EDUCACIÓN
SECRETARÍA DE EDUCACIÓN PÚBLICA

TECNOLÓGICO NACIONAL DE MÉXICO

Instituto Tecnológico de la Zona Maya

Dirección

"2020, Año de Leona Vicario, Benemérita Madre de la Patria"

VARIACIÓN ESTACIONAL EN LA PRODUCCIÓN DE BIOMASA Y CALIDAD DEL FORRAJE DE *Tithonia diversifolia* A DIFERENTES ALTURAS DE CORTE EN UN BANCO DE FORRAJE EN EL SUR DE MÉXICO

TESIS

Presentada como requisito parcial para obtener el Grado de:

MAESTRO (A) EN CIENCIAS EN AGROECOSISTEMAS SOSTENIBLES

Con orientación en: Producción pecuaria Sostenible

PRESENTADA POR:

Ing. Carol Estrella Uu Espens

DIRECTOR DE TESIS

Dr. Fernando Casanova Lugo

CODIRECTOR DE TESIS

Dr. Roger Rodolfo Canul Solís

Ejido Juan Sarabia, Othón P. Blanco, Quintana Roo. Enero 2021

El presente trabajo titulado: VARIACIÓN ESTACIONAL EN LA PRODUCCIÓN DE BIOMASA Y CALIDAD DEL FORRAJE DE *Tithonia diversifolia* A DIFERENTES ALTURAS DE CORTE EN UN BANCO DE FORRAJE EN EL SUR DE MÉXICO, fue realizado por la C., CAROL ESTRELLA UU ESPENS el cual ha sido revisado y aceptado por el Comité Tutorial como requisito parcial para obtener el Grado de **MAESTRA EN CIENCIAS EN AGROECOSISTEMAS SOSTENIBLES.**

Presidente: Firma

DR. FERNANDO CASANOVA LUGO

Secretario: Firma

M.C VÍCTOR F. DÍAZ ECHEVERRÍA

Vocal: Firma

DR. ALFONSO CHAY CANUL

Suplente: Firma

DR. ISMAEL PAT AKÉ

Ejido Juan Sarabia, Othón P. Blanco, Quintana Roo, enero 2021

DECLARATORIA DE PROPIEDAD INTELECTUAL

El suscrito, DECLARA que los datos contenidos en el Trabajo de Tesis: **VARIACIÓN ESTACIONAL EN LA PRODUCCIÓN DE BIOMASA Y CALIDAD DEL FORRAJE DE *Tithonia diversifolia* A DIFERENTES ALTURAS DE CORTE EN UN BANCO DE FORRAJE EN EL SUR DE MÉXICO** de la Maestría en Ciencias en Agroecosistemas Sostenibles del Instituto Tecnológico de la Zona Maya, son el resultado original del trabajo de campo considerados de mi entera propiedad intelectual, en él, se ha incluido la debida citación de obras, por lo que no existe plagio, ni se afecta intereses de terceras personas.

Por consiguiente, AUTORIZO al Instituto Tecnológico de la Zona Maya para la reproducción del documento con el fin de intercambio bibliotecario, siempre y cuando se dé el crédito correspondiente, indicando la fuente de procedencia de la información contenida.

Para los fines legales correspondientes, se expide la presente en el ejido Juan Sarabia, municipio de Othón P. Blanco, Quintana Roo, México a los 22 días del mes de enero del año 2021.

Ing. Carol Estrella Uu Espens

Agradecimientos

"La valentía no es tener fuerza para seguir adelante, sino seguir adelante cuando no tenemos fuerza para hacerlo."

Quiero agradecer a mis padres: **Angelica Espens** y **Rubén Uu** por darme la vida, por el gran apoyo que me han brindado durante estos tres años y sobre todo por el amor incondicional. También quiero agradecer a mis hermanos: **Paola, Rubí, Aaron** y **Ariadna** a pesar de la distancia siempre se han preocupado y me dan ánimos para concluir esta etapa.

A mis sobrinas: **Alejandra. Valeria, Jessi y Ximena** por ser mi motivo en esta vida.

A mi casa de estudios el **Instituto Tecnológico de la Zona Maya** por los siete años que han sido parte de mi formación académica.

A mi director de tesis **Dr. Fernando Casanova Lugo** y a mi Codirector **Dr. Jorge R. Canul Solís**, quiero agradecerles por la confianza que me han brindado para ser parte de este proyecto, por las sugerencias y comentarios para mejorar el presente documento.

A mi comité revisor, **Dr. Fernando Casanova Lugo, Dr. Alfonso J. Chay Canul y M.C. Víctor F. Diaz Echeverria** por sus sugerencias para mejor académicamente y profesional, por la paciencia y la amistad.

Al **Dr. Ángel Piñeiro Vázquez, Dr. Gilberto Villanueva**, **Dr. Deb R. Aryal y Dr. Dixan Pozo Leyva** por sus comentarios y sugerencias que ayudaron a mejorar este trabajo.

A mis amigos, **Alberto Cabañas, Armando Escobedo y Fernando Lugo**, por la gran amistad que tenemos de años. Por estar conmigo en las buenas y en las malas, por las risas, los buenos momentos y los consejos. Gracias, siempre estarán en mi corazón.

Pero sobre todo a MÍ por no rendirme jamás, a pesar de los momentos de depresión. Gracias carol eres una mujer fuerte y que vale mucho.

GRACIAS

Dedicatoria

A mis padres, por haber educado a cinco personas increíbles, por darnos la mejor herencia que fue una excelente educación, pero sobre todo por no rendirse jamás.

