For the estimation of C, the Van Benmelen factor of 1.724 was used, which results from the assumption that soil organic matter (OM) contains 58% C (Vela and Rodriguez, 2012), from the equation: %C = % OM/1.724 or %C = % OM (0.58).

Statistical analysis

The data were analyzed in R software (R Core Team, 2020), applying descriptive statistics, factorial analysis of variance (ANOVA) (Factors considered: moment, forage species, and depth), and, Tukey's test, with a significance level of 5% (Gutiérrez and De La Vara, 2012).

Results and discussion

Estimation of carbon in biomass

Table 1 shows the descriptive measures for C in biomass at the three moments of measurement according to the forage system.

Visualizing the initial period (moment 1) of evaluation, it is possible to detect that, the system conformed by colonial showed the highest average level of C (5.99 $t.ha^{-1}$), with a higher standard deviation (DE) (±1.49). However, the highest coefficient of variation (CV) was evidenced in *B. brizantha* (39.03%), with a minimum value (MN) of 0.87 $t.ha^{-1}$ and a maximum (MAX) of 3.09 $t.ha^{-1}$, denoting a greater variation margin, compared to the other species. Research made by Giraldo *et al*., (2006), who evaluated different types of pastures without trees, among them, estrella (*Cynodon plectostachyus*) and Guinea, Tanzania, and Mombasa (*Panicum maximum*), indicated a lower value (3.19 $t.ha^{-1}$) than those registered in colonial and in the consortium system (colonial+*L. leucocephala*). While Miranda *et al.,* (2007), mentioned for agrosilvopastoral systems in Cuba, an average value of C similar (1.63 $t.ha^{-1}$) to *B. brizantha*. However, in another study (Miranda *et al*., 2008), considering a silvopastoral system composed of *L. leucocephala* and *Andropogon guayanus,* the level was higher (8.55 $t.ha^{-1}$) in relation to the results obtained.

The results of Timoteo *et al.,* (2016) show an accumulation of C during the first year in biomass and aerial necromass in agroforestry systems of *L. leucocephala*, *Theobroma cacao,* and *Cajanus cajan* (11.37 $t.ha^{-1}$), in this sense, *L. leucocephala* is a species that presents good attributes to be used in silvopastoral systems, for being able to store large amounts of C in its biomass (Soto-Correa *et al*., 2019). For their part, Naranjo *et al*., (2012), state that the degraded and improved pastures are net emitters of GEI, with a value equivalent to 3.153 and 3.259 kg CO_2 $eq.h^{-1}.year^{-1}$, respectively; while the SSPi remove GEI from the atmosphere, i.e., they have a positive balance of 8,800 and 26.56 kg CO_2 $eq.h^{-1}.year^{-1}$ alone and associated with timber trees, respectively.

Table 1. Descriptive measures of C level ($t.ha^{-1}$) in biomass.

Moment	Forage species	Mean	DE	CV (%)	Minimum	Maximum
	B. brizantha	2.28	0.89	39.03	0.87	3.09
1	Colonial	5.99	1.49	24.91	4.15	7.90
	Consortium (Colonial+ *L. leucocephala.*)	5.39	1.42	26.41	3.50	7.43
	B. brizantha	1.72	0.48	27.98	1.17	2.39
2	Colonial	2.34	0.78	33.31	1.36	3.22
	Consortium (Colonial+ *L. leucocephala*)	3.04	0.60	19.76	2.40	3.74
	B. brizantha	2.35	0.35	14.94	2.05	2.87
3	Colonial	1.88	0.35	18.47	1.35	2.28
	Consortium (Colonial+ *L. leucocephala*)	2.78	0.33	11.87	2.44	3.23

DE: Standard deviation; CV: Coefficient of variation.

Likewise, Casasola *et al.*, (2013) manifest that total C stored in improved pastures of *B. brizantha* (153 $t.ha^{-1}$) was lower than in pastures of the same species associated with *Eucalyptus deglupta* (173.7 $t.ha^{-1}$) and, *Arachis pintoi* (186.8 $t.ha^{-1}$). Trees in pastures store significant amounts of C in their stems, which is very important since it has a greater permanence in the system than that one accumulated in the herbaceous vegetation. The management of improved pastures with trees in the humid and sub-humid tropics could potentially fix around 635,000 t of CO_2 per year. According to Callo *et al.* (2011), the efficiency of C fixation in pastures with improved grasses lies in the fact that they generally have deep root systems, which can contribute to the net primary productivity of the species and, therefore, to the C immobilization capacity.

Perennial plants can translocate more C than annual plants, which indicates that they have a higher capacity for C storage in the roots. In the case of perennial pastures, this property facilitates the regrowth after cutting or grazing (Schmitt *et al*., 2013). This dynamic translocation of C was evidenced in the forages included in this research.

