Seasonal variation in biomass yield and quality of *Tithonia diversifolia* at different cutting heights

Variación estacional en el rendimiento y calidad de *Tithonia diversifolia* a diferentes alturas de corte

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ABSTRACT. The objective of this research was to evaluate and compare the yield performance and quality of *Tithonia diversifolia* forage under different harvesting heights, during the dry and rainy seasons in tropical Mexico. The treatments consisted of three harvest heights 40, 60 and 80 cm from the ground level, cut every 60 days, during two seasons of the year. In each period, the biomass was harvested and separated into edible and non-edible components. We determined the biomass yield, and the concentration of crude protein (CP), neutral detergent fibre (NDF), acid detergent fibre (ADF), lignin, ash and organic matter (OM) of the forage. Cutting at 80 cm height yielded the highest forage biomass per harvest (2 008 kg DM ha^{-1}) while there were no significant differences in forage yield between 40 and 60 cm heights. The differences in cutting heights also affected the nutrient quality of the animal edible forage because the concentrations of CP, ADF and NDF varied significantly. There was a significant interaction between cutting heights and the season on forage production and quality. In the dry season, the content of NDF, FDA, lignin and ash were higher, while the PC and OM were lower. The use of *T. diversifolia* as a forage plant and cutting it to a height of 80 cm is recommended to maintain the best production and the quality of the forage throughout the year for livestock production.
Key words: Livestock systems, Mexican sunflower, native shrubs, nutritional quality, repeated harvesting.

RESUMEN. El objetivo de esta investigación fue evaluar y comparar el rendimiento y la calidad del forraje de *Tithonia diversifolia* bajo diferentes alturas de cosecha, durante las estaciones seca y lluviosa en el tropico de México. Los tratamientos consistieron en tres alturas de cosecha a 40, 60 y 80 cm del nivel del suelo cortadas cada 60 días, durante dos épocas del año. En cada período, la biomasa se cosechó y se separó en componentes comestibles y no comestibles. Se determinó el rendimiento de biomasa y la concentración de proteína cruda (CP), fibra detergente neutra (FDN), fibra detergente ácido (FDA), lignina, cenizas y materia orgánica (MO) del forraje. El corte a 80 cm de altura produjo la mayor biomasa de forraje por cosecha (2 008 kg MS ha^{-1}) mientras que no hubo diferencias significativas en el rendimiento de forraje entre 40 y 60 cm de altura. Las diferencias en las alturas de corte también afectaron la calidad de los nutrientes del forraje comestible animal porque las concentraciones de CP, FDA y FDN variaron significativamente. Hubo una interacción significativa entre las alturas de corte y la temporada en la producción y calidad del forraje. En la estación seca, el contenido de NDF, FDA, lignina y ceniza fue mayor, mientras que el PC y MO fueron menores. Se recomienda el uso de *T. diversifolia* como una planta forrajera y cosechar a una altura de 80 cm para mantener la mejor producción y la calidad del forraje durante todo el año para la producción ganadera.
Palabras clave: Sistemas ganaderos, girasol mexicano, arbustos nativos, calidad nutricional, cosechas repetidas.

INTRODUCTION

Livestock production in south-eastern Mexico is based on the use of monoculture pastures that have low levels of digestible protein and high fibre contents (Pozo-Leyva *et al.* 2021). The foliage of shrub and tree species has been considered, in most cases, as a nutritional alternative for the supplementation of ruminants in the tropics to improve the productive and nutritional level of the animals (Cardona *et al.* 2022). Mainly during periods of forage shortage, they reduce production costs and contribute to the profitability and sustainability of production systems (Pozo-Leyva *et al.* 2019).

A viable strategy for the integration of shrubs and trees for animal production is the implementation of silvopastoral systems (Cardona *et al.* 2022). These systems help to improve the productivity and quality of forage throughout the year, maintain good soil fertility due to the greater recycling of nutrients, favour high biodiversity compared to pasture monocultures, reduce heat stress of the animals and fix atmospheric nitrogen, among other benefits (Sales-Baptista *et al.* 2021).

