


## Impact of cattle ranching on vegetation, GHG emissions, and carbon sequestration in the Bolivian Chaco



Carmelo Peralta-Rivero <sup>a</sup>

Miguel Ángel Beltrán-Santoyo <sup>b</sup>

Néstor Cuellar-Álvarez <sup>a</sup>

Gregorio Álvarez-Fuentes <sup>b\*</sup>

<sup>a</sup> Centro de Investigación y Promoción del Campesinado. Claudio Peñaranda No. 2706. Zona Sopocachi. 5854. La Paz, Bolivia.

<sup>b</sup> Universidad Autónoma de San Luis Potosí. Instituto de Investigaciones en Zonas Desérticas. San Luis Potosí, México.

\*Corresponding author: [gregorio.alvarez@uaslp.mx](mailto:gregorio.alvarez@uaslp.mx)

### Abstract:

The ecosystem of the Chaco region in Bolivia is in a fragile state for productive activities. One of the causes is overgrazing, which limits its sustainable development. The objective was to evaluate the environmental impact of semi-intensive (SIFS) and extensive (EFS) cattle farming systems in the municipality of Macharetí, in the Chaco region of Bolivia. The evaluation was conducted using 16 environmental indicators in both livestock production systems, which were compared using analysis of variance for a completely randomized design and multiple mean comparisons ( $P \leq 0.05$ ). The SIFS involves a larger cattle population and higher milk production due to better management; it also includes a greater number of plant species; however, it shares 90 % of these with the EFS. The SIFS has a lower environmental impact, with lower emissions of greenhouse gases and degradation of native vegetation and soil. In general, the SIFS has a higher carbon content (71.1 t C/ha) in its various reservoirs compared to the EFS (60.7 t C/ha) ( $P < 0.05$ ). The type of livestock

management is a determining factor in the regeneration of natural vegetation, particularly of forage species, due to the type of grazing that occurs in this region.

**Keywords:** Animal production, Animal overload, Methane, Carbon sequestration.

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## Introduction

Deforestation to expand the agricultural and livestock frontier is the most significant cause of greenhouse gas (GHG) emissions from the global agricultural sector, with livestock accounting for 320 million tons of methane emissions per year, which represent 11 % of global GHG emissions<sup>(1,2,3)</sup>. Cattle production causes environmental impacts due to carbon dioxide emissions (CO<sub>2</sub>), methane (CH<sub>4</sub>), and nitrous oxide (N<sub>2</sub>O) with different warming potentials, as well as negative effects on natural resources such as water, soil, forests, and biodiversity, contributing to climate change (CC)<sup>(4,5)</sup>. By 2050, the global beef production is expected to double; therefore, it is important to at least halve the impacts of production systems. Given that the countries with the highest demand are exhausting their production capacity, the pressure will be on developing countries<sup>(6)</sup>. By 2025, there will be a ratio of two bovines per inhabitant in these countries, where ruminants are the largest emitters of methane by enteric fermentation; such is the case in Bolivia, where cattle farming in lowland areas concentrates the largest cattle population in the country<sup>(7,8)</sup>. Between 2000 and 2010, 0.94 million hectares have been deforested in this area to plant pastures for cattle ranching<sup>(9)</sup>. One of the most important cattle production areas is the Chaco region, which covers an area of approximately 13.5 million hectares<sup>(10)</sup> and is home to 11.6 % of Bolivia's cattle<sup>(11)</sup>. One of the problems caused by livestock farming in this region is related to the animal carrying capacity<sup>(12)</sup>. It is therefore essential to rethink the production model based on technical-scientific information that can contribute to the design and implementation of sustainable livestock management. The objective of this study was to evaluate the environmental impact on the vegetation, GHG emissions, and carbon sequestration by the semi-intensive (SIFS) and extensive (EFS) farming systems in two areas of the municipality of Macharetí, in the Chaco region of Bolivia.

## Material and methods

This research was conducted in two cattle production management systems in the Chaco region of Bolivia, in the municipality of Macharetí. The first is semi-intensive cattle ranch (SIFS) located on the lands of the Macharetí Zone Community Association (20°51'32" S; 62°21'29" W), while the second is an extensive cattle ranch (EFS) located on the private property "Los Mistoles" (20°45'50" S; 62°29'2" W)<sup>(13)</sup>.

The Chaco plain has a dry to semi-arid xerophytic climate, characterized by dry periods of up to 8 mo, an annual rainfall of 782 mm, and an annual average temperature of 20 °C. In some months of the year, maximum temperatures of 48 °C and minimum temperatures of -1 °C occur<sup>(14)</sup>. The predominant vegetation is dense to sparse xerophytic scrub, adapted to low rainfall, comprising mostly thorny species, and thriving at low altitudes<sup>(13)</sup>.

The environmental impact assessment was based on the analysis of 16 environmental indicators (Table 1). Three indicators were related to GHG emissions from livestock, seven to vegetation and carbon sinks, and six to soil impact<sup>(7)</sup>.