Regarding moment 2 (table 1), the colonial forage species consortium with *L. leucocephala* showed the highest average level of C (3.04 $t.ha^{-1}$), followed by colonial (2.34 $t.ha^{-1}$) and *B. brizantha* (1.72 $t.ha^{-1}$). The DE values had a decreasing behavior when comparing the forage species, being higher in colonial (±0.78) and lower in *B. brizantha* (±0.48). These variations denote a higher concentration around the central values for the levels of C uptake in the *B. brizantha* forage species. Taking into account the CV, a high value in colonial (33.3%) can be observed, followed by *B. brizantha* (27.91%) and finally, colonial consortium with *L. leucocephala* (19.47%), the latter showing greater homogeneity among the samples. However, the CV levels, for the most part, can be considered optimal in terms of data variability, giving confidence to the study (Martínez-López, 2017). About the C values themselves, Anguiano *et al.* (2013) obtained in their research higher storage levels in the graminoid component, Cuba CT 115, without associated *L. leucocephala*.

Concerning descriptive measures of the third biomass sampling by forage species, average values of C quantity were obtained as follows: colonial (1.88 $t.ha^{-1}$), *B. brizantha* (2.35 $t.ha^{-1}$), and colonial consortium with *L. leucocephala* (2.78 $t.ha^{-1}$), the latter standing out as the system with the highest uptake rate. The DE indicated that the consortium (colonial+ *L. leucocephala*) was characterized by a lower level of data spacing around the mean (±0.33) although the differences were minimal with the other pasture types.

Table 2 shows the results of the comparison of means using Tukey's test for the main factors and the one of interaction.

Overall, it was observed that at the first moment of evaluation, C levels were higher than in the following two measurements ($p<0.05$). However, in moments 2 and 3, the values were more stable. Regarding the grazing systems, the consortium recorded the highest average value of C (3.73 $t.ha^{-1}$), differing from *B. brizantha*, ($p<0.05$), not so from colonial ($p>0.05$). Regarding the significant interaction effect ($p<0.05$), that is, the C values suffered variations and were different in some combined levels of the factors (moment and forage species), it can be visualized that, in the initial period, in the colonial and consortium type pasture (colonial + *L. leucocephala*), the C concentrations were higher, showing statistically significant differences with the different treatments analyzed ($p<0.05$). This higher level of C storage recorded in the first measurement is due to the fact that it was evaluated at the beginning of the winter period, taking into account that we are working on C4 perennial forage species, categorized in this way, precisely because of the configuration of their photosynthetic system and the temperature requirements for their physiological dynamics (Ludlow, 1985; Winslow *et al*., 2003).

Studies developed in Costa Rica evidenced that the land use system with an improved pasture of *B. brizantha* plus trees, presented in the three evaluations the highest average values of MS, exceeding by 45 and 55% the yields of the system under degraded pastures (Ramos-Veintimilla, 2003). In general, it can be stated that when the pasture is used correctly, the biomass bank with implanted pastures can be an option to increase C storage in the soil, as its exploitation time increases, depending on its management system, among other factors. In this sense, Ferri (2014) concluded that the calculated increase of CO_2 in the atmosphere would be a determinant in the increase of productivity and/or would attenuate the effects of climatic variability on C4 pastures, as is the case of those used in this study. However, he stated that on the other hand, it would negatively affect the nutritive value of the forage, decreasing its protein concentration.

Table 2. Comparison of means for C level ($t.ha^{-1}$) in biomass.

Factors	Categories	Mean ± DE
Sampling moments	1	4.55 ± 2.07 a
	2	2.37 ± 0.81 b
	3	2.33 ± 0.50 b
Forage species	Consortium (Colonial+ *L. leucocephala*)	3.73 ± 1.48 a
	Colonial	3.40 ± 2.11 a
	B. brizantha	2.12 ± 0.64 b
Double interaction: Moment-forage species	1-Colonial	5.99 ± 1.49 a
	1-Consortium (Colonial+ *L. leucocephala*)	5.39 ± 1.42 a
	2-Consortium (Colonial+ *L. leucocephala*)	3.04 ± 0.60 b
	3-Consortium (Colonial+ *L. leucocephala*)	2.78 ± 0.33 b
	3-*B. brizantha*	2.35 ± 0.35 b
	2-Colonial	2.34 ± 0.78 b
	1-*B. brizantha*	2.28 ± 0.89 b
	3-Colonial	1.88 ± 0.35 b
	2-*B. brizantha*	1.72 ± 0.48 b

DE: Standard deviation; Different contiguous letters between rows indicate statistically different means between categories according to the factor considered, at a probability of error of 5%.

Soil carbon estimation

Table 3 shows the descriptive measures of C content at different soil depths, according to the moment of measurement and type of system.