In this regard, *Tithonia diversifolia* (Hemsl.) A. Gray. (Asteraceae), also called false sunflower or Mexican sunflower), is a shrub native to southeastern Mexico (Aboyeji *et al.* 2019). However, its distribution has been reported to the humid and sub-humid tropics of Central and South America (Ruiz *et al.* 2017). *Tithonia diversifolia* has been documented as an excellent alternative in ruminant feeding (Cardona *et al.* 2022). This is because the forage of this species contains moderate levels of fibre (30-35%) and high protein contents (14.8 to 28.8%), so it can replace up to 30% of the concentrate supplements in cattle feed without affecting production (Gutiérrez *et al.* 2017). One of the characteristics of forage shrub species is their high nutritional value regardless of the time of year (Ruiz *et al.* 2017). The dry matter digestibility can fluctuate from 72 to 85% (Gutiérrez *et al.* 2017) with CP concentrations of 23.5% (Vega-Granados *et al.* 2019). Neutral detergent fibre (NDF) is a parameter that indicates the concentration of fibres in the forage and includes cellulose, hemicellulose and lignin, and it is negatively correlated with the consumption of dry matter (Ángeles-Mayorga *et al.* 2022). The acid detergent fibre (ADF), while a similar measure, does not include hemicellulose and can be correlated with the digestibility of feed. The variations in the NDF and ADF contents of the forages are related to the forage species, the age of the tissue, the handling and the prevailing climatic conditions and seasons of the year (Horst *et al.* 2022).

One of the advantages of *T. diversifolia* is its rapid growth after harvest, tolerating repeated cuts throughout the year with high biomass production (Letty *et al.* 2021). Many farmers use *T. diversifolia* in forage banks for livestock feeding. However, the lack of evidence on appropriate cutting or harvest heights can cause a progressive 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 reserves, because they mobilise reserve carbohydrates to rebuild photosynthetic tissue after harvest, grazing or seasonal loss of foliage (Navale *et al.* 2022). Therefore, knowing the optimal harvest height of *T. diversifolia* is essential for the sustainable management of this important forage plant in animal production systems in the tropics (Ruiz *et al.* 2017, Letty *et al.* 2021). Our understanding of the yield and quality of *T. diversifolia* biomass in forage banks under different management schemes and at different times of the year under tropical conditions is still limited. Therefore, the objective of this research was to evaluate the performance and nutritional quality of *T. diversifolia* forage under different cutting heights, during the dry and rainy season, in the south of the state of Quintana Roo, Mexico.

MATERIALS AND METHODS

Site characteristics

The experiment was carried out at the Instituto Tecnológico de la Zona Maya in Quintana Roo state, Mexico from January 2019 to January 2020 (18°30' N and 89°41' W). The area presents a warm sub-humid climate, according to Uu-Espens *et al.* (2019). Climatic data during the experimental period (Figure 1)

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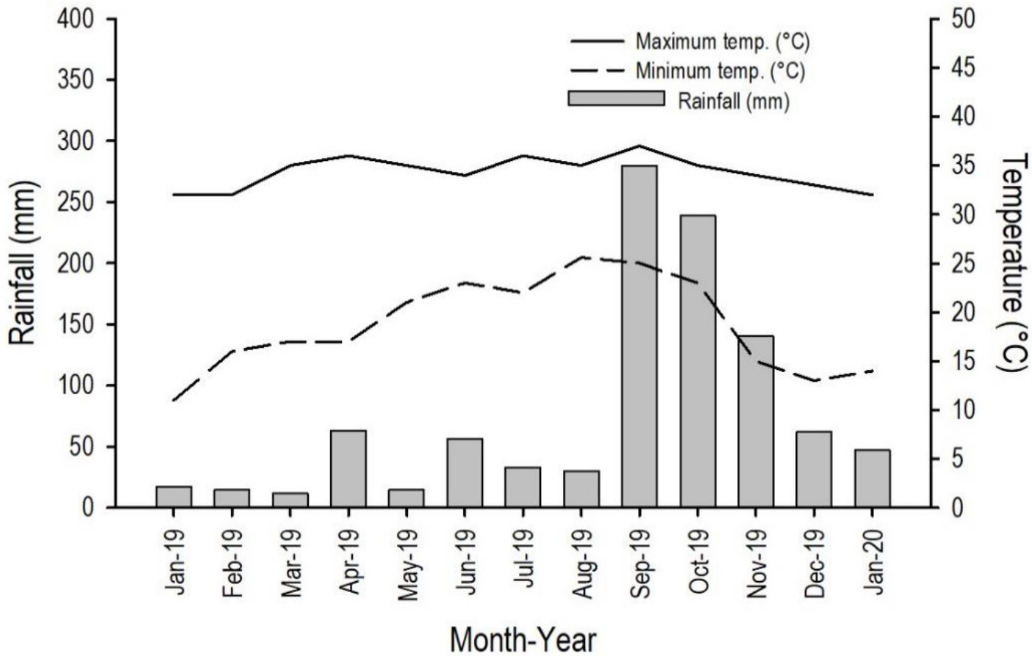

Figure 1. Minimum and maximum air temperatures and rainfall at the study site; data were taken from the microclimatic station at the Instituto Tecnológico de la Zona Maya in January 2019-January 2020.

was recorded daily with a WatchDog 2900ET Weather Station (Spectrum Technologies, Inc.). The mean, maximum and minimum annual temperatures and the total rainfall during this period were 26.5, 37.0, 11.0 °C and 1 009 mm, respectively.

