

# Production of dry matter and nutritional value of tropical forage shrub species in a biodiverse system

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## ABSTRACT

**Objective:** To estimate production, chemical composition, and ruminal degradation kinetics of dry matter from *Guazuma ulmifolia* and *Gliricidia sepium*.

**Design/Methodology/Approach:** *Guazuma ulmifolia* and *Gliricidia sepium* were studied at the Germplasm Bank of the Rosario Izapa Experimental Field of INIFAP, estimating dry matter production per plant and per hectare, chemical composition, in situ degradability of dry matter, and ruminal degradation parameters of dry matter.

**Results:** Both species recorded >19% crude protein content at 30, 45, and 60 days of regrowth. The *in situ* degradability of dry matter at 45 days of regrowth was higher in *G. sepium* at all incubation times, while dry matter production per plant and per hectare was higher in *G. ulmifolia* in all three regrowth times.

**Study Limitations/Implications:** Data collection and sampling followed manual defoliation. Evaluating the defoliation caused by grazing is still a pending matter.

**Findings/Conclusions:** The species *G. ulmifolia* and *G. sepium* have nutritional and productive characteristics that make them suitable for inclusion in biodiverse forage production systems. *G. ulmifolia* can be defoliated at 45 days of regrowth, while the defoliation of *G. sepium* requires 60 days.

**Keywords:** feeding, cattle, grazing, native species.

**Citation:** Guerra-Medina, C. E., Maldonado-Méndez, J. de J., Montañez-Valdez, O. D. & Gálvez-Marroquín, L. A. (2026). Production of dry matter and nutritional value of tropical forage shrub species in a biodiverse system. *Agro Productividad*. <https://doi.org/10.32854/n8snqq19>

**Academic Editor:** Jorge Cadena Iñiguez

**Associate Editor:** Dra. Lucero del Mar Ruiz Posadas

**Guest Editor:** Juan Francisco Aguirre Medina

**Received:** April 1, 2025.

**Accepted:** December 30, 2025.

**Published on-line:** March XX, 2026.

*Agro Productividad*, 19(1), January, 2026. pp: 61-70.

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## INTRODUCTION

In tropical regions, low nutritional quality and limited availability of forage cause nutritional deficiencies in livestock, negatively impacting average daily weight gain, reproductive performance, milk production, and immune function (Solorio *et al.*, 2017). To enhance forage production and quality for livestock feeding, sustainable technologies must be developed. Additionally, those technologies must be economically competitive and appealing to producers.

Biodiverse forage production for livestock feeding under intensive rotational grazing systems is based on native grasses, legumes (Fabaceae), and forage shrubs. The most outstanding of those species include *Gliricidia sepium* (Jacq.) Walp. and *Guazuma ulmifolia* Lam., given their natural adaptation to tropical ecosystems. These forage species contribute to the sustainability of the system, because they reduce production costs and dependency on external supplies to provide forage and protein to livestock, moderate both macro- and microclimatic conditions, improve soil fertility, and mitigate the impact of droughts (Aguirre *et al.*, 2021). *G. ulmifolia*, a species native to Central America, is recognized for its rapid regrowth after defoliation, an >18% foliage protein content, and its ability to produce forage during the dry season. Therefore, it could be a valuable alternative for high-quality forage production (Manríquez *et al.*, 2011).

*Gliricidia sepium* belongs to the Fabaceae family. This tree species is native to Central America and Mexico, but has spread to other tropical regions, due to its versatility and multiple uses. It has a remarkable capacity to produce foliage during the dry season, with a >20% crude protein content and a 50-70% dry matter digestibility, depending on growth conditions and management practices (Cuervo *et al.*, 2013; Canul *et al.*, 2018). Therefore, the objective of this study was to evaluate the forage production potential and nutritional quality of *G. ulmifolia* and *G. sepium* in a biodiverse forage production system, through the analysis of chemical composition and *in situ* digestibility.

