Revista Mexicana de Ciencias Agrícolas

DOI: https://doi.org/10.29312/remexca.v15i6.3338

Article

Production of *Crotalaria juncea* L. at different sowing densities and cutting ages

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Abstract

Mexico and most Latin American countries present poor management in forage production, as it is a determining factor in animal feeding. The objective was to evaluate the production of forage and crude protein of *Crotalaria juncea* L. sown at different sowing densities and harvested at different cutting times in the Costa Chica region of Guerrero, Mexico in 2021. The treatments were: three sowing densities at 400 000, 200 000 and 100 000 plants ha^{-1}. Growth was also analyzed at 30, 43, 50, 56, 63, 70, 77, 84, 91 and 98 days when considering that the pod was fully developed. The variables evaluated were: dry matter yield, leaf:stem ratio, morphological composition, crude protein, neutral detergent fiber, and acid detergent fiber. The average behavior of DMY, regardless of cutting age and according to the sowing densities, was as follows: 400 000 > 200 000 > 100 000 plants ha^{-1}, with 9 107, 7 750 and 5 874 kg DM ha^{-1}, respectively ($p\leq$ 0.05). Regardless of plant densities, in the first days of cutting, from 30 to 43 days, crude protein was higher with an average of 15.58 to 10.7%, respectively, and in the 56-day cutting frequency, the lowest percentage was observed at 8.3% ($p\leq$ 0.05). Crotalaria should be sown at a density of 400 000 plants ha^{-1} and cut after 70 days of growth; it also anticipates the start of flowering.

Keywords:

crude protein, legume, yield.

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Introduction

Mexico and most Latin American countries present poor management in forage production, as it is a determining factor in animal feeding; therefore, in the period of 'lean cows', feeds based on imported grains and concentrates are supplied, which increases production costs (Rivera *et al*., 2010); it is necessary to look for sustainable supplements such as legume plant species with nutritional quality that are produced with low inputs and costs (Sosa-Pérez *et al*., 2017).

Legumes are an economical protein alternative and replace the use of concentrates (Rubio and Molina, 2016); their production in association with other species or protein banks increases the nutritional quality of diets; they have leaves and fruits that can be used as a complement (Solomon, 2022).

They are species that contribute and fix nitrogen (N) to the soil in a biological way, thus reducing the economic costs due to the acquisition of chemical fertilizers, environmental pollution by denitrification, leaching or volatilization (Mascarenhas *et al*., 2003; Mendes *et al*., 2010; Siyal and Siyal, 2013); in addition, residual N is generated in the long term, which benefits the production system of subsequent crops (Hungria *et al*., 2013; Neto *et al*., 2017).

The genus *Crotalaria* belongs to the Fabaceae family, with distribution in the tropics and subtropics around the world (García *et al*., 2013); they are vigorous growing species with high biomass production in a short period of time (Pereira, 2006). Ríos-Hilario *et al*. (2022) evaluated *C. juncea* L., and they indicated that when the sowing density was 400 000 plants ha^{-1}, there was an average production of 19 837 kg ha^{-1}; nevertheless, this species is characterized by growing shrubby and as time passes, the stem increases, but the leaf:stem ratio decreases drastically; they also mention that pod production is better when the density is 200 000 plants ha^{-1}. Regarding harvest time, Maldonado-Peralta *et al*. (2022) state that *C. juncea* L., at 45 days after sowing, has the best leaf:stem ratio, growth rate, and morphological quality.

Studies carried out on other species, such as *C. spectabilis* it has yields of up to 26.28 t ha^{-1} (Avendaño, 2011) and *C. ochroleuca* has 36.17 t ha^{-1} (Rovaris *et al*., 2021) of green matter respectively. The yield depends on the environmental and edaphic conditions in which the crop develops, considering that the quality is better in the early stages of growth than in the late stages of development, which is a determining factor in animal nutrition.

