BIOMASS PRODUCTION AND CHEMICAL COMPOSITION OF *Tithonia diversifolia* BY THE DATE OF HARVESTING AT DIFFERENT CUTTING HEIGHTS †

[PRODUCCIÓN DE BIOMASA Y COMPOSICIÓN QUÍMICA DE *Tithonia diversifolia* POR FECHA DE COSECHA A DIFERENTES ALTURAS DE CORTE]

Carol Uu-Espens[1], Dixan Pozo-Leyva[1], Deb Raj Aryal[2], Benito Dzib-Castillo[3], Gilberto Villanueva-López[4], Fernando Casanova-Lugo[1]*, Alfonso Chay-Canul[5] and Jorge Canúl-Solís[6]

[1]Tecnológico Nacional de México Campus IT de la Zona Maya. Carretera Chetumal-Escárcega km 21.5, Ejido Juan Sarabia, C.P. 77960, Othón P. Blanco, Quintana Roo, México. Email. fkzanov@gmail.com
[2]CONACYT-UNACH, Facultad de Ciencias Agronómicas, Universidad Autónoma de Chiapas, México. Carretera Ocozocoautla – Villaflores km. 84.5, C.P. 30470, Villaflores, México.
[3]Tecnológico Nacional de México Campus IT de Chiná. Calle 11, Col. Centro Chiná, C.P. 24050, Campeche, México.
[4]El Colegio de la Frontera Sur, unidad Villahermosa. Carretera a Reforma 15.5 s/n Ra. Guineo 2ª Sección, C.P. 86280, Villahermosa, Tabasco, México.
[5]División Académica de Ciencias Agropecuarias, Universidad Juárez Autónoma de Tabasco. Carretera Villahermosa-Teapa, km 25, C.P. 8628, Villahermosa, Tabasco, México.
[6]Tecnologico Nacional de México Campus IT de Tizimín. Final de Aeropuerto Cupul s/n, C.P. 97700, Tizimín, Yucatán, México.
**Corresponding author*

SUMMARY

Background: The use of *Tithonia diversifolia* foliage can improve the quality of animal feed because its crude protein content doubles that of tropical grasses. However, plant response regarding biomass production to frequent harvest disturbances are not known well. **Objective**: To evaluate the effect of different cutting heights and repeated harvests on biomass production and nutrient content of *T. diversifolia* in fodder banks under warm sub-humid climate. **Methodology**: We used a completely randomized design with a factorial arrangement; the treatments consisted of six harvest dates: Mar, May, July, September, November 2019 and January 2020; and three harvest heights: 40, 60 and 80 cm from the ground level. After each harvest date, the biomass was separated into different components, weighed and dried. Samples were taken to analyse the chemical composition of the forage. **Results**: The highest yield of leaves was found in the month of January, while tender stems in November. The Senescent material and total biomass were lower in September. The cutting height influenced leaf yield. Crude protein content was higher in September at a cutting height of 60 cm. Neutral detergent fiber was higher in the month of November for all cutting heights. Likewise, the highest contents of acid detergent fiber were in November for all cutting heights and in January for the cutting height of 60 cm. Lignin content was similar for all treatments. **Implications**: These results contribute to the development sustainable livestock production by providing alternatives to reduce grassland degradation from overgrazing. **Conclusion**: Biomass yield and chemical composition of *T. diversifolia* are affected by harvest date and heights, so it is necessary to consider it in the management strategies for optimal use of forage resources, incorporation in silvopastoral systems and the development of sustainable livestock production.
Key words: fodder bank; forage quality; growth response; Mexican sunflower; repeated harvests.

---

† *Submitted April 7, 2023 – Accepted May 26, 2023. http://doi.org/10.56369/tsaes.4888*

ISSN: 1870-0462.
Authors ORCID = Fernando Casanova-Lugo: http://orcid.org/0000-0003-2485-9170; **Carol Estrella Uu-Espens:** http://orcid.org/0000-0002-0320-2981; **Dixan Pozo-Leyva:** http://orcid.org/0000-0002-3139-8512; **Deb Raj Aryal:** http://orcid.org/0000-0003-4188-3084; **Benito Bernardino Dzib-Castillo:** http://orcid.org/0000-0003-0965-330X; **Gilberto Villanueva-López:** http://orcid.org/0000-0001-9200-2553; **Alfonso Juventino Chay-Canul:** http://orcid.org/0000-0003-4412-4972; **Jorge Rodolfo Canúl-Solís:** http://orcid.org/0000-0001-9934-4302

RESUMEN

Antecedentes: El uso del follaje de *Tithonia diversifolia* puede mejorar la calidad de la alimentación animal debido a que su contenido de proteína cruda duplica al de las gramíneas tropicales. Sin embargo, la respuesta de la planta con respecto a la producción de biomasa a las frecuentes perturbaciones de la cosecha es poco conocida. **Objetivo**: Evaluar el efecto de diferentes alturas de corte y cosechas repetidas sobre la producción de biomasa y contenido de nutrientes de *T. diversifolia* en bancos forrajeros bajo clima cálido subhúmedo. **Metodología**: Se utilizó un diseño completamente al azar con arreglo factorial; los tratamientos consistieron seis fechas de cosecha: marzo, mayo, julio, septiembre, noviembre de 2019 y enero de 2020; y tres alturas de cosecha: 40, 60 y 80 cm desde el suelo. Después de cada fecha de cosecha, la biomasa se separó en diferentes componentes, se pesó y se secó. Se tomaron muestras para analizar la composición química del forraje. **Resultados**: El mayor rendimiento de hojas se encontró en el mes de enero, mientras que de tallos tiernos en noviembre. El material senescente y la biomasa total fueron menores en septiembre. La altura de corte influyó en el rendimiento de hojas. El contenido de proteína cruda fue mayor en septiembre a una altura de corte de 60 cm. La fibra detergente neutro fue mayor en el mes de noviembre para todas las alturas de corte. Asimismo, los mayores contenidos de fibra detergente ácido fueron en noviembre para todas las alturas de corte y en enero para la altura de corte de 60 cm. El contenido de lignina fue similar para todos los tratamientos. **Implicaciones**: Estos resultados contribuyen al desarrollo de una producción ganadera sostenible al brindar alternativas para reducir la degradación de los pastizales por sobrepastoreo. **Conclusión**: El rendimiento de biomasa y la composición química de *T. diversifolia* se ven afectados por la fecha y altura de cosecha, por lo que es necesario considerarlo en las estrategias de manejo para el aprovechamiento óptimo de los recursos forrajeros, la incorporación en sistemas silvopastoriles y el desarrollo de una producción pecuaria sostenible.