## MATERIALS AND METHODS

### Study area and climate

The study was conducted at the Rosario Izapa Experimental Field of INIFAP, located in the municipality of Tuxtla Chico, Chiapas, Mexico (latitude 14.961864, longitude -92.153272, 398.41 m.a.s.l.). The climate is classified as warm humid (INEGI, 2025). Mean, maximum, and minimum monthly temperatures recorded 26.2 °C, 27.0 °C, and 25.6 °C, respectively. The average annual precipitation is 3,894.6 mm. Most of the rainfall took place during the summer and the highest rainfall was recorded from June to September. Winter rains accounted for 5 to 10.2% of the annual total. The total annual evaporation is 1,384.2 mm, with an annual average of 115.35 mm, and maximum and minimum monthly values of 155.0 mm and 111.5 mm, respectively. Solar radiation intensity is approximately  $7 \pm 1$  h of sunshine per day (CONAGUA, 2024). The soil type is classified as Eutric Sideralic Cambisol (Clayic, Humic) (INEGI, 2025). Soil texture varies between horizons, ranging from clay to silty clay and clay loam. Soil pH ranges from 5.7 to 5.9, organic matter content from 1.2% to 1.3%, and total nitrogen content from 0.05% to 0.35% (Gómez *et al.*, 2018).

### Establishment of the biodiverse system

In May 2023, a *Guazuma ulmifolia* and *Gliricidia sepium* plantation was established in a 2,500 m<sup>2</sup> plot. The plants were arranged in double rows, with 1.5 m between them and 1.5 m between rows, resulting in a planting density of 1,600 plants per hectare. *Panicum maximum* grass was sown in a 10-meter alley between the rows. The three-month-old plants with an average height of  $\approx 0.5$  m were established in the plot. Four months after

field establishment, a uniformity cut was performed at a 1.1 m height, ensuring that  $\approx 0.30$ -m branches were left on the plants. Subsequently, evaluations were conducted at 30, 45, and 60 days of regrowth. For this purpose, three rows were randomly selected and 10 plants were randomly measured per row, totaling 30 plants per forage species and evaluation period. To determine dry matter production per plant, all regrowth was clipped with scissors 30 cm away from the main stem; the regrowth was placed in plastic bags and weighed using a 20-kg scale with a 10 g precision. To estimate dry matter production, samples were transferred to paper bags and dried in a forced-air oven at 60 °C for 48 h. After drying, the final weight was recorded and the dry matter percentage was calculated. Dry matter (DM) production per hectare ( $\text{MS ha}^{-1}$ ) was estimated with the following equation:

$$DM \text{ per plant (kg)} \times 1,600 \text{ plants}$$

The dried samples were ground using a mill with a 2-mm sieve and placed in labeled plastic bags for their subsequent analysis.

#### **Proximate chemical analysis**

The sample was analyzed in a laboratory located in Aguascalientes, Mexico. Total dry matter and crude protein (CP) were determined using the Kjeldahl method. Ether extract was measured following the Soxhlet method. Crude fiber and nitrogen-free extract (NFE) were calculated according to the Weende method, using the following formula:

$$NFE = 100 - (\text{ash} + \text{ether extract} + \text{protein} + \text{fiber})$$

Ash content was determined using the techniques described by AOAC (2012). Neutral detergent fiber (NDF) and acid detergent fiber (ADF) fractions were analyzed based on the methodology described by Van Soest *et al.* (1991).

#### **In situ degradability of dry matter**

This trial was conducted using two heifers, which were allowed to graze freely on *Digitaria swazilandensis* pastures and had free access to mineral salt. Both heifers had been fitted with ruminal fistulas. Degradability was determined through the methodology proposed by Ørskov (2000), using six incubation times. Approximately 5 g of *G. ulmifolia* or *G. sepium* dry samples were collected from the experimental materials at 45 days of regrowth, placed in 10 × 15 cm ANKOM™ nylon bags (ANKOM Technology, Fairport, NY, USA) with 53- $\mu\text{m}$  pores. They were incubated in rumen for 0, 6, 12, 24, 48, and 72 h, with three repetitions per incubation time. The bags were sequentially introduced into the rumen and subsequently washed according to the recommendations of Nocek and Grant (1987).

Rumen kinetics were analyzed using the model proposed by Ørskov and McDonald (1979):

$$P = a + b(1 - e^{-cet})$$

Where:  $P$ =proportion (%) of material that disappeared from the bag at time  $t$ ;  $a$ =ruminal solubility or the fraction disappearing at time zero (%);  $b$ =insoluble but potentially digestible fraction (%);  $c$ =rate of disappearance of fraction  $b$ ;  $t$ =incubation time.

### Statistical analysis

A completely randomized design was used, with two treatments and 10 and 3 repetitions, for dry matter production per plant and per hectare and for *in situ* degradability, respectively. The data were subjected to an analysis of variance (ANOVA) using the PROC GLM procedure (SAS, 2011). Mean comparisons between treatments were performed with Tukey's test, reporting statistically significant differences ( $P < 0.05$ ).