This research aimed to evaluate the production of forage and crude protein of *Crotalaria juncea* L. sown at different densities and harvested at various times in the Costa Chica region of Guerrero, Mexico.

Materials and methods

Location of the experimental site

The research was carried out in the experimental plots and the Animal Nutrition laboratory at the Faculty of Veterinary Medicine No. 2 of the Autonomous University of Guerrero, located in Cuajinicuilapa, Guerrero, Mexico (16° 28' 28" north latitude and 98° 25' 11.27" west longitude, at 46 masl). The region's climate is classified as Aw and called dry tropics (García, 2004). The temperature and precipitation were recorded at the CONAGUA agrometeorological station located 2 km from the experimental plots, the average annual temperature reported in the study period was 27.5 °C, and the accumulated precipitation in the study period was 668 mm.

Plot management

The experimental plot was established on June 29, 2021, during the rainy season. Each plot measured 3 x 3 m and one was sown for each week of evaluation (10 plots), in a completely randomized design, with three replications. The treatments were three sowing densities: 400 000, 200 000, 100 000 plants ha^{-1}, with the topological arrangement of 5, 10, and 20 cm between plants

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and 50 cm between rows. The weeds were controlled with the help of a hoe, whenever the crop needed it. No fertilizers or agrochemicals were used, and drip supplemental irrigation was applied every third day.

The seed was sown manually, each deposited in the furrow at a depth of four times its size. Evaluations began 30 days after emergence, which considered days 30, 43, 50, 56, 63, 70, 77, 84, 91, and 98 after emergence until the pod was fully developed, with a leaf area of 5 cm.

Variables evaluated

Dry matter yield

For forage yield (kg DM ha^{-1}), random destructive sampling of each experimental unit and replication was carried out by the linear method of 1 m. Forage was harvested at 10 cm above ground level. Subsequently, it was weighed (GT-4000®, TEquipment, Parsippany, New Jersey, USA), placed in paper bags, and dried at 60 °C in a forced-air electric oven (FE-243A; Felisa; Guadalajara, Mexico) until reaching a constant weight.

Leaf:stem ratio

The leaf:stem ratio was determined by dividing the dry weight expressed in kg DM ha^{-1} of the morphological fractions, leaf by stem, obtained from the subsample used to estimate the morphological composition.

Morphological composition

To determine the morphological composition, a subsample of 20% was taken from the sample obtained from the forage yield and separated into its morphological components: stem, leaf, flower, and pod. Each component was weighed, placed inside paper bags, and dried in an electric oven at a temperature of 60 °C until constant weight.

Chemical composition

Crude protein was determined using the methods of AOAC (2005) with procedure 984.13. Neutral detergent fiber (NDF) and acid detergent fiber (ADF) were evaluated using the Ankom Technology methodology according to Van Soest *et al*. (1991).

Statistical analysis

The experimental design was completely randomized with three replications. The data were analyzed using the PROC GLM procedure of SAS (2009), where the effects of sowing density and cutting frequency were considered as fixed. Multiple comparison of treatment means was performed with Tukey's test ($p\leq 0.05$).

Results and discussion

The dry matter yield of crotalaria at different sowing densities and cutting ages can be seen in Table 1; in this variable, the average behavior, regardless of cutting age, showed the following descending order according to the sowing densities: 400 000# 200 000# 100 000 plants ha^{-1} with 9 107, 7 750 and 5 874 kg DM ha^{-1}, respectively ($p\leq 0.05$).

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Table 1. Dry matter yield (kg DM ha^{-1}) of crotalaria (*Crotalaria juncea* L.) grown at different densities and cutting ages.