CONTENIDO

1. INTRODUCCIÓN GENERAL 11
2. ARTÍCULO CIENTÍFICO 14
Seasonal variation in biomass production and forage quality of *Tithonia diversifolia* at different cutting heights in a fodder bank in southern Mexico 14
2.1. Abstract 15
2.2. Introduction 15
2.3. Materials and methods 17
2.3.1. Site characteristics 17
2.3.2. Management of experimental plots 19
2.3.3. Experimental design 19
2.3.4. Biomass components and forage yield 19
2.3.5. Nutrient composition analysis 20
2.3.6. Statistical analysis 20
2.4. Results 20
2.4.1. Biomass components 20
2.4.2. Forage yield 21
2.4.3. Nutrient composition 23
2.5 Discussion 26
2.5.1. Biomass components 26
2.5.2. Biomass and forage yield 27
2.5.3. Nutrient composition 28
2.6. Conclusions 29
2.7. Acknowledgements 30
2.8. Conflict of interest 30
2.9. References 30

ÍNDICE DE TABLAS

		Pág.
Tabla 1.	Physical and chemical properties of the soil from the experimental plots of *Tithonia diversifolia*, under sub-humid tropical conditions…………..	18
Tabla 2.	Biomass components (%) and leaf-stem ration of *Tithonia diversifolia* at different cutting heights and during two seasons, under sub-humid tropical conditions …………………………………………………...	21
Tabla 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 ………………...………………………..	22
Tabla 4	Bromatological composition (%) of forage from *Tithonia diversifolia* at different cutting heights and during two seasons, under sub-humid tropical conditions……………………………………………………	24

ÍNDICE DE FIGURAS

Pág.

Figura 1. Location of the study site in the south Quintana Roo, Mexico ……………..… 17

Figura 2. Minimum and maximum air temperatures, and rainfall at the study site. Data taken from the microclimatic station at the Instituto Tecnológico de la Zona Maya in January 2019 - January 2020………..……….…………… 18

Figura 3. 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* ≤0.050)…………..… 22

Figura 4. 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* ≤0.050).…………………………………..…. 23

Figura 5. Crude protein, neutral detergent fiber and acid detergent fiber (%) 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* ≤0.050………………………….... 25

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 México tropical. Se plantó *T. diversifolia* en bancos de forrajes en un diseño completamente al azar con arreglo factorial 3 × 2. Los tratamientos consistieron en tres alturas de corte a 40, 60 y 80 cm del nivel del suelo cosechadas cada 60 días, durante dos épocas del año. En cada período, la biomasa fue recolectada, separada en componentes comestibles y no comestibles y secada en la estufa. Se determinó el rendimiento de biomasa y la concentración de proteína cruda (PC), 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 influyeron en la calidad de los nutrientes del forraje comestible dado que las concentraciones de PC, FDA y FDN variaron significativamente ($P < 0.05$). Hubo una interacción significativa entre la altura de corte y la temporada en la producción y calidad del forraje ($P < 0.05$). En la estación seca, el contenido de FDN, FDA, lignina y cenizas del forraje fueron mayores, mientras que el PC y MO fueron menores ($P < 0.05$). Se recomienda el uso *de T. diversifolia* 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, bancos de forrajes, arbustos nativos, cosechas repetidas, calidad nutricional, trópico subhúmedo.

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. We planted T. diversifolia in forage banks in a completely randomised 3 × 2 factorial design. 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, separated into edible and non-edible components and oven-dried. 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 (2008 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 ($P < 0.05$). There was a significant interaction between cutting heights and the season on forage production and quality ($P < 0.05$). In the dry season, the content of NDF, FDA, lignin and ash were higher, while the PC and OM were lower ($P < 0.05$). The use of T. diversifolia at a height of 80 cm is recommended to maintain the best production and the quality of the forage throughout the year for livestock production.

Keywords: Livestock systems, forage banks, native shrubs, repeated harvesting, nutritional quality, Sub-humid tropics.

1. INTRODUCCIÓN GENERAL

En la actualidad los efectos del cambio climático, han ocasionan cuantiosas pérdidas en las comunidades rurales y ecosistemas agropecuarios; sin embargo, esta situación se agrava en zonas de mayor degradación y desertificación (Aboyeji et al. 2017). Una de las limitaciones de los sistemas de producción agroforestales es la escasez de la economía, debido a los altos costos productivos, fundamentalmente por la alimentación; ya que los productores hacen un alto uso de productos externos a los sistemas productivos. En este sentido el empleo de forrajes de calidad es una alternativa para la reducción de costos, ya que disminuyen el empleo de concentrados comerciales aumentando así la rentabilidad y sostenibilidad de los sistemas (Pozo-Leyva et al. 2019).

Otro factor importante a considerar son los efectos del cambio climático mediante la presencia de lluvias erráticas y las variaciones de temperatura, lo que requiere del empleo de opciones forrajeras adaptadas a menores precipitaciones o a un régimen de lluvias diferente (Gómez-Miranda et al. 2020). La producción de ganado en el sureste de México se basa en el uso de monocultivos de pasto que tienen bajos niveles de proteína digestible y alto contenido de fibra. El follaje de especies arbustivas y arbóreas se ha considerado, en la mayoría de los casos, como una alternativa nutricional para la suplementación de rumiantes en el trópico para mejorar el nivel productivo y nutricional de los animales. Principalmente durante períodos de escasez de forrajes, reducen los costos de producción y contribuyen a la rentabilidad y sostenibilidad de los sistemas de producción (Mahecha et al.2007, Pozo-Leyva et al.2019).