The predominant soils are Gleysols according to the Food and Agriculture Organization (IUSS Working Group WRB 2022). For the physical and chemical analysis of the soil, three random samples were taken at depths of 0-30 cm from the surface. Soil organic matter was analysed by the Walkley-Black wet digestion method, total nitrogen was analysed by the Micro-Kjeldahl procedure, and available phosphorus was analysed by the Olson extraction method. Soil potassium was determined by colourimetry, and calcium and magnesium were determined by atomic absorption spectrophotometry methods. The potentiometric method was used to analyse soil pH and electrical conductivity. The physicochemical properties of soil are presented in Table 1.

Table 1. Physical and chemical properties of the soil from the experimental plots of *Tithonia diversifolia*, under sub-humid tropical conditions.

Parameter	Value
pH	7.7
Electric Conductibility (ds m^{-1})	0.2
Lime (%)	46.0
Clay (%)	45.8
Sand (%)	8.2
Organic material (%)	3.7
Total nitrogen (%)	0.2
Phosphorous (ppm)	43.3
Potassium (ppm)	1875.0
Calcium (ppm)	6100.0
Magnesium (ppm)	1611.0

Management of experimental plots

For the establishment of the forage banks, we used *T. diversifolia* cuttings 2.0 to 4.0 cm in diameter, which were taken from the middle and lower portion of the stems and cut to 50 cm in length. Later, they were submerged in water with a rooting agent 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 10 x 10 m sampling plots were delimited, which were made up of five rows of *T. diversifolia*, of which only three central rows were measured to avoid the edge effect in each experimental unit. The experiment ran from January 2019 to January 2020. Before the evaluation, a standardisation harvest was performed manually in January 2019. Measurements were started in March of the same year.

Experimental design

We used a completely randomised design with a 3 x 2 factorial arrangement; the treatments consisted of evaluating three harvest heights of *T. diversifolia* (40, 60, 80 cm) during two seasons of the year: the dry season, which ran from May to September 2019 and the rainy season, which ranged from November 2019 to January 2020. During the experimental period, five biomass harvests were carried out with a frequency of two months at the beginning of the month. Simultaneously, the alleys were cleaned to control weeds. It should be noted that no irrigation or fertilisers were applied.

Biomass components and forage yield

After each harvesting, the total biomass (leaves, edible stems, woody stems) from each experimental unit was weighed fresh. Harvested material from each treatment (cutting) was pooled and three sub-samples (of approximately 1.0 kg each) were randomly taken. These sub-samples were divided into leaves, edible stems (< 0.5 cm diameter) and woody stems ($\geq$ 0.5 cm diameter), which were dried at 60 ℃ in a forced circulation oven drier ED 400 (Binder Inc., Bohemia, NY, USA) to constant weight. Only leaves and edible stems were considered for calculating forage yield. Seasonal forage yield was obtained by adding the yield from all the harvests within the respective period.

Nutrient composition analysis

Forage sub-samples (leaves and edible stems) were ground using an electric mill IKA MF 10 (IKA Works, Inc. Wilmington, NC, USA) to a particle size of 1.0 mm and analysed for neutral detergent fibre (NDF), acid detergent fibre (ADF) and lignin, using an ANKOM A200 fibre analyser (ANKOM Technology, Macedon, NY, USA). The fraction of nitrogen (N) was estimated 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). The organic matter (OM) and ash contents were determined by ignition at 600 ℃ for four hours in a muffle furnace (AOAC 2019).

Statistical analysis

The biomass production data were analysed with an ANOVA model using PROC MIXED (SAS Institute Inc 2020) to examine the effect of different cutting heights, the season and their interactions. For biomass components and nutrient composition (data were square root transformed) and applied to a multivariate analysis of variance (MANOVA) using PROC GLM (SAS 2020). Where significant differences were observed, we compared the means using Tukey's statistic (P $\leq$ 0.05).

RESULTS

Biomass components

The cutting height did not show a significant effect (P > 0.05) on the proportion of fresh leaves, senescent material, tender stems, woody stems or the leaf:stem ratio of the biomass of *T. diversifolia* (Table 2). However, the proportion of leaves and the leaf-to-stem ratio during the dry season were higher (almost two and three times), compared to the rainy season (P < 0.05 and P < 0.01). The proportion of edible stems was two times lower (P < 0.01) during dry season compared to rainy season. The proportion of senescent material and woody stems of *T. diversifolia* was statistically indifferent (P > 0.05) between seasons (Table 2).