**Table 1:** Environmental assessment of the evaluation criteria and indicators for the two cattle-farming systems

Evaluation criteria	Indicators
Impact of GHG emissions from cattle	CH <sub>4</sub> emissions from enteric fermentation of cattle. CH <sub>4</sub> emissions from feces management
Impact on vegetation and carbon sinks	Animal carrying capacity. Soil organic carbon, leaf litter carbon, root necromass, and aboveground biomass. Natural regeneration of the vegetation.
Impact on soil resources	pH Water content Bulk density Porosity Pore spaces occupied by water Water content by volume

### Impact of greenhouse gas emissions from cattle

The assessment of methane (CH<sub>4</sub>) emissions was adjusted according to Beltrán *et al*<sup>(5)</sup> for herd size, number of producing and dry cows, average milk production, milk protein and fat

percentage, live weight, dry matter intake (DMI), and feces management. To calculate the CH<sub>4</sub> emission factor from enteric fermentation and feces management, feed utilization efficiency was defined as liters of milk produced per kilogram of dry matter (DM) and other feed sources ingested per day. The intensity of CH<sub>4</sub> emissions was calculated as the amount of enteric CH<sub>4</sub> and CH<sub>4</sub> from feces management per liter of milk<sup>(15)</sup>, for which purpose the milk production per year was adjusted for lactation days.

DMI (kg cow<sup>-1</sup> d<sup>-1</sup>) and total energy (TE) (Mcal cow<sup>-1</sup> d<sup>-1</sup>) were calculated with National Research Council software<sup>(16)</sup>. CH<sub>4</sub> emission was determined according to the Intergovernmental Panel on Climate Change IPCC<sup>(2)</sup>; equation (1) was used for CH<sub>4</sub> emission from enteric fermentation, equation (2) for CH<sub>4</sub> emission from feces management, and equation (3) was utilized to estimate the amount of excreted volatile solids.

(1)... Enteric methane emission factor kg cow<sup>-1</sup> year<sup>-1</sup> ( $EF_{eCH_4}$ )

$$EF_{eCH_4} = EI \times \frac{Ym}{100} \times \frac{365}{55.65}$$

Where EI= total energy intake, MJ d<sup>-1</sup> cow<sup>-1</sup>; Ym= CH<sub>4</sub> conversion factor, percentage of total feed energy converted to CH<sub>4</sub> of 6.5 % ± 1 %; 55.65 is the energy content of CH<sub>4</sub> in MJ kg.

(2)... CH<sub>4</sub> emission factor from feces management kg per cow per year ( $EF_{hCH_4}$ ).

$$EF_{hCH_4} = (VS \times 365) \times \left[ (B_0 \times 0.67 \text{ kg} \cdot \text{m}^{-3}) \times \frac{\sum MCF_{S,F}}{100} \times S \right]$$

Where, VS= volatile solids excreted per day; B<sub>0</sub>= maximum CH<sub>4</sub> production capacity of feces, 0.188 m<sup>3</sup> CH<sub>4</sub>/VS; 0.67: conversion factor from m<sup>3</sup> of CH<sub>4</sub> to kg of CH<sub>4</sub>, MCF<sub>S,k</sub>= CH<sub>4</sub> conversion factor for each feces management system (S) by climatic region (k), =1.5 %; MS<sub>(S,k)</sub>= fraction of feces managed in the system (S) in the climatic region (k), without dimension = 0.1.

(3)... Volatile solids excreted per day (VS)

$$VS = EI \times (0.5 + (0.04 \times EB)) \times \frac{0.92}{18.45}$$

Where EI= total energy (MJ d<sup>-1</sup> cow<sup>-1</sup>).

The live weight of the cattle was measured using a bovinometric tape; the live weight is reported directly (with 99 % effectiveness)<sup>(18,19)</sup>.

## Impact on vegetation and carbon sinks

Thirty  $5 \times 5$  m plots were sampled per cattle farming system to assess the ecological health of the vegetation and its natural regeneration. The height and normal diameter (ND) of trees and shrubs (height  $>20$  cm) were measured with a forestry caliper (Haglöf Mantax Blue, Germany), and so were those of individuals of the tree (height between 10 and 19.9 cm), sapling (height between 5 and 9.9 cm), and seedling (height  $< 5$  cm) categories.

The carbon in the different reservoirs of the management systems was measured according to the design of the sampling plots, in trees and shrubs ( $10 \times 100$  m; Trees  $10 \times 10$  m; Saplings  $5 \times 5$  m, and Seedlings; the necromass was measured in  $5 \times 5$  m plots, and the leaf litter and soil were sampled in  $1 \times 1$  m plots in order to calculate the amount of carbon. To determine the amount of carbon in understory vegetation, 100 sites with a surface area of  $1 \text{ m}^2$  were sampled for each livestock management system.

The aboveground biomass (AGB) carbon was measured using allometric equations for dry climate tree and shrub species ( $<1,500 \text{ mm year}^{-1}$ )<sup>(20)</sup>

$$AGB = 34.4703 - 8.0671ND + 0.6589ND^2$$

Where AGB= aboveground biomass, and ND= normal diameter at a height of 1.30 m. The root biomass (RBM) was estimated with the formula for hardwood species characteristic of the evaluated areas of the Chaco region:

$$RBM = e^{0.359} AGB^{0.639}$$

Where e= base of the logarithm, and AGB= aboveground biomass.