## RESULTS AND DISCUSSION

### Chemical composition and dry matter production

Table 1 shows the chemical composition of *Guazuma ulmifolia* and *Gliricidia sepium*. At 30 days, the crude protein (CP) content of *G. ulmifolia* was 25.2%, while *G. sepium* recorded 23.4%. At 45 days, CP content decreased to 22.7% and 23.02% in *G. ulmifolia* and *G. sepium*, respectively. By day 60, both species continued to show a decline in CP content: *G. ulmifolia* decreased to 19.16%, while *G. sepium* recorded 22.49%. From day 30 to 60, *G. ulmifolia* and *G. sepium* decreased by 5.6% and 0.91%, respectively. These values are higher than those reported by Jiménez *et al.* (2008) —who recorded 13.6% in *G. ulmifolia*— and Castrejón *et al.* (2016) —who reported 12.25% in *G. ulmifolia* and 16.32% in *G. sepium*. The differences with previous studies may be attributed to variations in the age of the plant at the time of sampling, which neither research team specified.

In tropical regions, the low crude protein (CP) content of grasses limits both productivity and reproductive performance in cattle. To maximize forage digestibility, the protein available in the rumen for microbial activity must exceed 8%, with the ultimate purpose of enhancing nutrient use and the overall energy value of the diet (Rayas *et al.*, 2012; Kichel *et al.*, 2018). In this study, the CP content of *G. ulmifolia* and *G. sepium* remained above 19% even at 60 days of regrowth, indicating that both species are an important protein source for livestock feeding. Their high CP content, even during the dry season, makes them viable alternatives for the mitigation of protein deficiencies in tropical cattle production systems.

**Table 1.** Chemical composition of *Guazuma ulmifolia* and *Gliricidia sepium* at three regrowth ages.

Variable	<i>G. ulmifolia</i>			<i>G. sepium</i>		
	30 days	45 days	60 days	30 days	45 days	60 days
Crude protein (%)	25.20	22.73	19.16	23.45	23.02	22.49
Crude fat (%)	2.68	2.30	2.44	3.17	2.39	2.25
Crude fiber (%)	29.55	35.47	41.67	26.14	22.19	24.34
Nitrogen-free extraction (%)	32.56	28.22	27.37	37.30	42.92	41.41
Neutral detergent fiber (%)	57.91	63.07	67.19	36.23	32.34	35.19
Acid detergent fiber (%)	33.80	38.20	44.20	28.65	25.76	27.37
Ash (%)	10.02	11.28	9.36	9.94	9.48	9.52

Crude fat (ether extract: EE) content at 30 days was 2.68% for *G. ulmifolia* and 3.17% for *G. sepium*. At 45 and 60 days, both species showed a slight decrease in fat content, but their levels remained above 2.2% (Table 1). These results are similar to those reported for *G. sepium* by Santana *et al.* (2019), who recorded a 2.33% EE, and by Winarti *et al.* (2022), who reported 4.47% EE. In the case of *G. ulmifolia*, Pereira *et al.* (2019) reported 2.57% EE—a similar value to the results of this study.

Regarding crude fiber (CF) content, *G. ulmifolia* registered 29.55% at 30 days, increasing to 41.67% at 60 days. In contrast, *G. sepium* showed a 26.14% and 24.34% CF content at 30 and 60 days, respectively (Table 1). These values are lower than those reported in leaf samples by Cabrera *et al.* (2018), who observed 54.3% CF for *G. ulmifolia* and 59.2% CF for *G. sepium*. CF has a positive effect on rumen function, helping to regulate pH and serving as a primary energy source for rumen microorganisms, particularly when livestock diets are forage-based (Dijkstra *et al.*, 2012). As the grass matures, both CF and lignin contents increase, while the ruminal digestibility of dry matter decreases (Van Soest, 1994). This disadvantage of grasses can be mitigated through the incorporation of forage trees with low fiber content into grazing diets.

At 30 days, the nitrogen-free extract (NFE) content of *G. ulmifolia* and *G. sepium* was 32.56% and 37.30%, respectively. At 45 days, NFE in *G. ulmifolia* decreased to 28.22%, while in *G. sepium* it increased to 42.92%. By day 60, *G. ulmifolia* further decreased to 27.37%, while *G. sepium* slightly decreased to 41.41% (Table 1). These results are similar to those reported by Okoruwa *et al.* (2018) (39.02%) and Julius *et al.* (2016) (44.53%). Higher values have also been reported, including the 54.51% NFE content recorded by Guna *et al.* (2023) and the 58.3% content found by Aye *et al.* (2012). In the case of *G. sepium*, the NFE contents in this study are lower than those reported by López *et al.* (2008) (45.14%) and Cabrera *et al.* (2018) (45.90%).