Por lo expuesto anteriormente, se hace necesario evaluar especies forrajeras mejor adaptadas a las condiciones agroecológicas y de manejo de los sistemas de producción bajo esquemas de silvopastoreo del sureste de México. Al respecto, *Tithonia diversifolia* Hemsl. A Gray (Asteraceae), es un arbusto originario del sureste de México y es conocida como falso girasol, no obstante, su distribución ha sido reportada en los trópicos húmedos y subhúmedos de América Central y del Sur (Ramírez-Rivera et al. 2010, Aboyeji et al. 2017). Se ha documentado que *T. diversifolia* representa una excelente alternativa en la alimentación de rumiantes (Jama et al. 2000). Lo anterior es debido a que el forraje de esta especie contiene bajos niveles de fibra (35 – 30 %) y alto contenido de proteína (>17%), por lo que puede sustituir hasta el 35% del suministro de concentrados comerciales en la alimentación del ganado sin afectar la producción de leche (Ramírez-Rivera et al. 2010). Además, la inclusión de *Tithonia diversifolia* a los sistemas de producción animal, mantiene una alta biodiversidad comparado con las pasturas en monocultivo, reduce el estrés calórico de los animales, incrementa el aporte de materia orgánica al suelo, y de calidad flexible a diferentes condiciones climáticas, lo que la torna atractiva para resolver las limitantes que presentan otras especies como *Leucaena leucocephala* en los sistemas silvopastoriles (Casanova-Lugo et al. 2014).

Una de las ventajas de *T. diversifolia* es su rápido crecimiento después de la cosecha, tolerando repetidos cortes a lo largo del año con una alta producción de biomasa. No obstante, cuando *T. diversifolia* es utilizada en bancos de forraje, los productores emplean diversas alturas de corte o cosecha que puede ocasionar una disminución progresiva de la producción de forraje debido a la reducción en el número de yemas del tallo que limitan el rebrote de nuevas hojas (Ramos-Trejo et al. 2015). Asimismo, ocasiona el agotamiento de las reservas de la planta, debido a que movilizan carbohidratos de reserva para reconstruir el tejido fotosintético después de la cosecha, el pastoreo o la pérdida estacional del follaje (Partey et al. 2011). Por ello, conocer la altura óptima de aprovechamiento (i.e. cosecha) de *T. diversifolia* es fundamental para el manejo sostenible del cultivo en los sistemas de producción animal. Al respecto, las investigaciones relacionadas con el rendimiento y calidad de la biomasa de *T. diversifolia* en bancos de forraje bajo diferentes esquemas de manejo y en las distintas épocas de año en condiciones tropicales son limitadas. Por lo anteriormente planteado, el objetivo de esta investigación fue evaluar el rendimiento y calidad nutricional del forraje de *T. diversifolia* bajo diferentes alturas de corte, durante la estación seca y lluviosa, en el sur del estado de Quintana Roo, México.

Los resultados obtenidos se encuentran descritos en el siguiente articulo intitulado: **Seasonal variation in biomass production and forage quality of *Tithonia diversifolia* at different cutting heights in a fodder bank in southern Mexico**.

Referencias

Aboyeji CM, Adekiya AO, Dunsin O, Agbaje GO, Olugbemi O, Okoh HO, Olofintoye TAJ (2017) Growth, yield and vitamin C content of radish (*Raphanus sativus* L.) as affected by green biomass of *Parkia biglobosa* and *Tithonia diversifolia*. Agrofor Syst. 93,803–812. https://doi:10.1007/s10457.

Casanova-Lugo F, Petit-Aldana J, Solorio-Sánchez FJ, Parsons D, Ramírez-Avilés L (2014) Forage yield and quality of *Leucaena leucocephala* and *Guazuma ulmifolia* in mixed and pure fodder banks systems in Yucatán, México. Agrofor Syst 8:29-39.

Gómez MA, Estrada FJ G, Morales AE, López GF, Flores CG, Arriaga JCM (2020) Barley or black oat silages in feeding strategies for small-scale dairy systems in the highlands of Mexico. Can. J. Anim. Sci. 100: 221-227 dx.doi.org/10.1139/cjas-2018-0237

Jama B, Palm CA, Buresh RJ, Niang A, Gachengo C, Nziguheba G, Amadalo B (2000) *Tithonia diversifolia* as a green manure for soil fertility improvement in western Kenya: A review. Agrofor Syst 49:201-221.

Mahecha L, Escobar JP, Suárez JF, Restrepo LF (2007) *Tithonia diversifolia* (HEMSL.) A. Gray (botón de oro) como suplemento forrajero de vacas F1 (Holstein por Cebú). Livest Res Rural Dev 19(2):1.

Partey ST (2011) Efecto de la frecuencia de poda y la altura de poda sobre la producción de biomasa de *Tithonia diversifolia* (HEMSL) A. GRAY. Agrofor Syst 83:181-187.

Pozo-Leyva D, López-González F, Olea-Pérez R, Balderas-Hernández P, Arriaga-Jordán CM (2019) Nitrogen utilization efficiency in small-scale dairy systems in the highlands of central Mexico. Tropi Anim Health Prod 51:1215-1223. https://doi.org/10.1007/s11250-019-01812-6

Ramírez-Rivera U, Sangineés-Garcia J R, Escobedo-Mex J G, Cen-Chuc F, Rivera-Lorca JA, Lara-Lara PE (2010) Effect of diet inclusion of *Tithonia diversifolia* on feed intake, digestibility and nitrogen balance in tropical sheep. Agroforest Syst 80(2):295-302

Ramos-Trejo O, Castillo-Huchín J, Sandoval-Gío JJ (2015) Effect of cutting intervals and heights in forage productivity of *Moringa oleifera*. Revista Bio Ciencias 3:187-194.