In order to estimate the aboveground and belowground biomass carbon, a value of 0.5 is assumed<sup>(2,20)</sup>. As for the leaf litter carbon, thirty samples of 500 g per system were collected and sent to the Tropical Agricultural Research Center (CIAT, Spanish acronym) to determine the amount of carbon by wet carbon combustion (Walkley-Black)<sup>(21)</sup>. The amount of carbon in the necromass or dead organic matter present in the management systems was determined with the methodology and equations used by Espinoza *et al*<sup>(22,23)</sup>

$$V = \pi^2 \times \sum \frac{D^2}{200}$$

Where, V= volume in  $\text{m}^3$  183;  $\pi = 3.1416$ ; D= diameter of necromass part (meters).

Biomass was calculated according to the formula of Espinoza *et al*<sup>(22)</sup>:

$$BM_{nm} = V \times \frac{P}{40}$$

Where,  $BM_{nm}$  = biomass of large necromass (t);  $V$  = volume in  $m^3$ , and  $p$  = stem density ( $t/m^3$ ), using averages of 0.2 for low density logs, 0.4 for medium density logs, and 0.6 for high density logs.

The necromass was calculated assuming that carbon makes up 50% of the biomass and extrapolating the data to determine the amount of necromass carbon per hectare. The soil carbon was calculated from 30 samples for each management system. For this purpose, cylinders 5 cm in diameter and 20 cm in length ( $392.7 \text{ cm}^3$ ) were used to obtain samples from a depth of 0 to 20 cm, which were placed in airtight plastic bags and identified<sup>(24)</sup>. The calculations for the carbon storage pools of the two systems were summed and extrapolated to hectares to subsequently determine the number of tons of carbon per hectare (t C/ha).

Finally, the stocking rate was calculated by animal units per hectare (UA/ha). For the SIFS, there were 20 linear transects, and 200 samples were obtained in six paddocks; for the EFS, there were 10 transects, and 100 samples were obtained because it is a homogeneous area without divisions. Each one measured 100 m linear, and the separation between them was 200 m. Forage samples were collected in a  $1 \text{ m}^2$  quadrant every 10 m of distance<sup>(25)</sup>. In each quadrant, the forage was cut at a height of 15 cm from the ground to a height of 1.5 cm. Samples included mainly grasses, perennial herbs, and leaves of trees and shrubs. The samples were weighed on a balance (Amazonbasics, EK3211, USA), then dried in a forced-air oven (Ecoshel Model Fa-45B, Mexico) to obtain the dry matter weight.

### Impact on the soil

Thirty (30) soil samples were taken per management system and analyzed at the CIAT. The pH was determined using a potentiometer (HANNA, Mexico) to determine the impact of soil compaction from cattle grazing according to the estimated soil bulk density—a procedure developed by García *et al*<sup>(26)</sup>. All the soil samples were weighed wet and then dried in an oven to obtain the dry weight. To determine the degree of soil compaction and other variables in the evaluated areas, the following formulas were utilized<sup>(27)</sup>:

Soil water content:

$$SWC_{g/g} = \text{soil wet weight} - \text{dry weight}$$

Soil bulk density:

$$SBD_{g/cm^3} = \text{soil dry weight} / \text{volume}$$

Soil porosity:

$$SP_{(\%)} = 1 - (\text{soil bulk density} / 2.65)$$

Pore spaces occupied by water:

$$PS_{(\%)} = \frac{\text{Water content by volume} * 100}{\text{Soil porosity}}$$

Water content by volume:

$$SWC = \text{soil water content}_{g/g} * \text{bulk density}$$

## Statistical analysis

With the information gathered, a normality test was performed on each of the GHG variables, Vegetation and Soil, whereby P values of >0.47 and >0.32 were estimated for Shapiro-Wilkings and Kolmogorov-Smirnov, respectively, with the UNIVARIATE procedure of the SAS 9.2 statistical package<sup>(28)</sup>. In addition, descriptive statistics were obtained; to compare the two management systems, an analysis of variance for a completely randomized design ( $P < 0.05$ ), taking each livestock production system as a treatment, and a Tukey's test of means ( $P \leq 0.05$ )<sup>(29)</sup> were performed.

## Results and discussion

### Impact of GHG emissions from livestock

Table 2 describes the characteristics of both livestock production systems; the land tenure regime differs, but the surface area is similar. In the SIFS, due to collective ownership, there are management chutes or paddocks, resulting in a larger cattle population with fewer producing cows, lower live weight (LW), but higher milk production per cow that yields 53.3 % more total milk than in the EFS.

**Table 2.** Characteristics of extensive (EFS) and semi-intensive (SIFS) livestock management systems

Characteristics	EFS	SIFS
Legal status of the land	Private property	Collective property
Area covered by vegetation, ha	500	533.6
Management chutes or paddocks	0	6
Herd size	182	200
Producing cows	60	50
LW of producing cows, kg	348.6 ± 55.3 <sup>a</sup>	328.1 ± 51.2 <sup>a</sup>
Average Production, L per cow/d <sup>-1</sup>	1.27 ± 0.32 <sup>b</sup>	2.86 ± 0.59 <sup>a</sup>
Total milk production, L	76.2 <sup>b</sup>	143.0 <sup>a</sup>

LW= live weight.