Nitrogen-free extract (NFE) is an estimate of the content of soluble carbohydrates (Apráz *et al.*, 2020)—readily fermentable compounds, such as starch and sugars. They are more easily available than cellulose and therefore support better microbial growth in the rumen (Bach *et al.*, 2005). Grazing cattle diets that contain an adequate concentration of soluble carbohydrates (NFE) significantly improves weight gain (Gaviria *et al.*, 2015).

The neutral detergent fiber (NDF) content at 30 days was 57.91% in *G. ulmifolia* and 36.23% in *G. sepium*. At 45 and 60 days, NDF in *G. ulmifolia* increased to 63.07% and 67.19%, respectively; meanwhile, it slightly decreased (35.19%) in *G. sepium* at 60 days (Table 1). For their part, Cortez *et al.* (2016) recorded 63.88% NDF for *G. ulmifolia*. Meanwhile, Ayala *et al.* (2006) reported 43.2% NDF and 27.2% acid detergent fiber (ADF) for *G. ulmifolia* and 44.2% NDF and 30.2% ADF for *G. sepium*. Finally, Pinto *et al.* (2010) observed 37.10% NDF and 30.17% ADF in *G. ulmifolia* and 46.26% NDF and 32.32% ADF in *G. sepium*.

Neutral detergent fiber (NDF) is primarily composed of cellulose, hemicellulose, and lignin (Van Soest *et al.*, 1991). Its concentration in the diet of ruminants is inversely related to voluntary dry matter intake. Meanwhile, the increase in acid detergent fiber (ADF)—which includes cellulose and lignin—is associated with the decrease of cellulose digestibility (Mertens, 2002). Therefore, the integration of forage trees with low NDF

and ADF content into biodiverse forage systems can enhance both digestibility and forage intake in grazing cattle.

Ash content at 30 days was 10.02% and 9.94% in *G. ulmifolia* and *G. sepium*, respectively. At 45 days, ash content in *G. ulmifolia* increased to 11.28%, while in *G. sepium* it decreased to 9.48%. By day 60, ash content was 9.36% in *G. ulmifolia* and 9.52% in *G. sepium* (Table 1). Other authors report variable ash content: Cortez *et al.* (2016) recorded 12.65% in *G. ulmifolia*, while Molina *et al.* (2013), Pacheco *et al.* (2013), and Mayren *et al.* (2018) reported 9.02%, 9.36%, and 11.3% content in *G. sepium*.

Meanwhile, dry matter production (DMP) ( $\text{kg plant}^{-1}$  and  $\text{t ha}^{-1}$ ) showed higher values in *G. ulmifolia* at 30-, 45-, and 60-days post-cutting ( $P < 0.05$ ). At 30 days, DMP for *G. ulmifolia* was  $0.489 \text{ t ha}^{-1}$ , which was higher than the DMP for *G. sepium* ( $0.328 \text{ t ha}^{-1}$ ). At 45 days, the production of *G. ulmifolia* increased to  $0.835 \text{ t ha}^{-1}$ , reaching  $1.082 \text{ t ha}^{-1}$  at 60 days. Meanwhile, *G. sepium* produced  $0.451 \text{ t ha}^{-1}$ . The DMP ( $\text{t ha}^{-1}$ ) of *G. ulmifolia* was 0.161, 0.498, and 0.631 higher than that of *G. sepium* at 30, 45, and 60 days, respectively.

Several authors have reported different dry matter (DM) yields under different conditions. Vargas (2017) reported a density of 10,000 plants per hectare with 45-day cutting intervals, in a *G. ulmifolia* forage bank in Colombia, recording  $5.8 \text{ t ha}^{-1}$  of leaf DM per year, 82 g DM per plant, and  $0.8 \text{ t ha}^{-1}$  per cut. In Yucatán, Mexico, Casanova *et al.* (2014) reported a  $3.7 \text{ t DM ha}^{-1}$  and  $5.3 \text{ t DM ha}^{-1}$  yield during the dry season and the rainy season, respectively. Their experiment was conducted in a plantation with  $2 \times 0.5 \text{ m}$  between plants, harvested every three months. Meanwhile, in Colima, Mexico, Palma (1997) reported the highest dry matter (DM) levels in *G. sepium* ( $1.456 \text{ t ha}^{-1}$ ), based on an average of five monthly harvests. Rangel (2023) obtained leaf DM yields ranging from  $10.5$  to  $14.8 \text{ t ha}^{-1}$  per year in a Brazilian plantation, with 1 m between rows and 50 cm between plants.