Considering the initial moment (1), the highest average concentration was recorded in *B. brizantha* pastures (26.95 $t.ha^{-1}$) at a depth of 0-20 cm, with a MIN value of 20.56 $t.ha^{-1}$ and a MAX of 33.45 $t.ha^{-1}$. In terms of DE, among the three forage species considered for the same soil level, the colonial type pasture consortium with *L. leucocephala*, presented the lowest value (±3.20), with a CV equal to 16.93%, showing homogeneity in the values referred to the same parameter, always around the mean, contrary to what was observed for the colonial pasture, where the amplitude was greater (MIN=11.49 $t.ha^{-1}$ and MAX=31.01 $t.ha^{-1}$), showing a high level of CV (58.13%), which denotes heterogeneous observations. This result could be due to the existence of topographic irregularities within the area where the soil samples were obtained.

The dynamics of C behavior, i.e., the C average values higher for each of the species, at a soil level (0-20 cm), was evidenced in the last two evaluation periods, although at moment 2, for the pasture formed by colonial with *L. leucocephala*, the means were similar, specifically at two depths, 0-20 and 40-60 cm, verifying in the latter, greater homogeneity in the data (CV=6.43%).

On the other hand, the increase in stored C associated with the greatest depth in the soil (moment 2), in the consortium forage system (21.83 $t.ha^{-1}$), could have been directly influenced by the powerful root system of *L. leucocephala*, evidenced in its type of pivoting growth. These types of roots contribute with high dynamics to the positive exchange of minerals between the plant-soil complex (Instituto Nacional de Tecnología Agropecuaria [INTA], 2019). And these interactions, according to their powerful root system, benefit soil productivity and conservation, storing significant amounts of organic matter (Torres-Guerrero *et al*., 2013). Regarding the final decrease of C in the greater depth of the consortium system, it would be associated with the deciduous character of *L. leucocephala*, evidenced since the low temperatures of the Paraguayan winter, registered at the end of July and August, which considerably reduces its capacity photosynthetic.

In similar research reported by Ibrahim *et al.,* (2007), much higher averages were found compared to those detected in this study. On the other hand, the results obtained by Mora-Calvo (2001), showed that at depths of 0-20 cm, the estrella forage species presented a higher average C level than the one consortium with trees, coinciding with the findings of this study, where, *B. brizantha* showed a higher average value than the colonial forage species consortium with *L. leucocephala*. Likewise, Lok *et al.,* (2013) maintain through their

Table 3. Descriptive measures of C level ($t.ha^{-1}$) in soil.

Moment	Forage species	Depth(cm)	Mean	DE	CV (%)	Mínimum	Maximum
1	*B. brizantha*	0-20	26.95	6.45	23.92	20.56	33.45
		20-40	16.02	1.60	9.98	14.28	17.42
		40-60	12.66	1.40	11.08	11.85	14.28
	Colonial	0-20	18.58	10.80	58.13	11.49	31.01
		20-40	9.06	0.35	3.86	8.71	9.41
		40-60	7.09	0.20	2.85	6.97	7.32
	Consortium (Colonial + *L. leucocephala*)	0-20	18.89	3.20	16.93	15.57	21.95
		20-40	15.91	7.04	44.23	11.85	24.04
		40-60	8.94	1.22	13.70	7,.66	10.10
2	*B. brizantha*	0-20	20.44	5.23	25.59	17.42	26.48
		20-40	14.75	3.84	26.03	12.19	19.16
		40-60	11.26	2.45	21.73	8.71	13.59
	Colonial	0-20	15.80	5.75	36.40	9.41	20.56
		20-40	10.34	0.53	5.12	9.76	10.80
		40-60	7.78	1.06	13.67	6.62	8.71
	Consortium (Colonial + *L. leucocephala*)	0-20	21.95	5.23	23.83	16.72	27.18
		20-40	13.36	0.73	5.45	12.54	13.94
		40-60	21.83	1.40	6.43	20.56	23.34
3	*B. brizantha*	0-20	23.23	0.53	2.28	22.65	23.69
		20-40	12.43	4.75	38.26	6.97	15.68
		40-60	8.71	0.93	10.63	8.01	9.76
	Colonial	0-20	15.44	4.49	29.09	10.45	19.16
		20-40	10.33	2.80	27.07	7.66	13.24
		40-60	7.21	0.73	10.09	6.62	8.02
	Consortium (Colonial + *L. leucocephala*)	0-20	21.02	3.62	1723	18.12	25.08
		20-40	11.61	0.88	7.55	10.80	12.54
		40-60	8.48	0.53	6.31	8.01	9.06

DE: Standard deviation; CV: Coefficient of variation; cm: centimeter.

investigations that, as the soil sampling depth increases, the C content decreases, since this is directly related to MO content, both in pasture and tree cover. In addition, Timoteo *et al.,* (2016) state that SOC represents almost 60% of the total C stored in agroforestry systems, such as those integrated by combinations with *L. leucocephala* (25,83 $t.ha^{-1}$), and, it is remarkable to point out that it increases during the first year of planting. However, Lara (2019) recorded that there are no significant statistical differences (p=0.45) since live fences and fodder banks reached 2.2% and scattered trees 2.7% of SOC, a situation that indicates that the practices do not have an influence on the storage of C in the soil.