<sup>ab</sup> Means with the same literal per row are equal ( $P<0.05$ ).

Enteric CH<sub>4</sub> emission intensity was much higher ( $70.8 \pm 22.5 \text{ g L}^{-1}$ ) for cows under the EFS management system ( $P<0.05$ ). This is also due to the fact that the cattle found in the pastures in the SIFS, especially in Yaguarenda of the Central Macharetí community, have a higher DMI ( $8.20 \pm 0.01 \text{ kg cow}^{-1} \text{ d}^{-1}$ ) than in the EFS; this difference is confirmed by the gross energy intake (GEI), which is also higher ( $P<0.05$ ) ( $9.22 \pm 0.05 \text{ Mcal d}^{-1}$ ).

Thus, the higher the dry matter intake, the greater the gross energy obtained, resulting in more energy available for lactation, which leads to increased milk production and decreased enteric and fecal CH<sub>4</sub> emissions (Table 3). This allows to infer that the SIFS herd emits less CH<sub>4</sub> than the EFS herd. According to Beltrán *et al*<sup>(5)</sup>, the higher the DMI and the better the cattle's diet, the lower the emissions. This also confirms what Bonilla and Lemus report<sup>(30)</sup> in extensive production systems: that production is lower due to the low quality of the diet that limits the intake of DM, the rate of passage and lower energy intake, resulting in low production yields and increased CH<sub>4</sub> emissions—a pattern that was observed in the present study. The EI of enteric CH<sub>4</sub> and feces per cow  $\text{g/L}^{-1}$  was higher ( $P<0.05$ ) in the EFS, due to lower milk production per cow per day.

**Table 3:** Dry matter intake (DMI), gross energy consumed (GEC), and emissions from extensive (EFS) and semi-intensive (SIFS) cattle farming systems

Characteristics	EFS	SIFS
DMI, kg per cow <sup>-1</sup> d <sup>-1</sup>	7.67 ± 0.12 <sup>b</sup>	7.9 ± 0.04 <sup>a</sup>
GEC, Mcal per cow <sup>-1</sup> d <sup>-1</sup>	8.67 ± 0.13 <sup>b</sup>	8.9 ± 0.07 <sup>a</sup>
Enteric EF, kg per cow <sup>-1</sup> yr <sup>-1</sup>	24.78 ± 0.37 <sup>a</sup>	26.45 ± 0.21 <sup>a</sup>
Volatile solids, kg per cow <sup>-1</sup> d <sup>-1</sup>	1.52 ± 0.02 <sup>b</sup>	1.67 ± 0.01 <sup>a</sup>
Feces EF, kg per cow yr <sup>-1</sup>	0.11 ± 0.001 <sup>b</sup>	0.12 ± 0.002 <sup>a</sup>
EI enteric CH <sub>4</sub> and feces per cow <sup>-1</sup> g/L <sup>-1</sup>	70.75 ± 22.5 <sup>a</sup>	30.52 ± 1.56 <sup>b</sup>

DMI= dry matter intake; GEC= gross energy consumed; EF= emission factor; EI= emission intensity.

<sup>ab</sup> Means with the same letter in the same row are equal ( $P < 0.05$ ).

This demonstrates that effective management of a cattle farming system is crucial to guarantee a stable supply of feed. For this reason, it is essential to have a management calendar for pastures or paddocks to ensure cattle-feeding supplies throughout the year. This situation does not occur in the EFS, as shown by the indicators of the environmental impact on vegetation described below. Also, EFS cows spend more energy searching for feed.

### Impact on vegetation and carbon sinks

As for natural vegetation, 17 species were identified in the EFS and 19 species in the SIFS. The species hackberry (*Celtis* sp.) and chorimimi (*Maytenus scutioides* (Griseb) Lourteig & O'Donnell) were found in the SIFS only in very low density; the other species grow in both areas, indicating that both systems share more than 90 % of the same vegetation types.

The most abundant species in both systems were choroque (*Salta triflora* (Griseb.) Adr. Sanchez), *garrancho* (*Acacia praecox* Griseb.), *iscayante* (*Mimozyanthus carinatus* (Griseb.) Burkart), *bola verde* (*Anisocapparis speciosa* (Griseb.)), and *sacha sandía* (*Capparis salicifolia* Griseb.), all of them are in the category of seedlings and saplings, i.e., individuals with DBH <10 cm, and, in general, this type of species is important as fodder. Among the dominant species of the tree layer in both systems, red quebracho (*Schinopsis balansae* Engl.) and white quebracho (*Aspidosperma quebracho-blanco* Schtdl.) predominate.

The tree category included the following species: *Caesalpinia paraguariensis*, *Cercidium praecox*, *Zyziphus mistol* Griseb, *Aspidosperma quebracho-blanco*, *Schinopsis balansae*, *Schinopsis cornuta*, *Celtis tala*, *Ceiba insignis* (Kunth) P.E.Gibbs & Semir; the shrub category: *Maytenus scutioides*, *Salta triflora* (Griseb.), *Anisocapparis speciosa*,

*Mimozyanthus carinatus* (Griseb.) Burkart, *Acacia praecox*, *Achatocaraus praecox*, *Bouganvillea infesta*, *Capparis retusa*, *Capparis salicifolia*, *Morrenia brachystephana*, *Stetsonia coryne* (Salm-Dyck); the category of herbaceous plants: *Sida rodrigoii*, *Sida cordifolia* L., *Abutilon indicum* (L.) Sweet, *Solanum chacoense* Bitter, and the category of grasses: *Setaria lachnea* and *Leptochloa mucronata*.