Biomass yield

The average yield of forage harvested at a cutting height of 80 cm was 2 008 kg DM ha^{-1} harvest^{-1}, a value that was 29 and 32% higher (P < 0.05) than the cutting heights of 40 and 60 cm,

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Table 2. Biomass components (%) and the leaf:stem ratio of *Tithonia diversifolia* at different cutting heights and during two seasons, under sub-humid

Treatments	Leaves	Senescent material	Edible stems	Woody Stems	Leaf-to-stem ratio
Cutting heights	ns	ns	ns	ns	ns
40 cm	46.2	6.1	45.3	2.5	1.0
60 cm	53.4	7.8	36.9	1.9	1.4
80 cm	57.9	6.6	34.0	1.5	1.6
SEM	10.0	1.3	5.2	0.7	0.5
Season	*	ns	**	ns	**
Dry	64.5^a	8.3	24.9^b	2.3	2.4^a
Rainy	40.6^b	5.4	52.4^a	1.6	0.8^b
SEM	2.7	2.0	3.6	0.7	0.2

Means within columns followed by different letters are significantly different (Tukey's statistic). SEM, standard error of the mean; ns, non-significant; * P < 0.05; ** P < 0.01.

respectively (Table 3). The total biomass yield of *T. diversifolia* in the rainy season was slightly more than double (P < 0.01) that of the dry season (2 606 vs. 1 059 kg DM ha^{-1} harvest^{-1}; Table 3). Likewise, the forage yield in the rainy season was 2 436 kg DM ha^{-1} harvest^{-1}, a value that was almost three times higher (P < 0.01) than that of the dry season (Table 3).

Table 3. Mean biomass and forage yield (kg DM ha^{-1} harvest^{-1}) of *Tithonia diversifolia* at different cutting heights and during two seasons, under sub-humid tropical conditions.

Treatments	Total biomass	Forage
Cutting heights	ns	*
40 cm	1 670.2	1 550.6^b
60 cm	1 656.1	1 520.7^b
80 cm	2 170.8	2 007.9^a
SEM	193.9	167.5
Season	**	**
Dry	1 058.7^b	950.7^b
Rainy	2 606.0^a	2 435.5^a
SEM	141.3	136.1

Means within rows followed by different letters are significantly different (Tukey's statistic). SEM, standard error of the mean; ns, non-significant; * P < 0.05; ** P < 0.01.

There was a significant interaction between cutting height and the season (P < 0.01) on the forage yield of *T. diversifolia* (Figure 2). There was a gradual increase in forage yield with the increase in cutting height during the rainy season but the trend was different during the dry season. The highest forage yield was recorded in the rainy season and with cutting heights of 80 cm (2 999 kg DM ha^{-1} harvest^{-1}), while the lowest forage yield was presented in the dry season and with a cutting height of 60 cm (823 kg DM ha^{-1} harvest^{-1}; Figure 2).

On the other hand, the cutting height of 80 cm showed the greatest (P < 0.05) cumulative yield of the *T. diversifolia* forage (10 066 kg DM ha^{-1} year^{-1}), followed by the cutting heights of 40 and 60 cm, with values of 8 228 and 7 728 kg DM ha^{-1} year^{-1}, respectively (Figure 3).

Nutrient composition

The crude protein contents of *T. diversifolia* forage harvested at cutting heights of 40 and 60 cm showed an increase of 8.4 and 10.9% (P < 0.05), compared to the height of 80 cm. However, the forage harvested to 80 cm from the ground level showed the highest acid detergent fibre. The content of neutral detergent fibre, lignin, ash and organic matter of *T. diversifolia* forage were statistically indifferent (P > 0.05) between cutting heights (Table 4).

The CP content varied significantly between the season of the year (17% in the dry season and 26% in the rainy season). The OM contents of *T. diversifolia* forage in the rainy season were 3.4% higher than that of the dry season (P < 0.01). The contents of neutral detergent fibre, acid detergent fibre, lignin and ash were higher during the dry season, since they had increases of 20.0, 17.8, 12.5, 24.2%, respectively, compared to the rainy season (Table 4).