2. ARTÍCULO CIENTÍFICO

Seasonal variation in biomass production and forage quality of *Tithonia diversifolia* at different cutting heights in a fodder bank in southern Mexico

Carol Uu-Espens[1], Jorge R. Canul-Solís[2], Alfonso J. Chay-Canul[3], Ángel T. Piñeiro-Vázquez[4], Víctor F. Díaz-Echeverría[1], Gilberto Villanueva-López[5], Deb R. Aryal[6], Dixan Pozo-Leyva[1], Fernando Casanova-Lugo[1]*

[1]Tecnológico Nacional de México Campus I. T. de la Zona Maya. Carretera Chetumal-Escárcega km 21.5, Ejido Juan Sarabia. C.P. 77960, Othón P. Blanco, Quintana Roo, México.
[2]Tecnologico Nacional de México Campus I. T. de Tizimín. Avenida Cupules km 2.5, CP. 97700. Tizimín Yucatán, México.
[3]División Académica de Ciencias Agropecuarias, Universidad Juárez Autónoma de Tabasco. México. Carretera Villahermosa-Teapa, km 25, R/a. La Huasteca 2ª. Sección, C.P. 86280. Villahermosa, Tabasco, México.
[4]Tecnológico Nacional de México Campus I. T. Conkal. Antigua carretera Mérida-Motul km 16.3, Conkal, Yucatán, México.
[5]El Colegio de la Frontera Sur, Unidad Villahermosa, Tabasco México
[6]CONACYT-UNACH, Facultad de Ciencias Agronómicas, Villaflores, Chiapas, México
Corresponding author: fkzanov@gmail.com

Este manuscrito fue elaborado de acuerdo a las normas de la revista Agroforestry Systems, editada por Springer, la cual se encuentra en diversos índices internacionales de reconocido prestigio como Web of Science (Thomson Reuters) y Scopus.

2.1. 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. We planted *T. diversifolia* in forage banks in a completely randomised 3 × 2 factorial design. 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, separated into edible and non-edible components and oven-dried. 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 (2008 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 ($P < 0.05$). There was a significant interaction between cutting heights and the season on forage production and quality ($P < 0.05$). In the dry season, the content of NDF, FDA, lignin and ash were higher, while the PC and OM were lower ($P < 0.05$). The use of T. diversifolia at a height of 80 cm is recommended to maintain the best production and the quality of the forage throughout the year for livestock production.

Keywords: Livestock systems, forage banks, native shrubs, repeated harvesting, Nutritional quality, Sub-humid tropics.

2.2. Introduction

Livestock production in southeastern Mexico is based on the use of monoculture pastures that have low levels of digestible protein and high fibre contents. 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. Mainly during periods of forage shortage, they reduce production costs and contribute to the profitability and sustainability of production systems (Mahecha et al. 2007, Celis-Alvarez et al. 2016, Pozo Leyva et al. 2019).

A viable strategy for the integration of shrubs and trees for animal production is the implementation of silvopastoral systems. 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 (Casanova-Lugo et al. 2014, Casanova-Lugo et al. 2016).

In this regard, *Tithonia diversifolia* (Hemsl.) A. Gray. (Asteraceae), also called false sunflower or Mexican sunflower), is a shrub native to southeastern Mexico. However, its distribution has been reported to the humid and sub-humid tropics of Central and South América (Jama et al. 2000, Ramírez-Rivera et al. 2010, Aboyeji et al. 2017). *Tithonia diversifolia* has been documented as an excellent alternative in ruminant feeding (Jama et al. 2000). This is because the forage of this species contains low levels of fibre (35–30%) and high protein contents (> 17%), so it can replace up to 35% of the concentrate supplements in cattle feed without affecting production (Ramírez-Rivera et al. 2010). One of the characteristics of forage shrub species is their high nutritional value regardless of the time of year. The in vitro dry matter digestibility can fluctuate from 54 to 65% with CP concentrations of 18% (Ramírez-Rivera et al. 2010). 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 (Piñeiro-Vázquez et al. 2013). 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 (Ortega-Vargas et al. 2013).

One of the advantages of *T. diversifolia* is its rapid growth after harvest, tolerating repeated cuts throughout the year with high biomass production. 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 (Ruiz et al. 2012, Ramos-Trejo et al. 2015). 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 (Partey et al. 2011). Therefore, knowing the optimal harvest height (i.e. harvest) of *T. diversifolia* is essential for the sustainable management of this important forage plant in animal production systems in the tropics.

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.

2.3. Materials and methods

2.3.1. 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; Fig. 1). The area presents a warm sub-humid climate (type Aw1), according to Garcia (1988). Climatic data during the experimental period (Fig. 2) 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 1009 mm, respectively.

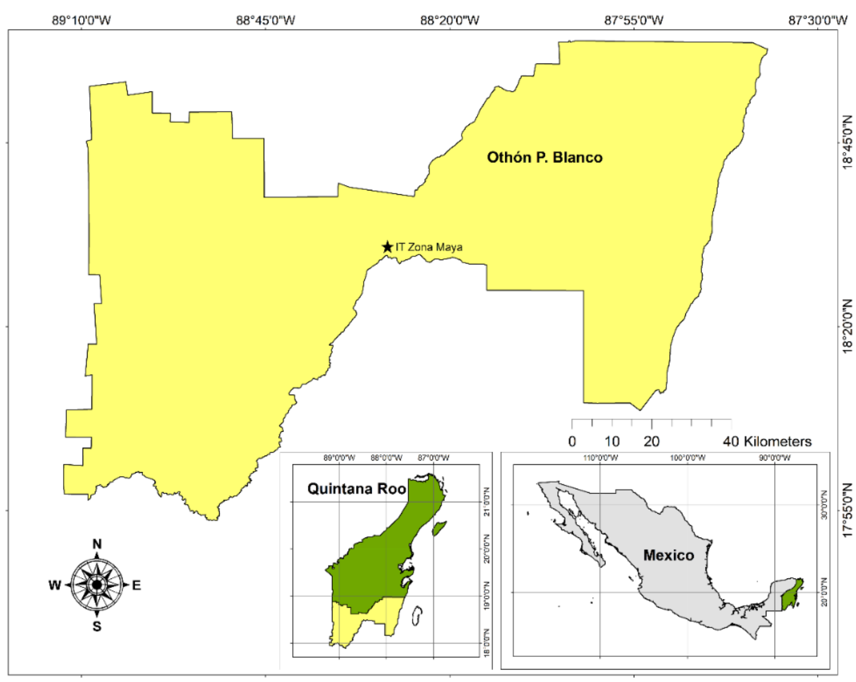

Figure 1. Location of the study site in the south Quintana Roo, Mexico.