For the categories “saplings and grasslands”, the number of species is similar in both management systems (8 species), while the abundance of individuals is different (4,250 vs 5,333 saplings and 907 vs 1,307 grasslands respectively per production system) ( $P < 0.05$ ); this indicates that the type of livestock is a determining factor in the regeneration of natural vegetation of forage species, particularly due to the grazing management carried out in both systems. However, there are no statistically significant differences ( $P > 0.05$ ) between the two management systems for the categories of shrubs and trees, as well as for trees and shrubs. This is why the problem falls under the categories of natural regeneration. This scenario of alteration in population structure is characteristic when the vegetation is under pressure and the population density of the species is changing<sup>(31)</sup>.

Thus, based on the results, it can be inferred that the type of livestock management allows or limits natural regeneration, which is an indicator of the ecological health of the native vegetation. The EFS has deficiencies due to the lack of management practices to ensure natural regeneration, as pointed out by Ureña and Villagra<sup>(12)</sup>; these authors assert that, to ensure the natural regeneration of vegetation in the Bolivian Chaco, the pastures must be managed through deferred grazing practices, controlling these by means of wire fences, so that the vegetation may be used rationally—an aspect that influences the increase of forage vegetation. It is also recommended to create exclusion areas with wire fences before the rainy season to allow plants to produce seeds and ensure natural regeneration<sup>(32)</sup>.

The quantification of carbon in the different pools reveals a significant difference between the two cattle-farming systems. In general, the SIFS has a greater amount of carbon (71.1 t C/ha) in its various pools compared to the EFS (60.7 t C/ha) ( $P < 0.05$ ). The largest carbon pool in both systems was found in the aerial vegetation and soil, followed by the roots and necromass, with the leaf litter having the lowest carbon sequestration. Within these categories, the largest carbon accumulation was found in trees and shrubs, being higher ( $P < 0.05$ ) in the SIFS than in the EFS. However, soil carbon accumulation was higher ( $P < 0.05$ ) in the EFS than in the SIFS (Table 4). The difference is larger in the necromass carbon pools. Furthermore, in all categories except soil, the available carbon is greater in the SIFS ( $P < 0.05$ ) because the EFS includes less aerial vegetation. Another category in which the amount of carbon stored is larger in the SIFS ( $P < 0.05$ ) is the trees and shrubs, due to the greater abundance of individuals.

**Table 4:** Carbon stocks by category in the extensive (EFS) and semi-intensive (SIFS) cattle farming systems in the Bolivian Chaco

Carbon pools	Categories	EFS (t C/ha)	SIFS (t C/ha)
Aerial vegetation	Trees and shrubs	19.7	20.9
	Trees	2.6 <sup>b</sup>	3.8 <sup>a</sup>
	Saplings	5.4 <sup>b</sup>	7.0 <sup>a</sup>
	Undergrowth*	0.05 <sup>b</sup>	0.34 <sup>a</sup>
Roots	Trees and shrubs	2.29	2.58
	Trees	0.93 <sup>b</sup>	1.16 <sup>a</sup>
	Saplings	3.2 <sup>b</sup>	4.3 <sup>a</sup>
Soil		24.2 <sup>a</sup>	23.7 <sup>b</sup>
Leaf litter		0.07 <sup>a</sup>	0.22 <sup>b</sup>
Necromass		2.2 <sup>b</sup>	7.2 <sup>a</sup>
Total		60.7 <sup>b</sup>	71.1 <sup>a</sup>

\* Includes seedlings and low saplings, as well as grasses and herbaceous species of different species.

<sup>ab</sup> Means with the same letter in the same row are statistically similar ( $P < 0.05$ ).

The amount of carbon sequestered in the SIFS is in agreement with that reported by Baccini *et al*<sup>(33)</sup> for the northern Chaco region, at 68 t C/ha; in the case of EFS, it is below this average. However, in both systems, the amounts are lower than those reported by Pérez *et al*<sup>(34)</sup>, who report equal or lower carbon sequestration in the soil of pastures than in corn production, where tillage releases the captured carbon. In the extensive cattle farming system, overgrazing and trampling result in very little carbon capture. The difference in carbon sequestration between the two systems is a crucial factor to consider for climate change mitigation and adaptation practices, especially since, up to 2016, at least 875,674 ha were lost in the Chaco region, of which 151,815 ha were deforested between 2012 and 2016<sup>(35)</sup>. On the other hand, there is a difference in the availability of forage biomass between the two systems, which is reflected in their carrying capacity for animals. For the EFS, the average availability of dry matter is of 330 kg per hectare, and the animal carrying capacity is 14 ha per AU per year, which means that, in 500 ha, it can feed only 36 AU; nevertheless, at the time of measurement, 151 AU, resulting from 182 heads of cattle of different categories, were estimated. On the other hand, the SIFS has an average stocking rate of 5.7 ha per AU, according to the average availability of 891 kg of DM per hectare per year. The performed analysis indicates that the SIFS of 533.6 ha has the capacity to feed up to 94.3 AU per year; however, it housed 155 AU at the time of the inventory.