There were interactions between cutting height and the season (P < 0.01) on CP, NDF and ADF content of the *T. diversifolia* forage (Figure 4). The highest CP content was recorded in the rainy season and with a cutting height of 60 cm (28.3%), while the lowest CP contents were found in the dry season regardless of the heights of cut with values ranging from

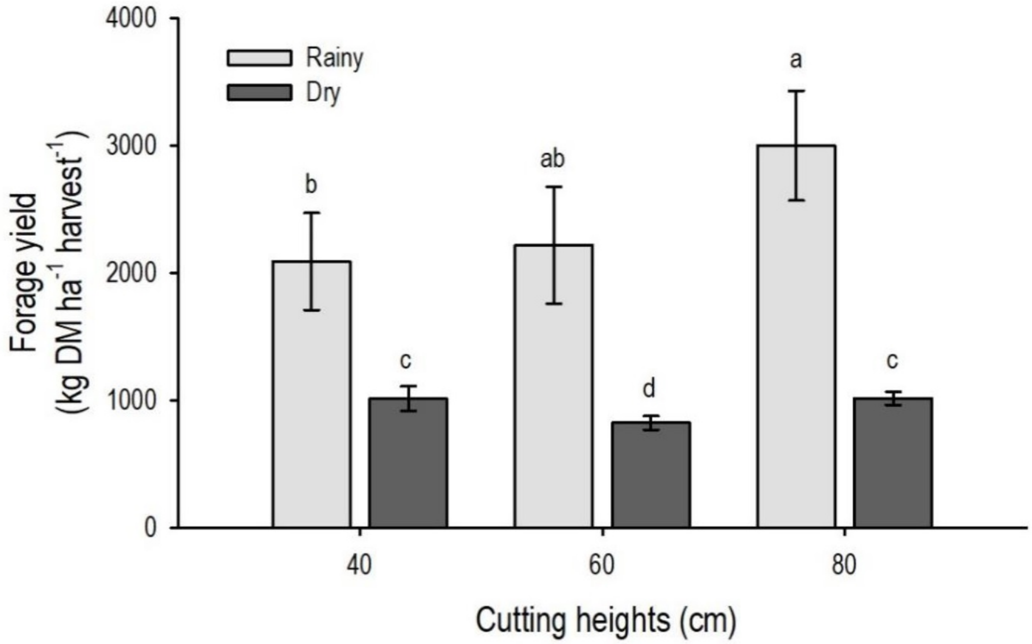

Figure 2. Mean forage yield per harvest of *Tithonia diversifolia* at different cutting heights and during two seasons, under sub-humid tropical conditions; error bars represent the standard error of the mean; means labelled by different letters are significantly different (Tukey's statistic, P $\leq$ 0.05).

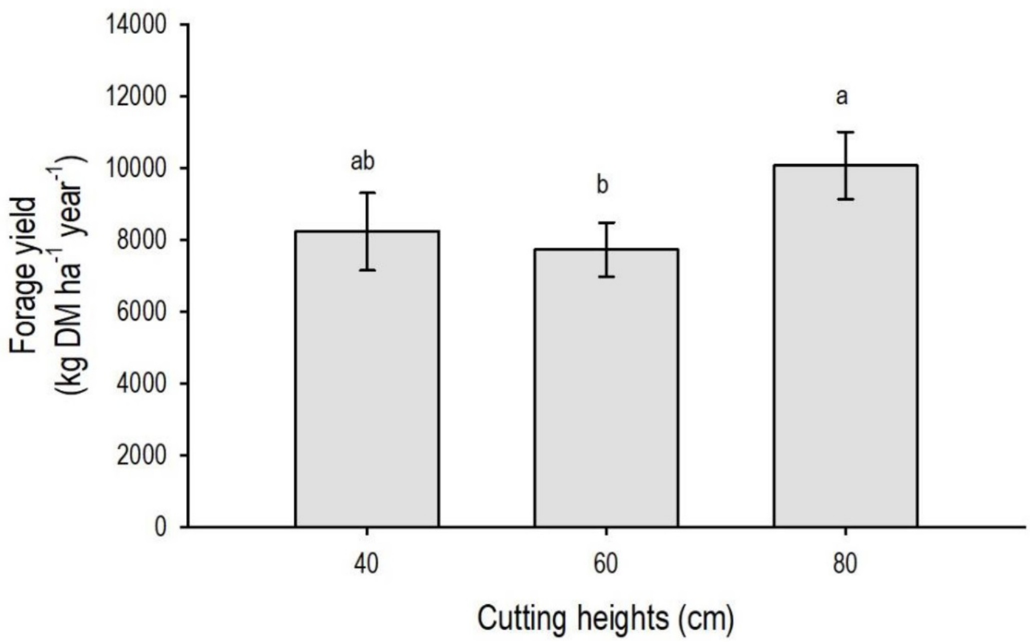

Figure 3. Annual forage yield of *Tithonia diversifolia* at different cutting heights, under sub-humid tropical conditions; error bars represent the standard error of the mean; means labelled by different letters are significantly different (Tukey's statistic, P $\leq$ 0.05).

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16.5 to 17.9% (Figure 4).