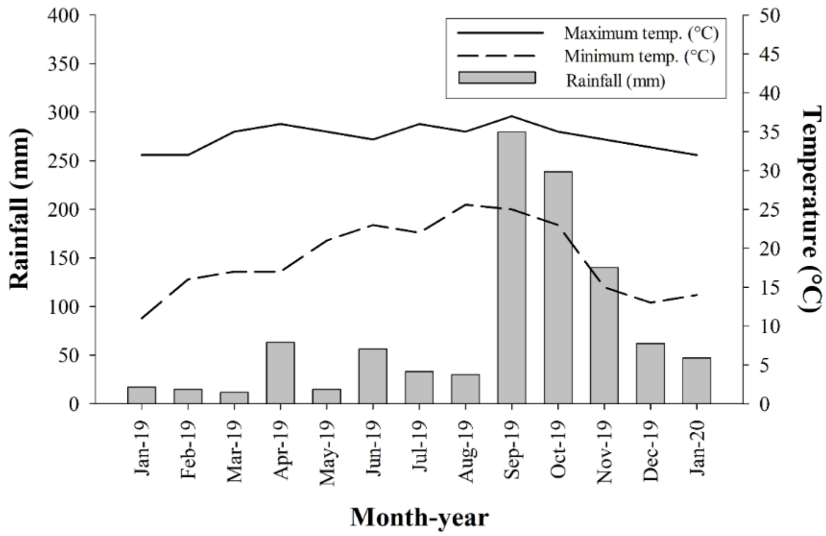

Figure 2. Minimum and maximum air temperatures, and rainfall at the study site. Data taken from the microclimatic station at the Instituto Tecnológico de la Zona Maya in January 2019 - January 2020.

The predominant soils are Gleysols according to the Food and Agriculture Organization (IUSS Working Group WRB 2015). 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.

Parameters	**Values**
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

2.3.2. 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 as recommended by Mahecha et al. (2007). 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 × 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 (i.e. the effects of harvest heights on biomass production and nutrition quality).

2.3.3. Experimental design

We used a completely randomised design with a 3 × 2 factorial arrangement; the treatments consisted of evaluating three harvest heights of *T. diversifolia* (i.e. 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.

2.3.4. 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 subsamples were divided into leaves, edible stems (<0.5 cm diameter) and woody stems (≥0.5 cm diameter), which were dried at 60 °C 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.

2.3.5. 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 & Southgate, 1992). The organic matter (OM) and ash contents were determined by ignition at 600 °C for four hours in a muffle furnace (AOAC, 2000).

2.3.6. Statistical analysis

The biomass production data were analysed with an ANOVA model using PROC MIXED (SAS, 2004) 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, 2004). Where significant differences were observed, we compared the means using Tukey's statistic ($P \leq 0.05$).

2.4. Results

2.4.1. Biomass components

The cutting height did not show a significant effect ($P > 0.05$) on the proportion of leaves, senescent material, tender stems, woody stems or the leaf-to-stem ratio of the biomass of *T. diversifolia* (Table 2). 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), while the proportion of edible stems was two times lower (P < 0.01). The proportion of senescent material and woody stems of *T. diversifolia* was statistically indifferent (P > 0.05) in both seasons (Table 2).

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

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
SE	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
SE	2.7	2.0	3.6	0.7	0.2

SE, standard error; ns, non-significant.

* *P* <0.05, ** *P* <0.01

2.4.2. Forage yield

The average yield of forage harvested at a cutting height of 80 cm was 2,008 kg DM ha-1 harvest1, a value that was 29 and 32% higher (P < 0.05) than the cutting heights of 40 and 60 cm, 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	1670.2	1550.6 b
60 cm	1656.1	1520.7 b
80 cm	2170.8	2007.9 a
SE	193.9	167.5
Season	**	**
Dry	1058.7 b	950.7 b
Rainy	2606.0 a	2435.5 a
SE	141.3	136.1

SE, standard error; 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* (Fig 3). 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 3).

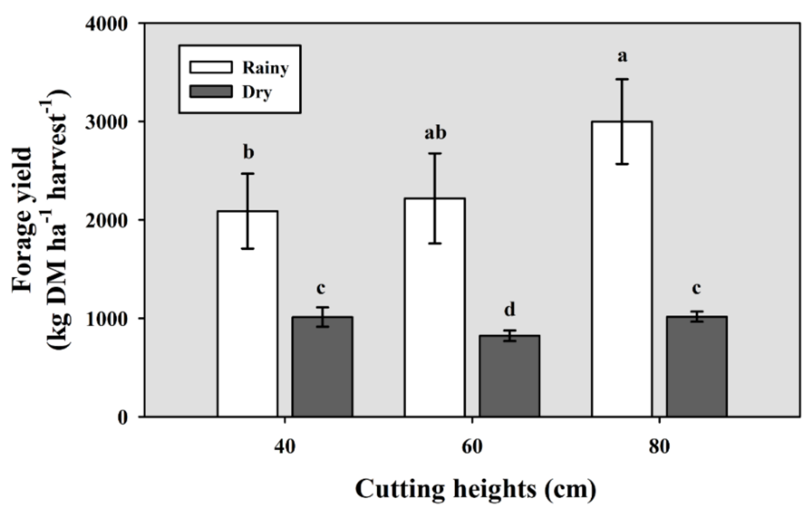

Figure 3. Mean forage yield per harvest of *Tithonia diversifolia* at different cutting heights and during two seasons, under sub-humid tropical conditions. *Error bars* represent the standard error of the mean. Means labelled by different letters are significantly different (Tukey's statistic, P ≤0.050).