Regarding animal carrying capacity, the SIFS has a higher biomass availability of an additional 561 kg of dry matter per hectare as cattle feed, a situation also reported for other areas of the Chaco<sup>(12,32)</sup>. However, the SIFS must increase the management area to guarantee

optimal nutrition for its herd, unlike the EFS, whose extension does not correspond to the feeding demand of its herd, consisting of 182 head of cattle.

This same situation occurs in almost all the EFS in the Chaco region of Bolivia, given that few areas of the Chaco region of Bolivia still have pastures slightly exceeding their animal load (5 ha/AU), while in others, cattle farming exerts pressure on the vegetation not only in the Chaco region but also in other areas not fit for this activity.

### Impact on the soil

Soil pH and bulk density are similar in both systems; however, the other variables exhibit statistically significant differences ( $P<0.05$ ), with better conditions in the SIFS (Table 5), as this has a lower animal load and less soil compaction. Consequently, the soil there has better drainage and aeration due to the greater abundance of seedlings and saplings, which leads to greater production of biomass necessary to maintain the soil organic matter that regulates and sustains the structure, quality, and functioning of the soil.

**Table 5:** Comparison of soil physical and chemical characteristics between semi-intensive (SIFS) and extensive (EFS) livestock management systems

Indicator	SIFS	EFS
pH	6.6	6.5
Water content, g	6.87 <sup>a</sup>	5.07 <sup>b</sup>
Bulk density, g/cm <sup>3</sup>	1.46 <sup>a</sup>	1.49 <sup>a</sup>
Pore spaces occupied by water, %	45.1 <sup>a</sup>	43.7 <sup>b</sup>
Water content by volume, %	14.8 <sup>a</sup>	11.6 <sup>b</sup>
Porosity, g/cm <sup>3</sup>	9.9 <sup>a</sup>	7.56 <sup>b</sup>

<sup>ab</sup> Means with the same letter in the same row are similar ( $P<0.05$ ).

Soils with low vegetation cover generally suffer from water or wind degradation, which, combined with cattle farming practices, accelerate the loss of organic matter. In this regard, certain authors<sup>(26,36)</sup> point out that organic matter is not a property of the soil; nevertheless, it exerts a considerable influence on its physical properties, especially in regard to biological activity. Therefore, vegetation cover is very important, especially in soils with low organic matter content, where there is less carbon, and the biological degradation is greater, affecting their quality and fertility. In the EFS, this situation may become more detrimental with increasing cattle farming without regulating stocking rates or improving management practices, given that grazing reduces the net annual rate of C accumulation due to excessive trampling<sup>(37)</sup>.

Finally, it is essential to note that damage to the physical properties of the soil, combined with nutrient losses, constitutes a “hidden cost” for production systems, and in many cases, is already becoming “visible and tangible”, especially in the EFS, making it difficult to sustain production levels.

## Conclusions and implications

The SIFS has better management and higher total milk production with a smaller number of cows, due to the greater availability of dry matter and gross energy consumption by the cattle, resulting in a decrease in enteric and fecal CH<sub>4</sub> emissions. The impact on native vegetation is greater in the EFS, where there is a lower abundance of individuals per species, and, therefore, less carbon sequestration by trees and shrubs, which are one of the largest carbon sinks after the soil, where carbon sequestration was similar. The type of cattle farming is a determining factor in the regeneration of native vegetation, particularly its forage species, due to the specific grazing practices employed in each system. These practices influence the physicochemical characteristics of the soil, with the SIFS being the system that offers the best conditions.

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## Conflict of interest

The authors declare that they have no conflict of interest.

## Literature cited:

1. Sauniois M, Stavert AR, Poulter B, Bousquet P, Canadel JG, Jackson RB, *et al.* The global methane budget 2000–2017. *Earth System Science Data* 2020;12(3):1561–1623. <https://doi.org/10.5194/essd-12-1561-2020>.