Palabras clave: banco de forraje; calidad forrajera; cosechas repetidas; girasol mexicano; respuesta de crecimiento.

INTRODUCTION

Livestock production occupies two-thirds (34 Mkm^2) of the world´s agricultural land (49 Mkm^2) for production of animal feed (grazed pastures, 80 %, and feed crop, 20 %), while a quarter (3.5 Mkm^2) of the crop area (15.2 Mkm^2) produces animal feed (Foley *et al*., 2011). Livestock provide about 40 % of the value of world agricultural production and a third in developing countries. It supports the livelihoods and food security of almost 1.3 billion people around the world, as it is one of the main sources of protein in the diet and central to the survival of much of the rural population (Alders *et al*., 2021). Global demand for livestock products, principally milk and meat, is expected to double by 2050, particularly in developing countries (Herrero *et al*., 2013). Livestock in Mexico has grown 4 % annually, more than double the values of world average (2.8 %) (Kolb and Galicia, 2018), and is represented by 3.1 million production units, which contribute 45 % of the value of agricultural production and provide more than one million permanent jobs. As in the rest of the world, this growth is directly related to the increase in the human population and the consequent increase in the demand, mainly for milk and meat (Graesser *et al*., 2015). Despite the above, this activity exerts progressive pressure on natural resources and the environment, and causes a simplification of the landscape, due to the conversion of forests to treeless pasture lands (Morales-Ruiz *et al*., 2021).

At present, livestock faces various problems, among which the variability of the quantity and quality of forage throughout the year stands out, which has a negative impact on the productive and reproductive parameters of livestock (Valenzuela-Que *et al*., 2022). Faced with this situation, the use of foliage of trees or shrubs can be a good alternative, since these resources have great potential as forage; that is, they have nutritional characteristics superior to tropical grasses and excellent biomass yields (Cardona *et al*., 2022).

In this regard, some tropical forage shrubs maintain their chemical characteristics during the dry season with digestibility values ranging from 54 to 90 % and crude protein (CP) concentrations above 17 %, which makes them a better forage option than tropical grasses alone. The latter often have low digestibility of 35-38 % and CP contents lower than 10 % (Gutiérrez *et al*., 2017). In fact, it has been documented that shrub plants can replace up to 35 % of commercial concentrate feed imports for livestock production farming (Cardona *et al*., 2022).

Within the tropical shrubs, *Tithonia diversifolia* (Hemsl.) A. Gray, a plant of the Asteraceae family native to Mexico knowns as “Mexican sunflower” poses a high potential for livestock feeding. This shrub has a wide distribution because it can be found in the humid and sub-humid tropics of Central and South America, Asia, and Africa (Ruiz *et al*., 2017). It is a fast-growing plant with high yields of green biomass, withstands repeated harvests, responds to the diverse sowing methods, the cutting frequency, resistant to water deficit, temperature extremes and have a good nutrient composition (Aboyeji *et al*., 2017; Senarathne *et al*., 2019). Other relevant characteristics are the absence of thorns, low demand for inputs and their easy propagation, which makes *T. diversifolia* an attractive option for animal farmers since it can be easily included in livestock systems as fodder (Letty *et al*., 2021). It is also appreciated by beekeepers as a source of nectar, making it a good species for agroforestry practices. In Costa Rica, it has been used to increase production in improved fallows (Mustonen *et al*., 2012). It is considered that *T. diversifolia* provides nutrients such as phosphorus for the development of crops in nutrient poor soils (Aboyeji, 2022). In the Philippines it is used as a green manure in rice crops and goat feeding in a cut and carry system. In Venezuela they use it as fresh forage without chopping for the consumption of sheep and goats. In Colombia, an excellent consumption by Holstein cows has been observed in browsing, but they also offer it minced in mixture with other forages such as *Trichanthera gigantea* (Humb. & Bonpl.) Nees, *Erythrina edulis* Micheli, *Morus alba* L. and *Saccharum* ssp., for cattle feeding (Cairns, 1997). However, the plant response to different agronomic management and the inclusion in the animal nutrition of *T. diversifolia* has been poorly documented in south-eastern of Mexico. The lack of evidence on the plant response to appropriate cutting or harvest heights can cause a decrease in forage production due to the reduction in the number of stem buds that limit the regrowth of new leaves (Letty *et al*., 2021). Likewise, it causes the depletion of plant nutrient reserves because they mobilise reserve carbohydrates to rebuild photosynthetic tissue after harvest, grazing or seasonal loss of foliage (Navale *et al*., 2022). Therefore, the objective of this study was to assess the effect of different cutting heights and repeated harvesting on biomass production and chemical composition of *T. diversifolia* in a fodder bank livestock system in Southern Mexico.

MATERIALS AND METHODS

Site study

The study was carried out at the experimental plots of Tecnológico Nacional de México Campus IT de la Zona Maya in the state of Quintana Roo, Mexico from January 2019 to January 2020 (18° 30' N and 89° 41' W). The area presents a warm sub-humid climate (Aw_1). The mean, maximum and minimum annual temperatures and the total rainfall during this period were 26.4, 34.3, 18.5 °C and 1008.5 mm, respectively (Table 1). The predominant soils are Gleysols according to the Food and Agriculture Organization soil classification system (IUSS Working Group WRB, 2022), with a bulk density of 1.2 g cm^{-3}, pH value of 7.7, organic matter content of 3.7 %, and total nitrogen concentration of 0.2 % in the arable layer (0-30 cm deep).