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 4).

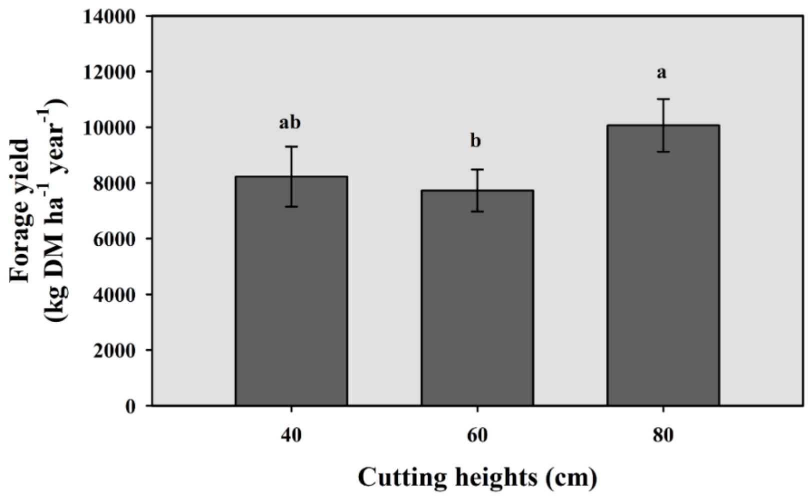

Figure 4. Annual forage yield of *Tithonia diversifolia* at different cutting heights, under sub-humid tropical conditions. *Error bars* represent the standard error of the mean. Means labelled by different letters are significantly different (Tukey's statistic, *P* ≤0.050).

2.4.3. 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).

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

Treatments	**CP**	**NDF**	**ADF**	**ADL**	**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
SE	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
SE	0.5	0.5	0.1	0.1	0.3	0.3

CP, crude protein; NDF, neutral detergent fiber; ADF, acid detergent fiber; ADL, acid detergent lignin; OM, organic Matter.

SE, standard error; ns, non-significant.

** P <0.05, ** P <0.01

There were interactions between cutting height and the season (P <0.01) on CP, NDF and ADF content of the *T. diversifolia* forage (Figure 5). 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 16.5 to 17.9% (Figure 5).

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 5). 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 5).

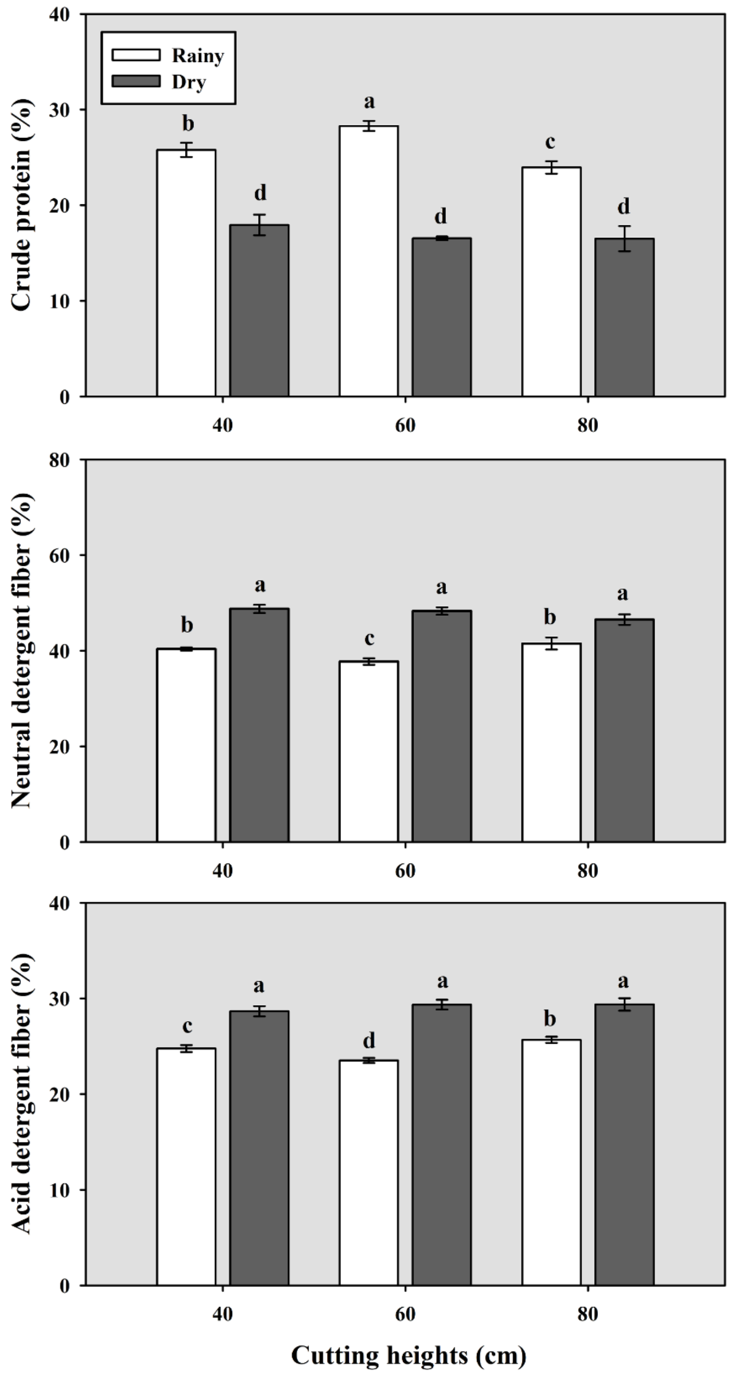

Figure 5. Crude protein, neutral detergent fiber and acid detergent fiber (%) of forage from *Tithonia diversifolia* at different cutting heights and during two seasons, under sub-humid tropical conditions. *Error bars* represent the standard error of the mean. Means labelled by different letters are significantly different (Tukey's statistic, $P \leq 0.050$).