Cutting age (days)	Sowing density (plants ha^{-1})			Average
	400 000	200 000	100 000	
30	436A b	536A c	436A f	470 f
43	1 870A b	2 003A bc	1 766A f	1 880 e
50	1 136A b	1 043A c	613A f	931 f
56	5 640AB ab	8 067A ab	4 573B de	6 093 d
63	6 720A ab	8 547A ab	6 400A cd	7 222 c
70	11 560A ab	12 760A a	9 627A ab	11 316 b
77	17 507A a	10 800A a	10 507A a	12 938 a
84	16 080A a	11 320A a	7 120A bcd	11 507 b
91	16 817A a	10 853A a	9 787A ab	12 486 a
98	13 307A ab	11 573A a	7 907B abc	10 929 b
Average	9 107 A	7 750 B	5 874 C	7 577

ABC= means with the same uppercase letter in the same row are not different ($p \leq 0.05$); abc= means with the same lowercase letter in the same column are not different ($p \leq 0.05$).

Regarding the cutting age, days 77 and 91 obtained the highest results in dry matter yield, with 12 938 and 12 486 kg DM ha^{-1}, and the cut of day 30, the lowest (470 kg DM ha^{-1}), regardless of sowing densities (*p*# 0.05). Santos *et al*. (2011); Mosjidis *et al*. (2013) mention that crotalaria has yields between 15 831 and 10 000 kg DM ha^{-1}, which can be attributed to the sowing season, management, sowing density (Jiménez *et al*., 2005) and climatic conditions, mainly precipitation and temperature, results similar to those of this trial.

There are studies on legume dry matter yield in sowing densities, and the authors mention that it can be variable, as in this study, and it depends mainly on interspecific competition for nutrients and light (Mattera *et al*., 2013). Ríos-Hilario *et al*. (2022) state that sowing density is an important factor in forage yield in crotalaria.

The leaf:stem ratio of crotalaria at different sowing densities and cutting ages is shown in Table 2. Maldonado-Peralta *et al*. (2022) state that the leaf:stem ratio in crotalaria is a quality reference; if it is greater than 1, the quantity of the leaf component is greater than the stem. The leaf:stem ratio was highly variable in the result regardless of the cutting age, having the highest leaf:stem ratio in the sowing densities of 400 000 and 100 000 plants ha^{-1}, with 0.36, and the lowest in the density of 200 000 plants ha^{-1}, with 0.32 ($p \leq 0.05$).

Table 2. Leaf:stem ratio of crotalaria (*Crotalaria juncea* L.) grown at different densities and cutting ages.

Cutting age (days)	Sowing density (plants ha^{-1})			Average
	400 000	200 000	100 000	
30	0.83A a	0.83A a	0.8A a	0.82 a
43	0.43A b	0.42A b	0.39A b	0.41 c
50	0.42B b	0.38B b	0.7A a	0.5 b
56	0.32A b	0.33A bc	0.26A b	0.3 d
63	0.29A b	0.27A bcd	0.37A b	0.31 d
70	0.26A b	0.27A bcd	0.31A b	0.28 e
77	0.22A b	0.24A bcd	0.23A b	0.23 e
84	0.21A b	0.18A cd	0.18A b	0.19 f
91	0.4A b	0.15A cd	0.2A b	0.25 e

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Cutting age (days)	Sowing density (plants ha^{-1})			Average
	400 000	200 000	100 000	
98	0.18A b	0.13A d	0.13A b	0.15 f
Average	0.36 A	0.32 B	0.36 A	0.34

ABC= means with the same uppercase letter in the same row are not different ($p\leq$ 0.05); abc= means with the same lowercase letter in the same column are not different ($p\leq$ 0.05).

The highest leaf:stem ratio was obtained at 30 days of age, with an average of 0.82, which decreased by 80% (0.15) when forage was cut at 98 days ($p\leq$ 0.05). On the other hand, Maldonado-Peralta *et al*. (2022) obtained a leaf:stem ratio of 0.55 to 0.65 in crotalaria at different cutting stages and sowing densities similar to those of this research. This trend has been reported in *Crotalaria longirostrata* (Maldonado-Peralta *et al*., 2023), with an average of 0.69 depending on the sowing density. On the other hand, in different alfalfa varieties Rojas-García *et al*. (2017) obtained a leaf:stem ratio of 0.88 to 1.55; a similar situation was found in this tropical species at early ages.