Establishment and management of experimental plots

The plots were established at the beginning of the rainy season, between the months of July and August 2017. For the establishment of the forage banks, we used *T. diversifolia* cuttings of 3.0±1.0 cm in diameter, and 50 cm long. Later, the stem segments were submerged in water with a rooting® agent (complex phytoregulator composed of Indole-3-butyric acid and N-(2-chloro-4-pyridyl)-N′-phenylure in a dose of 100 ml per liter) for 24 hours and then they were planted vertically in each plot at a depth of 20 cm from the soil surface and at a planting distance of 0.5 m between plants and 2.0 m between rows to obtain a planting density of 10,000 plants ha^{-1}. A total of 12 sampling plots (10 × 10 m) were delimited, which were made up of five rows of *T. diversifolia*, of which only three central rows were measured to avoid the boarder effect in each experimental unit. The experiment ran from January 2019 to January 2020. Before the evaluation, a standardization harvest was performed manually in January 2019; measurements were started in March of the same year. The alleys were cleaned manually to control weeds. It should be noted that no irrigation or fertilizers were applied.

Table 1. Maximum and minimum air temperatures and rainfall at the study site. Data were taken from the climatic station at the Instituto Tecnológico de la Zona Maya in January 2019–January 2020.

Month -Year	Temperature Maximum (°C)	Temperature Minimum (°C)	Rainfall (mm)
Jan-19	32.0	11.0	17.1
Feb-19	32.0	16.0	14.8
Mar-19	35.0	17.0	11.7
Apr-19	36.0	17.0	63.1
May-19	35.0	21.0	14.8
Jun-19	34.0	23.0	56.3
Jul-19	36.0	22.0	33.1
Aug-19	35.0	25.6	30.0
Sep-19	37.0	25.0	279.6
Oct-19	35.0	23.0	238.7
Nov-19	34.0	15.0	140.2
Dec-19	33.0	11.0	62.0
Jan-20	32.0	14.0	47.1

Experimental design

We used a completely randomised design due to the homogeneity of the land and the same characteristics of the soil; the treatments consisted of evaluating three cutting heights of *T. diversifolia* (i.e., 40, 60, 80 cm) and six harvesting dates (i.e., March, May, July, September and November of 2019, and January of 2020). During the experimental period, biomass harvests were carried out with an interval of two months, which was done at the beginning of the corresponding month.

Biomass production

After each harvesting, the total biomass (leaves, tender stems, woody stems, and senescent material) from each experimental unit was weighed fresh. Harvested material from each treatment was pooled and three sub-samples (1.0 kg each) were randomly taken. These subsamples were divided into leaves, tender stems (<0.5 cm diameter) and woody stems (≥0.5 cm diameter), which were dried at 60 °C in a forced circulation oven drier ED400 (Binder Inc., Bohemia, NY, USA) until reaching constant weight to calculate dry matter (DM).

Chemical composition analysis

Edible biomass sub-samples (leaves and tender stems) were grounded using an electric mill IKA MF 10 (IKA Works, Inc. Wilmington, NC, USA) to a particle size of 1.0 mm and they were analysed for neutral detergent fiber (NDF), acid detergent fiber (ADF) and lignin, using an ANKOM A200 fiber analyser (ANKOM Technology, Macedon, NY, USA). The fraction of nitrogen (N) was estimated by using a PerkinElmer 2400 Series II elemental analyser (PerkinElmer Inc., Massachusetts, USA), then converted to crude protein (CP) by the conversion factor 6.25 (Greenfield and Southgate, 1992).

Statistical analysis

The data were first tested for the normality of distribution (Shapiro-Wilk) and homogeneity (Levene´s test), of variances. The biomass production and nutrient composition data were square root transformed and applied to a multivariate analysis of variance to examine the effect of harvest time, cutting heights and their interactions, using PROC GLM (SAS Institute Inc, 2020). Where significant differences were observed, we compared the means using Tukey's statistic ($p \leq 0.05$).

RESULTS

Biomass production

The biomass production of *T. diversifolia* varied significantly between harvest months during the year (p <0.05). The highest leaf yield was obtained in January (p = 0.002), compared to the other harvest months. The greater yield of tender stems occurred in the month of November (p <0.001). Likewise, the highest yields of senescent material were observed in the months of March, May, July, November, and January (p <0.001), compared to the month of September. In November the highest yield of total biomass (p <0.001) was registered and the lowest in September (2988.7 and 889.5 kg DM ha^{-1} $harvest^{-1}$). Finally, the yield of woody stems was similar (p = 0.361) between harvest dates (Table 2).

The cutting height of 80 cm showed a higher yield of leaves (p = 0.003), compared to the heights of 40 and 60 cm. In contrast, the yield of tender stems, woody stems, senescent material, and total biomass was similar (p >0.05) between the evaluated cutting heights (Table 3). Likewise, the interaction between harvest date and cutting height did not show significant effects (p >0.05) on the biomass production of *T. diversifolia*.

On the other hand, the cutting height of 80 cm showed the greater (p <0.05) cumulative production (March 2019 to January 2020), of the *T. diversifolia* biomass (10893 kg DM ha^{-1} $year^{-1}$), followed by the cutting heights of 40 and 60 cm, with values of 8939 and 8544 kg DM ha^{-1} $year^{-1}$, respectively (Figure 1).

Nutrient composition

The statistical analysis showed that the interaction between harvest date and cutting height influenced the chemical composition of the edible biomass of *T. diversifolia* (Table 4). In this regard, it was found that the CP content was higher (p <0.001) in September harvested at a height of 60 cm (297.9 g kg^{-1} DM),

Table 2. Harvest date variation of total, tender stems, woody stems, and senescent biomass yield (kg DM ha^{-1} $harvest^{-1}$) of *Tithonia diversifolia* (Hemsl.) A. Gray in a fodder bank under tropical conditions.