The results show that, at 45 days of regrowth, *G. ulmifolia* reaches a dry matter production level of  $0.835 \text{ t ha}^{-1}$ , with a high crude protein (CP) content and low neutral detergent fiber (NDF) content. Given these characteristics, this forage species could be potentially included in biodiverse forage production systems.

**Table 2.** Dry matter production of *G. ulmifolia* and *G. sepium* per plant and per hectare, at different regrowth ages.

Days post-cutting	Dry matter production per plant (kg)		
	<i>Guazuma ulmifolia</i>	<i>Gliricidia sepium</i>	EEM
30	0.306a	0.205b	0.026
45	0.522a	0.211b	0.055
60	0.670a	0.282b	0.086
	Dry matter production per hectare (t)		
30	0.489a	0.328b	0.187
45	0.835a	0.337b	0.281
60	1.082a	0.451b	0.269

a, b: Means with different letters in different rows are statistically different, according to Tukey's test ( $P < 0.05$ ). SEM (EEM): standard error of the mean.

At all incubation times, *G. sepium* showed greater degradability than *G. ulmifolia* ( $P < 0.05$ ). Degradability in *G. sepium* exceeded 60% and 91% at 6 and 72 h, respectively. Meanwhile, it reached 58.55% at 24 h in *G. ulmifolia* (Table 3). *In situ* degradability is related to the chemical composition of the forage and the ability of ruminants to degrade it. Higher degradability is associated with a greater availability of forage nutrients for animal functions, including production (Krizsan *et al.*, 2012). In this study, *G. sepium* showed a lower percentage of crude fiber and neutral detergent fiber, which contributes to higher degradability and increased ruminal propionate production. Propionate acts as a hydrogen sink, resulting in a lower proportion of enteric methane (Jun *et al.*, 2023).

The degradation parameters and dry matter degradation rate showed a higher soluble fraction in *G. sepium* than in *G. ulmifolia*, indicating that a greater proportion of dissolved nutrients is available for microbial fermentation (Ørskov and McDonald, 1979).

Meanwhile, both forages recorded similar degradable fraction and degradation rate (Table 4), indicating that microbial enzymes in the rumen can efficiently degrade the nutrients in these forages at a moderate rate, which benefits microbial protein production and volatile fatty acid synthesis (Bach *et al.*, 2005).

The indigestible fraction of dry matter was higher in *G. ulmifolia* than in *G. sepium*; this situation is related to the higher NDF content and may limit digestion (Table 4). According to the results, *G. sepium* has better ruminal degradation parameters: a high soluble and degradable fraction, a low indigestible fraction, and a moderate degradation rate. These characteristics may allow the animal to make better use of other dietary nutrients, such as proteins, carbohydrates, and fats (Bach *et al.*, 2005).

**Table 3.** *In situ* dry matter degradability (%) of tropical forage shrubs at 45 days of regrowth.

Incubation time (h)	<i>Guazuma ulmifolia</i>	<i>Gliricidia sepium</i>	EEM
72	78.27b	91.24a	2.24
48	73.22b	81.90a	2.95
24	58.55b	76.27a	3.05
12	36.77b	64.03a	2.44
6	29.13b	63.00a	2.06
0	9.12b	39.78a	1.44

a, b: Means within different letters in different rows are statistically different according to Tukey's test ( $P < 0.05$ ). SEM (EEM): standard error of the mean.

**Table 4.** Dry matter fractions and degradation rate of the evaluated forages (%).

Fraction	<i>Guazuma ulmifolia</i>	<i>Gliricidia sepium</i>
Soluble (a)	34.21b	42.64a
Degradable (b)	43.72b	45.33a
Indigestible	22.07a	12.03b
Degradation rate (k d/h)	0.066a	0.062a

a, b: Means within different letters in different rows are statistically different, according to Tukey's test ( $P < 0.05$ ).

## CONCLUSIONS

The crude protein (CP) content in both species was >19% at 30, 45, and 60 days of regrowth, while the in situ dry matter degradability at 45 days of regrowth exceeded 58% after a 24-hour incubation. *Gliricidia sepium* stands out for its high proportion of soluble fraction and low indigestible fraction, which make it a better forage than *Guazuma ulmifolia* in terms of nutritional quality. However, the latter has a greater dry matter production at all three regrowth periods, showing a remarkably high production capacity starting from day 45. In conclusion, *G. ulmifolia* and *G. sepium* have a significant potential to produce high-quality forage in biodiverse forage production systems.

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