Table 4. Nutrient composition (%) of forage from *Tithonia diversifolia* at different cutting heights during two seasons, under sub-humid tropical conditions.

Treatments	CP	NDF	ADF	Lig	Ash	OM
Cutting heights	*	ns	*	ns	ns	ns
40 cm	21.9^a	44.6	26.7^b	3.2	12.9	87.1
60 cm	22.4^a	43.0	26.4^b	3.4	13.4	86.6
80 cm	20.2^b	44.0	27.5^a	3.4	14.1	85.9
SEM	0.6	0.6	0.3	0.2	0.4	0.4
Season	**	**	**	*	*	*
Dry	17.0^b	47.9^a	29.1^a	3.6^a	14.9^a	85.1^b
Rainy	26.0^a	39.9^b	24.7^b	3.2^b	12.0^b	88.0^a
SEM	0.5	0.5	0.1	0.1	0.3	0.3

Means within rows followed by different letters are significantly different (Tukey's statistic). CP, crude protein; NDF, neutral detergent fibre; ADF, acid detergent fibre; Lig, lignin; OM, organic matter; SEM, standard error of the mean; ns, non-significant; ** P < 0.05; ** P < 0.01.

The higher NDF contents of *T. diversifolia* forage were recorded in the dry season and with cutting heights of 40, 60 and 80 cm (48.8, 48.3 and 46.5%, respectively), while the lowest NDF content was found during the rainy season and with a cutting height of 60 cm (with a value of 37.7%, Figure 4). Similarly, the greatest ADF contents of *T. diversifolia* forage were recorded in the dry season and with cutting heights of 80 cm (29.4%), while the lowest ADF content was observed in the rainy season and with a cutting height of 60 cm with a value of 23.5% (Figure 4).

DISCUSSION

Biomass components

Our results showed that harvest height and the season are important factors that affect forage yield and the nutritional quality of *T. diversifolia* plant. The effect of harvest height on the biomass recovery and nutrient composition of forage shrub species has been poorly documented in south-eastern Mexico. A study by Ramos-Trejo *et al.* (2015), in eastern Yucatán, showed that the cutting height (40, 80 and 120 cm) at harvesting intervals of 45 and 60 days did not influence the leaf-to-stem ratio of the biomass of *Moringa oleifera* Lam., in forage banks. In addition, Ramos-Trejo *et al.* (2016) reported that the composition of leaves, stems and the leaf-stem relationship of *Gliricidia sepium* in forage banks did not differ with harvest heights of 45 and 90 cm. The results of these two investigations did not coincide with this experiment because the cutting height significantly affected the crude protein content of *T. diversifolia* forage in our study.

For their part, these results differ from the report made by Bacab-Pérez *et al.* (2012), who documented that the cutting height affected the length of the *Leucaena leucocephala* stem. However, in the case of the *Panimum maximum* grass, this behaviour was not reflected. These differences could be caused because the woody plants have low apical dominance, contributing to the early regeneration of foliar biomass. The response to cutting height could be different depending upon the species and/or the forage variety (Casanova-Lugo *et al.* 2014). Similarly, Senarathne *et al.* (2018) documented that an increase in the frequency of harvest increases the total foliage biomass yield of *T. diversifolia* and decreases the woody part of the biomass, while a decrease in the harvest frequency increased the woody biomass fraction and decreased the edible stems and foliage biomass.

The seasonal differences for the proportion of leaves and the leaf:stem ratio observed in this study may be attributed to the higher water availability compared to the dry season, which allowed a greater elongation of the edible stems and consequently, a greater proportion of them. Unlike the dry season where plants use more resources to form leaves, and therefore a better leaf: stem ratio (Horst *et al.* 2022). In addition, shrubs and trees in tropical livestock systems invest more in belowground components during the dry season compared to rainy seasons (Morales-Ruiz *et al.* 2020).

Another factor that could have intervened in this process was the temperature and the photoperiod since the temperatures registered at the beginning of the dry season (21 °C) were lower than those that were registered in the rainy season (23 °C). According to a study carried out by Navale *et al.* (2022), the decrease in temperatures coupled with a shorter photoperiod favours flowering and the transport of carbohydrates in plants. This can favour the elongation of