Harvest date	Leaves	Tender stems	Woody stems	Senescent material	Total
Mar-19	672.0^{c}	279.1^{c}	19.0^{a}	89.1^{a}	1059.2^{c}
May-19	716.9^{c}	300.8^{c}	28.3^{a}	126.7^{a}	1172.7^{c}
Jul-19	665.4^{c}	315.4^{c}	28.6^{a}	113.1^{a}	1122.5^{c}
Sep-19	632.7^{c}	220.5^{c}	18.9^{a}	27.4^{b}	899.5^{c}
Nov-19	843.2^{b}	1961.6^{a}	49.2^{a}	134.7^{a}	2988.7^{a}
Jan-20	1138.8^{a}	927.1^{b}	20.3^{a}	146.9^{a}	2233.1^{b}
SE	82.2	102.2	10.9	20.2	115.2
p–value	0.002	<0.001	0.361	<0.001	<0.001

Means labelled by different letters are significantly different according to Tukey's statistic (p ≤0.050). SE, standard error of the mean.

Table 3. Effect of cutting height from the ground level on leaves, tender stems, woody stems, and senescent material production in *Tithonia diversifolia* (Hemsl.) A. Gray (kg DM ha^{-1} $harvest^{-1}$) in a fodder bank under tropical conditions.

Cutting height (cm)	Leaves	Tender stems	Woody stems	Senescent material	Total
40	649.0^{b}	722.2^{a}	37.8^{a}	80.9^{a}	1489.9^{a}
60	719.8^{b}	568.1^{a}	24.0^{a}	112.0^{a}	1424.0^{a}
80	965.6^{a}	712.0^{a}	11.8^{a}	126.1^{a}	1815.5^{a}
SE	69.0	185.6	9.4	18.8	206.2
p–value	0.003	0.455	0.187	0.055	0.127

Means labelled by different letters are significantly different according to Tukey's statistic ($p \leq 0.050$). SE, standard error of the mean.

compared to the other treatments. The highest NDF contents ($p < 0.001$) occurred in November with values ranging between 501.5 to 516.5 g kg^{-1} DM, for all harvest heights, while the lowest NDF value was for the month of May, at a height harvest of 60 cm (353.8 g kg^{-1} DM). The ADF content was higher ($p < 0.001$) in November for all harvest heights (304.9, 292.4 and 316.1 g kg^{-1} DM), and January at 60 cm (294.6 g kg^{-1} DM), while the lowest content was presented in the May period with harvest heights of 40 and 80 cm, and for July at 40 cm. The lignin content did not show significant changes ($p = 0.859$) with harvest time and cutting height (Table 4).

DISCUSSION

Biomass production

The significant effects on the harvest date on the biomass production of *T. diversifolia* in this study are linked to the availability of water in the soil. This is explained by the fact that the lower production of senescent material was observed at the beginning of the rainy period, in September-2019 (Figure 2). While the highest yields of tender stems and leaves occurred in the months of November-2019 and January-2020, respectively. This is possibly due to the greater availability of water in the environment, since, during the period from September-2019 to January-2020, 76.1 % of the total precipitation was concentrated (768 mm), Furthermore, in the same period, average temperatures were recorded from 17.6 to 34.2 °C, suitable for the growth of *T. diversifolia*. These results differ from what was observed by Canúl-Solís *et al*. (2018), in eastern Yucatan, Mexico, who mention that the best forage productivity of *T. diversifolia* and *Gliricidia sepium* (Jacq.) Kunth ex Walp. in agroforestry systems was observed in periods of low rainfall (<100 mm), corresponding to the months of August, February and May.

In this regard, it has been mentioned that *T. diversifolia* grows in different agroecological conditions, although prefers to grow where mean annual temperatures range from 15 °C to 31 °C but it can tolerate temperatures from 12 °C to 38 °C (Orwa *et al*., 2009). It prefers environments with a mean annual rainfall in the range from 1000 mm to 2000 mm although it tolerates rainfall from 700 mm to 2500 mm (Ruiz *et al*., 2017). This species is adapted to grow in a wide range of soil types including sandy, loamy and clay soils with a pH range of 6.1-7.8 pH. This species prefers open and sunny areas and can tolerate moderate drought events (Orwa *et al*., 2009), and edaphoclimatic conditions like those of the present study.

Regarding the response to cutting heights, the greater production of leaves in *T. diversifolia* at a harvest height of 80 cm, was probably because the remaining stems maintain a greater number of buds that favors shoot growth, compared to the harvests at a lower height; showing a positive effect on leaf yield, which corresponds to that reported by Ramos-Trejo *et al*. (2015). Otherwise, Casanova-Lugo *et al*. (2014), documented that the implementation of severe pruning causes a reduction in the photosynthetic capacity of the plant and with it the depletion of its carbohydrate reserves, which would affect the recovery capacity after harvest.

In relation to the above, it was observed that *T. diversifolia* showed a high availability of leaves and low proportions of stems and senescent material, which is why it could be considered as a good option to be used as green manure or animal forage in agro-silvopastoral systems (Ruiz *et al*., 2017).

It is important to note that the low proportions of stems and senescent material may be due to their physiological adaptability and the frequency of harvest, which likewise increases the high availability of leaves. In fact, similar results have been reported by Canúl-Solís *et al*. (2018) who indicate that at 42 days of growth, the production of leaves and stems is higher. Likewise, Senarathne *et al*. (2019) documented that a decrease in harvest frequency results in an increase in woody biomass and a decrease in foliage biomass, while an increase in harvest frequency behaved inversely.