2.5 Discussion

2.5.1. Biomass components

The effect of harvest height on the biomass recovery and nutrient composition of forage shrub species has been poorly documented in southeastern Mexico. A study by Ramos-Trejo et al. (2015), in eastern Yucatán, showed that the cutting height (i.e. 40, 80 and 120 cm) at harvesting intervals of 45 and 60 days did not influence the leaf:stem ratio of the biomass of *M. oleifera*, 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 do not coincide with the data found in 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), Mohamed and Olavi (2003), 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. This response of crops behaves in different ways depending on 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 biomass of the foliage yield of *T. diversifolia* and decreases the woody part of the biomass, while a decrease in the frequency of pruning 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 (García-Soldevilla and Fernández 2004, Maya 2005). 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 intervene 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 Casanova-Lugo et al. (2014), the decrease in temperatures coupled with a shorter photoperiod favours flowering and the transport of carbohydrates in plants. This can favour the elongation of 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).

2.5.2. Biomass and forage yield

The reports of biomass production by woody forage species are varied due to the different management strategies applied. For example, 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 Southeastern 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 a study carried out with *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 influence the biomass yield in Columbian Andes (Guatusmal-Gelpud et al. 2020). However, in our research, the best forage yield was obtained with heights of 80 cm. 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-Marco (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 (Kang & Van Iersel 2004; Ehret et al. 2005).

It has been reported that one of the limiting factors for forage production is the low rainfall season (Zheng et al. 2016), 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.

2.5.3. 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 (i.e. 80 cm), they maintain higher residual biomass and, consequently, a higher proportion of buds, which contributed to improving the quality of forage. 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. 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. 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 (Yan et al. 2015).

The quality of the forage depends on the reserves of the plant for the development of morphostructural parts like branches and stems; in turn, the concentrated reserves of these components favour the foliar concentrations of sugars, proteins and minerals after regrowth. However, Cerdas-Ramírez et al. (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. However, Cabezas-Marco (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 (e.g. 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 (Ramírez Rivera et al. 2010, Casanova-Lugo et al. 2014).

In this sense, the NDF and ADF values reported in this study were lower than those commonly reported for tropical grasses (Rosales-Méndez & Gil 1997), 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. (Ortega-Vargas et al. 2013; Casanova-Lugo et al. 2014).

2.6. Conclusions

Harvest height is a factor that significantly affects the forage yield and nutrient composition of *T. diversifolia* grown in tropical fodder banks as one of the livestock systems. However, this effect varied with the parameters of biomass production and nutrient composition. There was a significant interaction between harvest heights and the seasons of the year on forage quality. The ratios 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 highest accumulated yield during the experimental period was for the cutting height of 80 cm, which also influenced crude the concentrations of crude protein and acid detergent fibre. The 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 finding of this research would greatly help livestock farmers in adopting appropriate harvest heights of this increasingly used plant species within the livestock production systems of the region.

2.7. Acknowledgements

The authors thank Tecnológico Nacional de México for financial support throughout this project (5437.19-P). We are also grateful to the Consejo Nacional de Ciencia y Tecnología for financing infrastructures project (270666) to carry out field and laboratory works and obtain a M.Sc. degree (of the first author) in Sustainable Agroecosystems.

2.8. Conflict of interest

The authors state that they have no conflicts of interest.

2.9. References

Aboyeji CM, Adekiya AO, Dunsin O, Agbaje GO, Olugbemi O, Okoh HO, Olofintoye TAJ (2017) Growth, yield and vitamin C content of radish (*Raphanus sativus* L.) as affected by green biomass of *Parkia biglobosa* and *Tithonia diversifolia*. Agrofor Syst. 93,803–812. https://doi:10.1007/s10457.

AOAC (2000) Association of Official Analytical Chemists. Official Method of Analysis. EUA.

Bacab HM, Solorio FJ, Solorio SB (2012). Efecto de la altura de poda en *Leucaena leucocephala* y su influencia en el rebrote y rendimiento de *Panicum maximum.* Avances en Investigación Agropecuaria 16(1):65-77

Botero-Londoño J, Gómez-Carabalí A, Botero-Londoño MA (2019) Rendimiento, parámetros agronómicos y calidad nutricional de la *Tithonia diversifolia* con base en diferentes niveles de fertilización. Revista Mexicana de Ciencias Pecuarias 10(3):789-800

Cabezas M, Sánchez CA (2008) Efecto de las deficiencias nutricionales en la distribución de la materia seca en plantas de vivero de curuba (*Passiflora mollissima* BAILEY). Agron Colom 26(2):197-204.

Casanova-Lugo F, Petit-Aldana J, Solorio-Sánchez FJ (2011) Los sistemas agroforestales como alternativa a la captura de carbono en el trópico mexicano. Rev Chapingo, Ser Cienc For y del Ambient 17:5-118.

Casanova-Lugo F, Petit-Aldana J, Solorio-Sánchez FJ, Parsons D, Ramírez-Avilés L (2014) Forage yield and quality of *Leucaena leucocephala* and *Guazuma ulmifolia* in mixed and pure fodder banks systems in Yucatán, México. Agrofor Syst 8:29-39.

Casanova-Lugo F, Ramírez-Avilés L, Parsons D, Caamal-Maldonado A, Piñeiro-Vázquez AT, Díaz-Echeverría V (2016) Environmental services from tropical agroforestry systems.