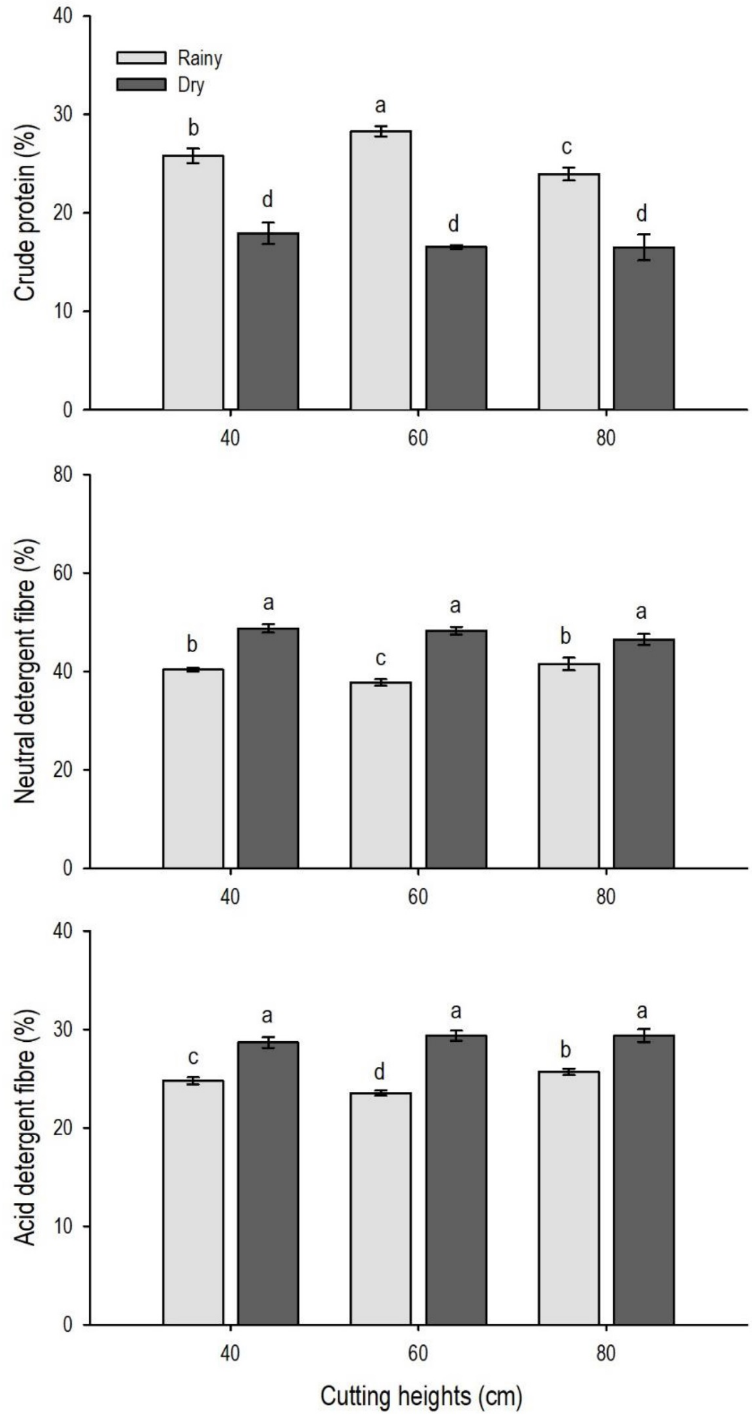

Figure 4. Crude protein, neutral detergent fibre and acid detergent fibre (%) of forage from *Tithonia diversifolia* at different cutting heights and during two seasons, under sub-humid tropical conditions; error bars represent the standard error of the mean; means labelled by different letters are significantly different (Tukey's statistic, P $\leq$ 0.050).

stems and the formation of flowers at the expense of the formation of leaves. This goes hand in hand with the flowering and seed production period of *T. diversifolia*, which coincides with October-November. In this type of study, the comparison of results with previous research is usually complex, since the results may differ depending on the methodology used, the age of the plant, the cutting height, the planting density and the agrometeorological characteristics of the study site (Senarathne *et al*. 2018).

Biomass yield

In our research, the best forage yield was obtained with height of 80 cm. The highest forage yields of *M. oleifera* (1 912 kg DM ha^{-1} harvest^{-1}), were recorded at heights of 40 cm, compared to heights of 80 and 120 cm in South-eastern Mexico (Ramos-Trejo *et al*. 2015). In contrast, the forage yield of *G. sepium* with harvest heights of 45 and 90 cm were similar in the same region (Ramos-Trejo *et al*. 2016).

In Columbian Andes, *T. diversifolia* harvested at cutting heights of 10 and 50 cm and *Sambucus nigra* L. with cutting heights of 30 and 50 cm, the cutting height did not affect the biomass yield (Guatusmal-Gelpud *et al*. 2020). In addition to the cutting height, other factors influence the forage yield of woody species, such as climatic conditions, soil types, water and nutrient availability. The reduction of forage leaves and stems in the dry season in our study is consistent with that found by Cabezas y Sánchez (2008) who showed that the low contents of macronutrients affected plant growth as nitrogen deficiency lowered the heights, stem growth, size and thickness of leaves of *Passiflora mollissima* plants. There are studies in other parts of the world showing that nutrient limitation in the soil during the dry season can affect biomass production (Letty *et al*. 2021).