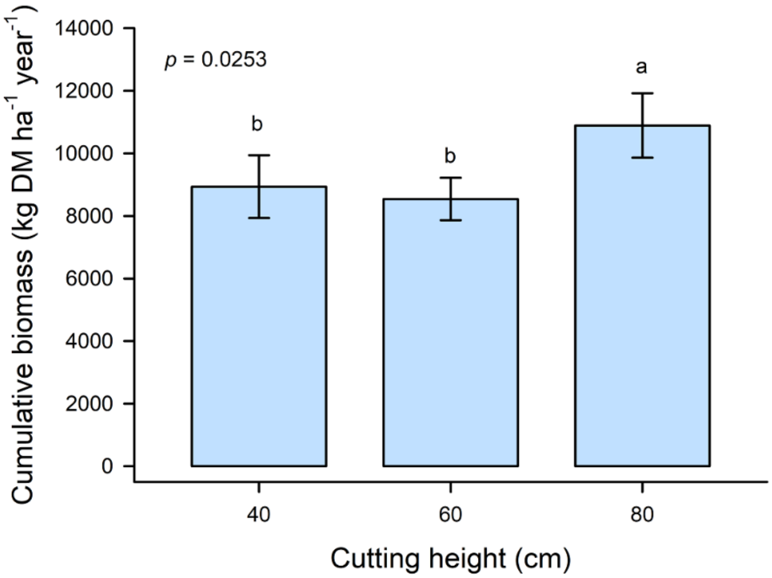

Figure 1. Cumulative production (March 2019 to January 2020) of *Tithonia diversifolia* (Hemsl.) A. Gray. biomass at different cutting heights from the ground level in a fodder bank under tropical conditions. Error bars represent the standard error of the mean; means labelled by different letters are significantly different (Tukey's statistic, $p \leq 0.05$).

Table 4. Effect of harvest date and cutting height interaction on edible biomass nutrient content (g kg^{-1} DM) of *Tithonia diversifolia* (Hemsl.) A. Gray in a fodder bank under tropical conditions.

Harvest date	Cutting height (cm)	CP	NDF	ADF	Lignin
Mar-19	40	257.8^{c}	403.5^{c}	247.6^{d}	32.5^{a}
	60	282.8^{b}	377.3^{d}	235.1^{d}	38.7^{a}
	80	239.4^{d}	415.1^{c}	256.7^{c}	35.2^{a}
May-19	40	252.2^{c}	406.5^{c}	250.4^{c}	29.4^{a}
	60	285.5^{b}	353.8^{f}	233.9^{d}	33.4^{a}
	80	236.8^{d}	374.3^{e}	258.1^{c}	31.1^{a}
Jul-19	40	236.9^{d}	413.2^{c}	258.0^{c}	35.1^{a}
	60	265.3^{c}	399.5^{c}	243.9^{d}	44.1^{a}
	80	221.0^{e}	409.9^{c}	265.9^{b}	39.3^{a}
Sep-19	40	284.3^{b}	391.0^{d}	234.5^{d}	32.6^{a}
	60	297.9^{a}	378.7^{d}	227.7^{d}	38.8^{a}
	80	260.8^{c}	461.2^{b}	246.2^{d}	35.2^{a}
Nov-19	40	142.5^{g}	516.5^{a}	304.9^{a}	31.5^{a}
	60	167.7^{f}	508.9^{a}	292.4^{a}	25.2^{a}
	80	120.0^{h}	501.5^{a}	316.1^{a}	34.8^{a}
Jan-20	40	216.1^{e}	458.6^{b}	268.3^{b}	30.5^{a}
	60	163.1^{f}	457.1^{b}	294.6^{a}	35.5^{a}
	80	210.1^{e}	428.6^{c}	271.3^{b}	33.5^{a}
SE		4.7	3.4	2.3	4.2
p–value		<0.001	<0.001	<0.001	0.859

Means labelled by different letters are significantly different according to Tukey's statistics ($p \leq 0.050$). SE, standard error of the mean.

Mejía-Díaz *et al*. (2017) reported the production of green biomass ranging from 30 to 70 t ha^{-1} year^{-1}, values that coincide with what was found in the present study during the period from May 19 to January 2020 (i.e., 35.1 t ha^{-1} year^{-1} on average). However, these same authors point out that the factors that determine yields are mainly planting density, cutting frequency, type of soil, vegetative state, and the harvesting system, either under grazing or cut and carry. For their part, Guatusmal-Gelpud *et al*. (2020) studied cutting heights of 10 and 50 cm and obtained accumulated yields of 2.46 and 2.38 t DM ha^{-1} year^{-1}, respectively. Studies carried out by Casanova-Lugo *et al*. (2014), in tropical fodder banks pruned at a height of one meter, show that the accumulated yields of *Guazuma ulmifolia* Lam. and *Leucaena leucocephala* (Lam.) de Wit. were 9.0 and 6.9 t DM ha^{-1} year^{-1}, values that are lower than those found in the present study when *T. diversifolia* was harvested at 80 cm.

An important factor that intervenes in this process is the photoperiod, when there is a decrease in the photoperiod, the transport of carbohydrates is favored, resulting in greater flowering, elongation of the stems and therefore an increase in the production of seeds which intervene in the volume of biomass. The foregoing corresponds to that reported by Casanova-Lugo *et al*. (2014) and could be related to the results presented here.

Nutrient composition

In the present study, a variation in the content of CP, NDF and FDA of *T. diversifolia* was found because of the sampling period and the cutting height (Table 3). This effect may be related to the climatic conditions of the site such as temperature, precipitation, and the phenological state of the plant, which prevailed during the experimental period. The above showed that even though *T. diversifolia* is a species with great adaptability, the different management conditions have an impact on the nutritional quality of the edible biomass. Cediel-Devia *et al*. (2020) documented that when the *T. diversifolia* plantation is exposed to temporary conditions with frequent rainfall, the concentrations of CP and OM increase while the content of NDF, FDA and ash decreases due to a greater mobilization of nutrients by the plant. On the other hand, *T. diversifolia* may be playing a very important role in the recycling of labile nutrients from the soil that would otherwise be lost through leaching. In the case of phosphorus, the association with mycorrhizae may be playing an important role in its mobilization (Oros-Ortega *et al*., 2020). This fact is especially interesting when these resources are scarce.