The results of the ANOVA analysis taking into account moment, forage species, and depth are shown below (table 4).

Based on the results obtained, it can be indicated that there is no significant difference between sampling moments (p>0.05). However, the effects concerning forage species, depth, and the double interaction (moment*forage species) are active or influence the level of C (p<0.05). These results do not coincide with the findings of Callo *et al*. (2002), who found no significant differences in different land-use systems such as primary forest, secondary forest, shade coffee, silvopasture, and pasture. However, the results found here, show some similarity with those obtained by Anguiano *et al*. (2013), who reported interaction between treatments in the different periods evaluated.

Analytically evaluating the fluctuation of C to identify the statistically different means, both for the main factors and the double interaction, the Tukey's test was performed, the results of which are shown below.

Table 4. ANOVA for the content of C ($t.ha^{-1}$) in soil.

Variation source	SC	gl	CM	P-value
Moment	68.82	2	34.41	0.1095
Forage species	406.49	2	203.24	<0.0001
Depth	1432.10	2	716.05	<0.0001
Moment*Forage species	152.36	4	38.09	0.0494
Moment*Depth	120.92	4	30.23	0.1038
Forage species*Depth	65.29	4	16.32	0.3691
Moment*Forage species*Depth	175.33	8	21.92	0.1906
Error	806.02	54	14.93	

SC: Sum of square; gl: Degrees of freedom; CM: Mean square; P-value<0.05 indicates significant effect at a 5% probability of error.

Table 5. Comparison of means for C level ($t.ha^{-1}$) in soil.

Factors	Categories	Mean ± DE
Forage species	*B. brizantha*	16.27 ± 6.54 a
	Consortium (Colonial+ *L. leucocephala*)	15.78 ± 5.94 a
	Colonial	11.29 ± 5.52 b
Depth	0-20	20.26 ± 5.86 a
	20-40	12.65 ± 3.68 b
	40-60	10.44 ± 4.59 b
Double interaction: Moment-Forage Species	2- Consortium (Colonial+ *L. leucocephala*)	19.05 ± 5.07 a
	1- *B. brizantha*	18.54 ± 7.30 a
	2- *B. brizantha*	15.48 ± 5.30 ab
	3- *B. brizantha*	14.79 ± 6.97 ab
	1- Consortium (Colonial+ *L. leucocephala*)	14.58 ± 5.91 ab
	3- Consortium (Colonial+ *L. leucocephala*)	13.70 ± 5.96 ab
	1-Colonial	11.58 ± 7.58 b
	2-Colonial	11.30 ± 4.60 b
	3-Colonial	10.99 ± 4.48 b

DE. Standard deviation; Different contiguous letters between rows indicate statistically different means between categories according to the factor considered, at a 5% probability of error.

Globally, when taking into account the forage species, the mean values were high (16.27 and 15.78 $t.ha^{-1}$) and similar in both *B. brizantha* and consortium pastures (colonial+ *L. leucocephala*), however, they showed significant dissimilarities with the colonial species (p<0.05). These results differ from those obtained by Ibrahim *et al*. (2007), where *B. brizantha* presented the lowest level of C. Regarding C values in soil samples at different depths, the 0-20 cm category differed from the deeper strata (p<0.05), presenting the highest concentration. Finally, observing the double interaction, there were significant differences in C levels at moment "1" for *B. brizantha* and moment "2" for the consortium (colonial+*L. leucocephala)* compared to the colonial species in the three evaluation periods (p<0.05).

The decrease in stored C as root depth increases was expected behavior, similar to that reported by authors such as Céspedes *et al*. (2012) for grasslands in pastures under grazing. It is recommended to use improved pasture systems and consortium with shrubs, to improve C storage and to achieve stable and productive systems, in correspondence with their potentialities.

Conclusions

Overall, the highest storage of C in biomass corresponds to the system constituted by the colonial pasture in consortium with *L. leucocephala*. Among all the evaluation moments, the initial period presents the highest C value.

At the soil level, from the analysis between different depths, it was found that the stratum: 0-20 cm concentrates the highest content of C. However, the systems constituted by *B. brizantha* grass and the consortium (colonial+*L. leucocephala*), show similar behaviors. Finally, it is noted that in the three evaluation periods, the colonial species shows the lowest level of C.

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