It has been reported that one of the limiting factors for forage production is the low rainfall season (Navale *et al*. 2022), which is consistent with the results of this research. On the other hand, studies carried out on *G. ulmifolia* and *L. leucocephala* in tropical forage banks did not show a negative effect on forage yield during the dry season (Casanova-Lugo *et al*. 2014). This reflects a greater tolerance to drought by *G. ulmifolia* and *L. leucocephala*, compared to *T. diversifolia*. In the Colombian Andes, Guatusmal-Gelpud *et al*. (2020), reported a cumulative yield of *T. diversifolia* of 24 600 and 23 850 kg DM ha^{-1} year^{-1}, for cutting heights of 10 and 50 cm, values higher than that we found in this study with heights of 60 cm (7 727.6 kg DM ha^{-1} year^{-1}). Differences in edaphoclimatic conditions, the planting density, the age of the plants and the management can explain the differences in forage yield.

Nutrient composition

In this study, we observed that the cutting height influenced the CP and ADF content of the *T. diversifolia* forage. This may be related to the regrowth capacity of the plant, since at taller cutting heights (80 cm), they maintain higher residual biomass and, consequently, a higher proportion of buds, which contributed to improving the quality of forage (Letty *et al*. 2021). Another factor that influences the nutrient composition of *T. diversifolia* forage is seasonality. For example, we observed that the total carbohydrate contents were higher during the rainy season while structural fractions of the carbohydrates were higher during the dry season (Gutiérrez *et al*. 2017). This implies that the easily digestible (labile) fractions of the carbohydrates were higher during the rainy season favouring the digestibility of the forage. During the rainy season, there was a greater mobilisation of resources in the plant due to the greater availability of water for growth and development (Navale *et al*. 2022). The above favoured the quality of the forage with an increase in CP and OM and lower concentrations of NDF, ADF and ash. This was consistent with those proposed by Cediel-Devia *et al*. (2020), who likewise reported that seasonality intervened in the concentration of CP, NDF and ADF of *T. diversifolia* forage. Such an increase in CP is favoured in the rainy season (Senarathne *et al*. 2018). In addition, the leaf biomass of *T. diversifolia* also increases with increasing rainfall (Uu-Espens *et al*. 2019).

The quality of the forage depends on the reserves of the plant for the development of morpho-structural parts like branches and stems; in turn, the concentrated reserves of these components favour the foliar concentrations of sugars, proteins and minerals after regrowth (Gutiérrez *et al*. 2017). Nevertheless, Ramírez (2018) documented that for *T. diversifolia* grown in low levels of nitrogen fertilisation, the production of dry forage, leaf content and protein production increased by applying N. However, Botero-Lodoño *et al*. (2019) mentioned that the DM contents decrease with increasing fertilisation levels and that the CP and ash contents increase. Cabezas y Sánchez (2008) showed that the deficiency of N and K in the soil presents a reduction in biomass of 50%, which affects the size of leaves. *Tithonia diversifolia* forage has a high CP content compared to traditional tropical grasses (7% CP and dry matter digestibility of 38%). In addition, they maintain CP concentrations higher than 17% throughout the year, which corresponds to excellent quality forage for feeding ruminants and backyard animals (Vega-Granados *et al*. 2019).

In this sense, the NDF and ADF values reported in this study were lower than those commonly reported for tropical grasses (Gutiérrez *et al*. 2017), highlighting the superior quality of *T. diversifolia* forage as a forage alternative to replace or reduce the amounts of commercial concentrates for animal feeding. Pastures have a higher concentration of structural tissues (like cellulose, hemicellulose and lignin) and a lower concentration of CP compared to the foliage of trees and shrubs, which provides them with an advantage in terms of digestibility, forage consumption and a favourable effect on animal production and performance (Horst *et al*. 2022).

CONCLUSIONS

We obtained the highest cumulative forage yield of *T. diversifolia* plant to a cutting height of 80 cm and demonstrated that harvest height influenced forage quality in terms of crude protein and acid detergent fibre contents. The proportions of leaves, edible stems and the leaf:stem ratio are favoured during the rainy season. The height of 80 cm showed the highest average forage yields during the rainy season. The nutritional quality of the *T. diversifolia* forage was influenced by the cutting height and the season of the year. The cutting height of 80 cm showed the best quality of the forage throughout the year under the edaphoclimatic and management conditions reported in this research. The results are useful for animal farmers to manage livestock systems in terms of forage production and quality during different seasons of the year.

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