Despite the above, the CP content was in the range of 120 to 298 g kg^{-1} DM, values that are higher than most of the grasses commonly used in the livestock systems of the tropics (Mejía-Díaz *et al*., 2017). Furthermore, these results coincide with Aboyeji *et al*. (2017), who reported that the CP content was 250 g kg^{-1} DM in a study carried out in Nigeria where annual rainfall was less than 1300 mm. Likewise, Vega-Granados *et al*. (2019), reported that the edible biomass of *T. diversifolia* (i.e. young leaves and stems), contains 220 g kg^{-1} DM of CP. Additionally, Ramírez-Rivera *et al*. (2010), mention that 16.6 % of the protein in *T. diversifolia* leaves is soluble and represents 40.2 % of the total protein content, which makes it a plant with high potential in animal feed and that regardless of the time of year the shrub species used as forages maintain a high nutritional level, with an average of 180 g kg^{-1} DM of CP.

Tithonia diversifolia contains higher concentrations of CP (230 g kg^{-1} DM) and lower levels of NDF (428 g kg^{-1} DM) and ADF (261 g kg^{-1} DM), compared to other tropical woody species such as *G. ulmifolia* Lam. (145, 456 and 292 g kg^{-1} DM) and *L. leucocephala* (228, 452 and 283 g kg^{-1} DM), respectively (Casanova-Lugo *et al*., 2014). This, together with its palatability and resistance to adverse weather conditions, indicate that *T. diversifolia* can be a good feeding alternative to mitigate the effects of climate change with respect to other local forage species in the region.

The biomass of *T. diversifolia* is considered of excellent quality for livestock feeding, being used as a feeding strategy in the dry season, when the pastures have a lower concentration of nutrients (Canúl-Solís *et al*., 2018). In ruminants, it can replace up to 35 % of commercial concentrates, which reduces animal production costs (Mejía-Díaz *et al*., 2017). In fact, a study by Ramírez-Rivera *et al*. (2010) mentioned that one of the main reasons for choosing *T. diversifolia* for feeding ruminants is its acceptable concentrations of NDF and FDA (Cediel-Devia *et al*., 2020), compared to other commonly used grasses, which corresponds with the results obtained in this research.

Mauricio *et al*. (2014) reported that the average concentrations of ADF of *T. diversifolia* were 386 g kg^{-1} DM, consequently they found a lower digestibility (48.9 %). These values differ with that reported in the present study, since the contents of ADF in general were slightly lower (316.1 to 227.7 g kg^{-1} DM). However, these differences could be related to the phenological state of the plant and the sampling time, since they correspond to the pre-flowering stage (Mauricio *et al*., 2014). Similarly, Mejía-Díaz *et al*. (2017) reported NDF concentrations ranging from 333 to 559 g kg^{-1} DM, while for the ADF from 241 to 476 g kg^{-1} DM, ranges, consistent with the results of this experiment. The acceptable fiber content of *T. diversifolia* compared to conventional pastures is a favourable indicator of forage quality since it stimulates the voluntary intake of DM by the animals (Canúl-Solís *et al*., 2018).

On the other hand, it was found that the lignin content of *T. diversifolia* forage did not vary with harvest date and cutting height. This could be considered as an excellent attribute that is related to the maturity of traditional forages such as grasses. In fact, the lignin content of shrubs in advanced phenological stages is closely related to cellulose and hemicellulose. It causes ruminant bacteria to have difficulties for their degradation and decreases the digestibility of the forage. The foregoing agrees with Mejía-Díaz *et al*. (2017), who recommend the use of *T. diversifolia* at regrowth intervals of 50 to 60 days, since this limits the flowering stage of the plant.

The chemical composition of the edible biomass of *T. diversifolia* in general can vary depending on various factors, it has already been mentioned that the higher the phenological state of the plant, the lower the concentration of nutrients (Gutiérrez *et al*., 2017). In fact, the heterogeneity in the nutrient concentrations of the edible biomass of *T. diversifolia* obtained in the present study are mainly influenced by the age of harvest and plantation management, the soil fertility, and the climatological conditions of the site (Senarathne *et al*., 2019).

Finally, this information, together with that of edible biomass production and the plant's recovery capacity in successive cuts, is important to determine the more adequate cutting frequencies if the purpose is to obtain forage with a protein level more than 18 %. However, it will be necessary to carry out more studies to reduce the harvest interval from 60 days, as tested in the present study, to intervals of 40-50 days. In addition, in this trial, it was initially proposed to evaluate the response of *T. diversifolia* under drought conditions. However, this situation could limit the growth potential of the crop due to the marked dry season. Therefore, it is advisable to evaluate the effect of irrigation during the dry season on the behaviour of *T. diversifolia* to increase its production and quality of edible biomass. Likewise, it will be necessary to carry out animal feeding trials with forage mixtures that include *T. diversifolia*, with the purpose of looking for improvements in the production and quality of milk or meat, as well as in the reduction of feeding costs.

CONCLUSIONS

Biomass yield and chemical composition of *T. diversifolia* were affected by harvest date and cutting heights. Total biomass was lower in the month of September, as well as its crude protein content at a cutting height of 60 cm. The highest acid detergent fiber contents were found in January for a cutting height of 60 cm. It is of vital importance to be considered in the management strategies for the optimal use of forage resources and its incorporation in silvopastoral systems. These results are very useful, since they allow the application of different management strategies for the optimal utilization of *T. diversifolia* biomass in forage banks, under the edaphoclimatic conditions of south-eastern Mexico. These results also imply for the development sustainable livestock production by providing alternatives to reduce grassland degradation from overgrazing.

Acknowledgements
The authors thank Tecnológico Nacional de México (TecNM) for financial support throughout this project. We are also grateful to the Consejo Nacional de Humanidades Ciencias y Tecnologías (Conahcyt) for financing infrastructures project to carry out field and laboratory works and obtain a M.Sc. degree (of the first author) in Sustainable Agroecosystems.

Funding. This research study was supported by project of the TecNM (11129.21-P and 17102.23-P) and Project 316492 granted by CONAHCyT.

Conflict of interest. The authors declare no conflict of interest.

Compliance with ethical standards. Not applicable due to the nature of the study.

Data availability. The data is available upon request with the corresponding author fkzanov@gmail.com.