Revista Chapingo Serie Ciencias Forestales y del Ambiente 22:269-284. https://doi.org/10.5154/r.rchscfa.2015.06.02

Cediel-Devia D, Sandoval-Lozano E, Castañeda-Serrano R (2019) Effects of different regrowth ages and cutting heights on biomass production, bromatological composition and in vitro digestibility of *Guazuma ulmifolia* foliage. Agrofor Syst 94:1199-1208.

Celis-Alvarez MD, López-González F, Martínez-García CG, Estrada-Flores JG, Arriaga-Jordán CM (2016) Oat and ryegrass silage for small-scale dairy systems in the highlands of central México. Trop Anim Health Prod 48:1129-1134.

Ehret DL, Menzies JG, Helme T (2005) Production and quality of greenhouse roses in recirculating nutrient systems. Scientia Hort 106:103-113.

García E (1988) Modificaciones al sistema de clasificación de Köppen. Instituto de Geografía, UNAM. México, D.F. pp 219.

García-Soldevilla F, Fernández R (2004) Influencia de la frecuencia de poda y la época sobre los rendimientos de biomasa de la morera (*Morus alba*). Rev Computadorizada de Producción Porcina 11(1).

Greenfield H, Southgate DAT (1992) Food Composition Data. London, Elsevier Applied Science.

Guatusmal-Gelpud C, Escobar-Pachajoa LD, Meneses Buitrago DH, Cardona-Iglesias JL, Castro-Rincón E (2020) Producción y calidad de *Tithonia diversifolia* y *Sambucus nigra* en trópico altoandino colombiano. Agron Mesoam 31(1):193-208.

IUSS Working Group WRB (2015) World Reference Base for Soil Resources 2014, update 2015 International soil classification system for naming soils and creating legends for soil maps. World Soil Resources Reports No. 106. FAO, Rome.

Jama B, Palm CA, Buresh RJ, Niang A, Gachengo C, Nziguheba G, Amadalo B (2000) *Tithonia diversifolia* as a green manure for soil fertility improvement in western Kenya: A review. Agrofor Syst 49:201-221.

Kang JC, van IMW (2004) Nutrient solution concentration affects shoot:root ratio, leaf area ratio, and growth of subirrigated salvia (*Salvia splendens*). Hort Science 39(1):49-54.

Mahecha L, Escobar JP, Suárez JF, Restrepo LF (2007) *Tithonia diversifolia* (HEMSL.) A. Gray (botón de oro) como suplemento forrajero de vacas F1 (Holstein por Cebú). Livest Res Rural Dev 19(2):1.

Maya MGE, Durán CCV, Ararat JE (2005) Altura, disponibilidad de forraje y relación hoja-tallo del pasto estrella solo y asociado con leucaena. Acta Agronómica 54(2):1-6

Morales-Ruiz D E, Aryal D R, Pinto-Ruiz R, Guevara-Hernández F, Casanova-Lugo F, Villanueva-López G (2020). Carbon contents and fine root production in tropical silvopastoral systems. Land Degrad Dev 1-19. https://doi.org/10.1002/ldr.3761

Ortega-Vargas E, Lopez-Ortiz S, Burgueño-Ferreira JA, Campbell WB, Jarillo-Rodríguez J (2013) Date of pruning of *Guazuma ulmifolia* during the rainy season affects the availability, productivity and nutritional quality of forage during the dry season. Agrofor Syst 87:917-927.

Partey ST (2011) Efecto de la frecuencia de poda y la altura de poda sobre la producción de biomasa de *Tithonia diversifolia* (HEMSL) A. GRAY. Agrofor Syst 83:181-187.

Piñeiro-Vázquez AT, Ayala-Burgos AJ, Chay-Canul AJ, Ku-Vera JC (2013) Dry matter intake and digestibility of rations replacing concentrates with graded levels of *Enterolobium cyclocarpum* in pelibuey lambs. Trop Anim Health Prod 45:577-583.

Pozo-Leyva D, López-González F, Olea-Pérez R, Balderas-Hernández P, Arriaga-Jordán CM (2019) Nitrogen utilization efficiency in small-scale dairy systems in the highlands of central Mexico. Tropi Anim Health Prod 51:1215-1223. https://doi.org/10.1007/s11250-019-01812-6

Ramírez-Rivera U, Sangineés-Garcia J R, Escobedo-Mex J G, Cen-Chuc F, Rivera-Lorca JA, Lara-Lara PE (2010) Effect of diet inclusion of *Tithonia diversifolia* on feed intake, digestibility and nitrogen balance in tropical sheep. Agroforest Syst 80(2):295-302

Ramos-Trejo O, Castillo-Huchín J, Sandoval-Gío JJ (2015) Effect of cutting intervals and heights in forage productivity of *Moringa oleifera*. Revista Bio Ciencias 3:187-194.

Rosales-Mendez M, Gill M (1997) Tree mixtures within integrated farming systems. Livest Res Rural Dev, 9:56-66.

Ruiz TE, Febles G, Diaz H (2012). Plantation distance, frequency and cutting height on the biomass production of *Tithonia diversifolia* collection 10 during the year. Cuban Journal of Agricultural Science, 46(4):423-426.

SAS (2004) Statiscal Analysis System, Users. SAS Institute, Cary

Senarathne SHS, Atapattu AJ, Raveendra T, Mensah S, Dassanayake KB (2018) Biomass allocation and growth performance of *Tithonia diversifolia* (HEMSL.) A. GRAY in coconut plantations in Sri Lanka. Agrofor Syst. doi:10.1007/s10457-018-0290-y

Yan H, Liang C, Li Z, Liu Z, Miao B, He C, Sheng L (2015) Impact of precipitation patterns on biomass and species richness of annuals in a dry steppe. PLoS ONE 10(4):e0125300. https://doi.org/10.1371/journal.pone.0125300

Zheng Y, Zhang Y, Wu J (2016) Yield and quality of *Moringa oleifera* under different planting densities and cutting heights in southwest China. Industrial Crops and Products 91:88-96.