2. IPCC. Intergovernmental Panel on Climate Change. Refinement to the 2006 IPCC guidelines for National Greenhouse Gas Inventories. 2019. <https://www.ipcc.ch/report/2019-refinement-to-the-2006-ipcc-guidelines-for-national-greenhouse-gas-inventories/>.
3. Wolf J, Asrar G, West T. Revised methane emissions factors and spatially distributed annual carbon fluxes for global livestock. *Carbon Balance Management* 2017;12(1):16. doi:10.1186/s13021-017-0084-y.
4. Gerber PJ, Hristov AN, Henderson B, Makkar H, Oh J, Lee C, *et al.* Technical options for the mitigation of direct methane and nitrous oxide emissions from livestock: A review. *Animal* 2013;7(s2):220–234. <https://doi.org/10.1017/s1751731113000876>.
5. Beltrán SMA, Álvarez FG, Pinos RJM, Contreras SC. Emisión de metano en los sistemas de producción de leche bovina en el Valle de San Luis Potosí, México. *Agrociencia* 2016;50(3):297-305.
6. Steinfeld H, Gerber P, Wassenaar T, Castel, V, Rosales M, Haan C. La larga sombra del ganado: Problemas ambientales y opciones. Rome FAO: 2009. <http://www.fao.org/3/a-a0701s.pdf>.
7. Peralta RC, Cuellar AN. La ganadería en la región del Chaco de Bolivia. Una evaluación de la sustentabilidad de los sistemas de manejo de ganadería semi-intensiva y extensiva. Centro de Investigación del Campesinado. Cuaderno de Investigación 85. Bolivia. 2018.
8. García E, Arana I, Paz O, Angulo W. Inventario de gases de efecto invernadero emitidos por la actividad agropecuaria boliviana. *J Cienc Tecnol Agr* 2012;2(3):351-370. [https://www.researchgate.net/publication/264310265\\_Inventario\\_de\\_gases\\_de\\_efecto\\_invernadero\\_emitidos\\_por\\_la\\_actividad\\_agropecuaria\\_boliviana](https://www.researchgate.net/publication/264310265_Inventario_de_gases_de_efecto_invernadero_emitidos_por_la_actividad_agropecuaria_boliviana).
9. Müller R, Larrea ADM, Cuéllar S, Espinoza S. Causas directas de la deforestación reciente (2000-2010) y modelado de dos escenarios futuros en las tierras bajas de Bolivia. *Ecología en Bolivia* 2014;49,1:20-34. [http://www.scielo.org.bo/pdf/reb/v49n1/v49n1\\_a03.pdf](http://www.scielo.org.bo/pdf/reb/v49n1/v49n1_a03.pdf).
10. Rojas JC. Análisis de la situación agropecuaria en el Chaco Boliviano. CIPAC. Ed. Fundación Xavier Albó. Centro de Servicios Bibliográficos. 2018. <https://isbn.cloud/9789997432001/analisis-de-la-situacion-agropecuaria-en-el517chaco-boliviano/>.
11. INE. Instituto Nacional de Estadística. Censo agropecuario 2018, Bolivia. Instituto Nacional de Estadística. La Paz. 2022. <https://www.ine.gob.bo/index.php/estadisticas-economicas/ganaderia-y-avicultura/ganaderia-cuadros-estadisticos/>.

12. Ureña R, Villagra R. Aportes para una ganadería comunitaria sostenible. Experiencias de comunidades Guaranís del Chaco Boliviano. CIPCA 2016. <https://cipca.org.bo/publicaciones-e-investigaciones/libros/aportes-para-una529-ganaderia-comunitaria-sostenible-experiencias-en-comunidades-guaranis-del-chaco-boliviano>.
13. IDRS. Instituto para el Desarrollo Rural de Sudamérica. Contribuciones para una agenda de gestión integral del agua. La Paz – Bolivia. Ed. PREVIEW GRÁFICA. 2017. [https://www.sudamericarural.org/images/impresos/archivos/Machareti\\_para\\_una\\_agenda\\_de\\_gestion\\_integral\\_del\\_agua.pdf](https://www.sudamericarural.org/images/impresos/archivos/Machareti_para_una_agenda_de_gestion_integral_del_agua.pdf).
14. SENAMHI. Servicio Nacional de Meteorología e Hidrología de Bolivia. Atlas Climatológico de Bolivia. 2019. [https://www.senamhi.gob.bo/agromet/investigaciones/AtlasClimatologicosBolivia\\_final.pdf](https://www.senamhi.gob.bo/agromet/investigaciones/AtlasClimatologicosBolivia_final.pdf).
15. Leslie M, Aspin M, Clark H. Greenhouse gas emissions from New Zealand agriculture: issues, perspectives and industry response. *Australian J Exper Agr* 2008;48(2):1-5. doi: 10.1071/EA07306.
16. NRC. National Research Council. Nutrient requirements of dairy cattle. National Research Council. National Academy Press. Washington, DC, USA. 2001. <https://nrc-nutrient-requirements-of-dairy-cattl.software.informer.com/>.
17. IPCC. Intergovernmental Panel on Climate Change. Directrices del IPCC de 2006 para los inventarios nacionales de gases de efecto invernadero, Volumen 4: Agricultura, silvicultura y otros usos de la tierra. IPCC. (Intergovernmental Panel on Climate Change). IGES. (Institute for Global Environmental Strategies). Japón. 2006.
18. Mahecha L, Angulo J, Manrique LP. Predicción del peso vivo a través del perímetro torácico en la raza bovina Lucerna. *Rev Colomb Cienc Pecu* 2002;15:88-91. <https://www.redalyc.org/pdf/2950/295026068009.pdf>.
19. Aguirre L, Zhinin L. Métodos de pesaje de bovinos. CEDAMAZ. Ecuador 2010. [https://www.researchgate.net/publication/216072790\\_metodos\\_de\\_pesaje\\_en\\_bovinos](https://www.researchgate.net/publication/216072790_metodos_de_pesaje_en_bovinos).
20. Gómez CH, Pinto RR, Guevara HF, González RA. Estimaciones de biomasa aérea y carbono almacenado en *Gliricidia sepium* (lam.) y *Leucaena leucocephala* (jacq.) y su aplicación en sistemas silvopastoriles. *ITEA-Inf Tec Econ Agrar* 2010;106(4):256-270. [https://www.aida-itea.org/aida-itea/files/itea/revistas/2010/106-4/256\\_ITEA\\_106-4.pdf](https://www.aida-itea.org/aida-itea/files/itea/revistas/2010/106-4/256_ITEA_106-4.pdf).