Author contribution statement (CRediT). **C. Uu-Espens**: Conceptualization, Investigation, Writing – original draft, and Writing – review & editing. **D. Pozo-Leyva**: Supervision, Visualization, and Writing – review & editing. **D. Aryal**: Conceptualization, Formal Analysis, and Writing – review & editing. **B. Dzib-Castillo**: Visualization, and Writing – review & editing. **G. Villanueva-López**: Methodology, and Writing – review & editing. **F. Casanova-Lugo**: Conceptualization, Methodology, Data curation, Formal Analysis, Validation, Writing – original draft, Writing – review & editing, Funding acquisition, Resources, and Project administration. **A. Chay-Canul**: Conceptualization, Validation, and Writing – review & editing. **J. Canúl-Solís**: Methodology, Visualization, and Writing – review & editing.

REFERENCES

Aboyeji, C. M., Adekiya, A. O., Dunsin, O., Agbaje, G. O., Olugbemi, O., Okoh, H. O. and Olofintoye, T. A. J., 2017. Growth, yield and vitamin C content of radish (*Raphanus sativus* L.) as affected by green biomass of *Parkia biglobosa* and *Tithonia diversifolia*.

Agroforestry Systems, 93, pp. 803–812. https://doi.org/10.1007/s10457-017-0174-6

Aboyeji, C. M., 2022. Effects of application of organic formulated fertiliser and composted *Tithonia diversifolia* leaves on the growth, yield and quality of okra. *Biological Agriculture and Horticulture*, 38(1), pp. 17–28. https://doi.org/10.1080/01448765.2021.1960604

Alders, R. G., Campbell, A., Costa, R., Guèye, E. F., Hoque, M. A., Perezgrovas-Garza, R., Rota, A. and Wingett, K., 2021. Livestock across the world: diverse animal species with complex roles in human societies and ecosystem services. *Animal Frontiers*, 11(5), pp. 20–29. https://doi.org/10.1093/af/vfab047

Cairns, M. F., 1997. A Property Rights Dimensions of Indigenous Fallow Management (IFM): Summary of Ten Intersecting Issues@ document prepared for the Asia-Pacific Resource Tenure Network (ARTN) Indonesia.

Canúl-Solís, J. R., Castillo-Sánchez, L. E., Escobedo-Mex, J. G., López-Herrera, M. A. and Lara-Lara, P. E., 2018. Forage yield and quality of *Gliricidia sepium*, *Tithonia diversifolia* and *Cynodon nlemfuensis* in monoculture and agroforestry systems. *Agrociencia*, 52(6), pp. 853–862. https://www.agrociencia-colpos.org/index.php/agrociencia/article/view/1709/1709

Cardona, J. L., Angulo, J. and Mahecha, L., 2022. Less nitrogen losses to the environment and more efficiency in dairy cows grazing on silvopastoral systems with *Tithonia diversifolia* supplemented with polyunsaturated fatty acids. *Agroforestry Systems*, 96, pp. 343–357. https://doi.org/10.1007/s10457-021-00722-7

Casanova-Lugo, F., Petit-Aldana, J., Solorio-Sánchez, F. J., Parsons, D. and Ramírez-Avilés, L., 2014. Forage yield and quality of *Leucaena leucocephala* and *Guazuma ulmifolia* in mixed and pure fodder banks systems in Yucatán, México. *Agroforestry Systems*, 88, pp. 29–39. https://doi.org/10.1007/s10457-013-9652-7

Cediel-Devia, D., Sandoval-Lozano, E. and Castañeda-Serrano, R., 2020. Effects of different regrowth ages and cutting heights on biomass production, bromatological composition and *in vitro* digestibility of *Guazuma ulmifolia* foliage. *Agroforestry Systems*, 94, pp. 1199–1208. https://doi.org/10.1007/s10457-019-00354-y

Foley, J. A., Ramankutty, N., Brauman, K. A., Cassidy, E. S., Gerber, J. S., Johnston, M., Mueller, N. D., O'Connell, C., Ray, D. K., West, P. C., Balzer, C., Bennett, E. M., Carpenter, S. R., Hill, J., Monfreda, C., Polasky, S., Rockström, J., Sheehan, J., Siebert, S., Tilman, D. and Zaks, D. P. M., 2011. Solutions for a cultivated planet. *Nature*, 478, pp. 337–342. https://doi.org/10.1038/nature10452

Graesser, J., Aide, T. M., Grau, H. R. and Ramankutty, N., 2015. Cropland/pastureland dynamics and the slowdown of deforestation in Latin America. *Environmental Research Letters*, 10(3), 034017. https://doi.org/10.1088/1748-9326/10/3/034017

Greenfield, H. and Southgate, D. A. T., 1992. Food Composition Data. London, Elsevier Applied Science.

Guatusmal-Gelpud, C., Escobar-Pachajoa, L. D., Meneses-Buitrago, D. H., Cardona-Iglesias, J. L. and Castro-Rincón, E., 2020. Producción y calidad de *Tithonia diversifolia* y *Sambucus nigra* en trópico altoandino colombiano. *Agronomía Mesoamericana*, 31(1), pp. 193–208. https://doi.org/10.15517/am.v31i1.36677

Gutiérrez, O., La, O. O., Scull, I. and Ruiz, T., 2017. Nutritive value of *Tithonia diversifolia* for animal feeding. *In*: Savon, V. L. L., Gutiérrez, B. O. and Febles, P. G. (Eds). Mulberry, moringa and tithonia in animal feed and other uses. Results in Latin America and the Caribbean. FAO/ICA, Habana, Cuba, pp.203–221.

Herrero, M., Havlík, P., Valin, H., Notenbaert, A., Rufino, M. C., Thornton, P. K., Blümmel, M., Weiss, F., Grace, D. and Obersteiner, M., 2013. Biomass use, production, feed efficiencies and greenhouse gas emissions from global livestock systems. *Proceedings of the National Academy of Sciences*, 110(52), pp. 20888–20893. https://doi.org/10.1073/pnas.1308149110

IUSS Working Group WRB., 2022. World Reference Base for Soil Resources. International soil classification system for naming soils and creating legends for soil maps. 4th edition.

International Union of Soil Sciences (IUSS), Vienna, Austria.

Kolb, M. and Galicia, L., 2018. Scenarios and story lines: drivers of land use change in southern Mexico. *Environment, Development and Sustainability*, 20, pp. 681–702. https://doi.org/10.1007/s10668-016-9905-5

Letty, B. A., Makhubedu, T., Scogings, P. F. and Mafongoya, P., 2021. Effect of cutting height on non-structural carbohydrates, biomass production and mortality rate of *pigeon peas*. *Agroforestry Systems*, 95, pp. 659–667. https://doi.org/10.1007/s10457-021-00616-8

Mauricio, M. R., Ribeiro, S. R., Silveira, R. S., Silva, L. P., Calsavara, L., Pereira, G. R. L. and Paciullo, S. D., 2014. *Tithonia diversifolia* for ruminant nutrition. *Tropical Grasslands*, 2(1), pp. 82–84. https://doi.org/10.17138/tgft(2)82-84

Mejía-Díaz, E., Mahecha-Ledesma, L. and Angulo-Arizala, J., 2017. *Tithonia diversifolia*: specie for grazing in silvopastoral systems and methods for estimating consumption. *Agronomía Mesoamericana*, 28(1), pp. 289–302. https://doi.org/10.15517/am.v28i1.22673

Morales-Ruiz, D. E., Aryal, D. R., Pinto-Ruiz, R., Guevara-Hernández, F., Casanova-Lugo, F. and Villanueva-López, G., 2021. Carbon contents and fine root production in tropical silvopastoral systems. *Land Degradation and Development*, 32(2), pp. 738–756. https://doi.org/10.1002/ldr.3761

Mustonen, P. S. J., Oelbermann, M. and Kass, D., 2012. Using *Tithonia diversifolia* (Hemsl.) Gray in a short fallow system to increase soil phosphorus availability on a Costa Rican andosol. *Journal of Agricultural Science*, 4(2), pp. 91–100. https://doi.org/10.5539/jas.v4n2p91

Navale, M. R., Bhardwaj, D. R., Bishist, R., Thakur, C. L., Sharma, S., Sharma, P., Kumar, D. and Probo, M., 2022. Seasonal variations in the nutritive value of fifteen multipurpose fodder tree species: A case study of north-western Himalayan mid-hills. *Plos One*, 17(10), e0276689. https://doi.org/10.1371/journal.pone.0276689

Oros-Ortega, I., Lara-Pérez, L. A., Casanova-Lugo, F., Díaz-Echeverría, V. F., Villanueva-López, G., Ramírez-Barajas, P. J. and Cetzal-Ix, W., 2020. Diversity and importance of the relationship between arbuscular mycorrhizal fungi and nitrogen-fixing bacteria in tropical agroforestry systems in Mexico. *In*: Varma, A., Tripathi, S. and Prasad, R. (Eds). Plant Microbe Symbiosis. Springer, Cham. https://doi.org/10.1007/978-3-030-36248-5_2

Orwa, C., Mutua, A., Kindt, R., Jamnadass, R. and Anthony, S., 2009. Agroforestree Database: A Tree Reference and Selection Guide, Version 4.0. Kenya: World Agroforestry Centre. http://www.worldagroforestry.org/output/agroforestree-database

Ramírez-Rivera, U., Sanginés-García, J. R., Escobedo-Mex, J. G., Cen-Chuc, F., Rivera-Lorca, J. A. and Lara-Lara, P. E., 2010. Effect of diet inclusion of *Tithonia diversifolia* on feed intake, digestibility and nitrogen balance in tropical sheep. *Agroforestry Systems*, 80, pp. 295–302. https://doi.org/10.1007/s10457-010-9320-0

Ramos-Trejo, O., Castillo-Huchín, J. and Sandoval-Gío, J. J., 2015. Effect of cutting intervals and heights in forage productivity of *Moringa oleifera*. *Revista BioCiencias*, 3(3), pp. 187–194. http://dx.doi.org/10.15741/revbio.03.03.05

Ruiz, T. E., Febles, G. J., Alonso, J., Crespo, G. and Valenciaga, N., 2017. Agronomy of *Tithonia diversifolia* in Latin America and the Caribbean region. *In*: Savon, V. L. L., Gutiérrez, B. O. and Febles, P. G. (Eds). Mulberry, moringa and tithonia in animal feed, and other uses. Results in Latin America and the Caribbean. FAO/ICA, Habana, Cuba, pp.171–201.

SAS Institute Inc., 2020. SAS® Enterprise Guide 8.3: Guía del usuario. Cary, NC: SAS Institute Inc.

Senarathne, S. H. S., Atapattu, A. J., Raveendra, T., Mensah, S. and Dassanayake, K. B., 2019. Biomass allocation and growth performance of *Tithonia diversifolia* (Hemsl.) A. Gray in coconut plantations in Sri Lanka. *Agroforestry Systems*, 93, pp. 1865–1875. https://doi.org/10.1007/s10457-018-0290-y

Valenzuela-Que, F. G., Villanueva-López, G., Alcudia-Aguilar, A., Medrano-Pérez, O. R., Cámara-Cabrales, L., Martínez-Zurimendi, P., Casanova-Lugo, F. and Aryal, D. R., 2022.

Silvopastoral systems improve carbon stocks at livestock ranches in Tabasco, Mexico. *Soil Use and Management*, *38*(2), 1237–1249. https://doi.org/10.1111/sum.12799

Vega-Granados, E., Sanginés-García, L., Gómez-Gurrola, A., Hernández-Ballesteros, A., Solano, L., Escalera-Valente, F. and Loya-Olguin, J. L., 2019. Replacement of alfalfa with *Tithonia diversifolia* in lambs fed sugar cane silage-based diets and rice polishing. *Revista Mexicana de Ciencias Pecuarias*, 10(2), pp. 267–282. https://doi.org/10.22319/rmcp.v10i2.4455