21. García J, Ballesteros M. Evaluación de parámetros de calidad para la determinación de carbono orgánico en suelos. *Rev Colomb Quim* 2005;34(2):201–209. <http://www.scielo.org.co/pdf/rcq/v34n2/v34n2a09.pdf>.
22. Espinoza DW, Krishnamurty L, Vásquez AA, Torres RA. Almacén de carbono en sistemas agroforestales con café. *Rev Chapingo Serie Cienc Forest Amb* 2012;18(1):57-70. <http://www.scielo.org.mx/pdf/rcscfa/v18n1/v18n1a6.pdf>.
23. Vos V, Vaca O, Cruz A. Sistemas agroforestales en la Amazonía Boliviana. Valoración de sus múltiples funciones. CIPCA. Bolivia 2015. <https://cipca.org.bo/publicaciones-e-investigaciones/cuadernos-de539investigacion/sistemas-agroforestales-en-la-amazonia-boliviana-una-valoracion-a-sus-multiples-funciones>.
24. Stolbovoy V, Montanarella L, Filippi N, Arwyn J, Gallego J, Grassi G. Soil sampling protocol to certify the changes of organic carbon stock in mineral soil of the European Union. 2nd ed. European Commission. Italy. 2007.
25. Esqueda C, Sosa E, Chávez A, Villanueva FJM, Royo M, Beltrán, S. Ajuste de carga animal en tierras de pastoreo, Manual de capacitación. Instituto Nacional de Investigaciones Forestales, Agrícolas y Pecuarias, México. 2011. [https://redgatro.fmvz.unam.mx/assets/ajustes\\_carga\\_animal.pdf](https://redgatro.fmvz.unam.mx/assets/ajustes_carga_animal.pdf).
26. García Y, Ramírez W, Sánchez S. Indicadores de la calidad de los suelos: una nueva manera de evaluar este recurso. *Pastos y Forrajes* 2012;35,(2):125-138. <http://scielo.sld.cu/pdf/pyf/v35n2/pyf01212.pdf>.
27. USDA. Soil quality test kit guide. Soil Quality Institute, Agricultural Research Service, Natural Resources Conservation Service. USDA. Washington, DC.1999. [https://efotg.sc.egov.usda.gov/references/public/WI/Soil\\_Quality\\_Test\\_Kit\\_Guide.pdf](https://efotg.sc.egov.usda.gov/references/public/WI/Soil_Quality_Test_Kit_Guide.pdf)
28. SAS. SAS User's Guide: Statistics (version 9.2 ed.). Cary NC, USA: SAS Inst. Inc. 2001.
29. Steel RGD, Torrie JH, Dickey DA. Principles and procedures of statistics: A biometrical approach. 3ra ed. New York, USA: McGraw-Hill Book Co.; 1997.
30. Guariguata RM, García FC, Sheil D, Nasia R, Herrero JC, Cronkleton P, *et al.* Compatibility of timber and non-timber forest product management in natural tropical forests: Perspectives, challenges, and opportunities. *Forest Ecol Management* 2010;259(3):237-245. <https://doi.org/10.1016/j.foreco.2009.11.013>.

31. Torrico-Albino JC, Peralta-Rivero C, Pelletier E. Evaluación de la capacidad de resiliencia de sistemas de producción agroforestales, agricultura bajo riego y ganadería semi intensiva. *J Agr Sci Technol* 2017;1:37-48 <https://www.researchgate.net/publication/324174900>.
32. Baccini A, Goetz S, Walker W, Laporte N, Sun M, Sulla MD, *et al.* Estimated carbon dioxide emissions from tropical deforestation improved by carbon-density maps. *Nature Climate Change* 2012;2:182-193. <https://doi.org/10.1038/nclimate1354>.
33. Pérez IH, Rodríguez DI, García BR. Secuestro de carbono por el suelo y sus fracciones en agrosistemas tropicales de la región costa ecuatoriana. *Rev Universidad Sociedad* 2021;13(2):141-149.
34. ABT. Autoridad de Fiscalización y Control Social de Bosques y Tierras. Mapa de la superficie deforestada legal e ilegal del periodo 2011-2016 a nivel municipal y predial de los departamentos con mayor cobertura boscosa. Autoridad en Fiscalización y Control Social de Bosques y Tierra. Santa Cruz. Bolivia 2017. <http://abt.gob.bo/index.php?lang=es>.
35. Ingaramo OE, Indicadores físicos de la degradación de suelo [tesis doctoral]. La Coruña España: Universidade da Coruña; 2003.
36. Céspedes FF, Fernández J, Gobbi JA, Bernardis A. Reservorio de carbono en suelo y raíces de un pastizal y una pradera bajo pastoreo. *Rev Fitotec Mex* 2012;35(1):79–86.