The morphological composition of crotalaria at different sowing densities and cutting ages is shown in Table 3. The leaf component was lower on all cutting days, regardless of sowing density, with the highest percentage on day 30 after emergence and lowest on day 98, with 45.34 and 13.08%, respectively ($p\leq$ 0.05). Regardless of the densities and cutting days, the largest component was the stem; the highest proportion was reported at day 98, with an average of 87%, and the lowest when the plant presented 30 days of development, with an average of 55.43% of stem ($p\leq$ 0.05).

Table 3. Morphological composition (%) of crotalaria (*Crotalaria juncea* L.) grown at different densities and cutting ages in the dry tropics.

Cutting age (days)	400 000 (plants ha^{-1})			200 000 (plants ha^{-1})			100 000 (plants ha^{-1})		
	leaf	stem	flower	leaf	stem	flower	leaf	stem	flower
30	44.35a	55.65c	-	45.32a	54.68d	-	44.35a	55.65d	-
43	29.99ab	70.01bc	-	29.08b	70.92c	-	27.6b	72.4c	-
50	29.49abc	70.51abc	-	27.61b	72.39c	-	40.68a	59.32d	-
56	24.22bc	75.78ab	-	24.97bc	75.02bc	-	20.63bcd	79.37abc	-
63	22.64bc	77.36ab	-	20.79bcd	79.21abc	-	26.89b	73.11c	-
70	20.56bc	79.74ab	-	21.44bcd	78.56abc	-	23.78bc	76.22bc	-
77	17.93 bc	82.07 ab	0.81 a	19.08 bcd	80.92 abc	0.89 abc	18.58 bcd	81.42 abc	1.03 a
84	17.5 bc	82.5 ab	0.92 a	15.52 bc	84.48 ab	0.5 bc	15.31 cd	84.69 ab	0.95 a
91	26.2 bc	73.8 ab	1.18 a	13.23 d	86.77 a	1.52 a	16.65 bcd	83.35 abc	1.3 a
98	14.74 c	85.26 a	1.14 a	11.67 d	88.33 a	1.13 ab	11.66 d	88.34 a	1.27 a
Average.	24.76 B	75.27 A	0.41 C	22.87 B	77.13 A	0.4 C	24.61 B	75.39 A	0.46 C

ABC= means with the same uppercase letter in the same row are not different ($p\leq$ 0.05); abc= means with the same lowercase letter in the same column are not different ($p\leq$ 0.05)

The flower component began at the cutting age of 77 days; of the three sowing densities, that of 100 000 plants ha^{-1} was the highest, with 0.46%, and those of 400 000 and 200 000 plants ha^{-1} the lowest, with 0.41% ($p\leq$ 0.05). Therefore, the lower the sowing density, the greater the flower production and, therefore, the greater the pod production, as reported by other researchers when evaluating different sowing densities in crotalaria (Ríos-Hilario *et al*., 2022).

In this sense, Abdul-Baki *et al*. (2001) state that the morphological composition is determined by the vegetative development cycle since, at the beginning, there is a higher percentage of leaves, then this decreases over time, and the stem, flower, and pod increase, as reported in this research. In this regard, Oliveira *et al*. (2020) mention that, in crotalaria, sowing density is a determining factor in morphological composition, and they indicate that, as density increases, biomass yield increases and pod production decreases. This factor could not be observed in this research because pod

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production began 98 days after emergence, and no statistical differences were found between the highest and lowest density evaluated.

Table 4 shows the percentage of CP, neutral detergent fiber, and acid detergent fiber (%) of crotalaria when varying the density of plants and cutting days. The plant density with the highest average CP was 400 000 plants ha^{-1}, with 11.04%, and the densities of 200 000 and 100 000 plants ha^{-1} had the lowest percentage, with 10.8% ($p \leq 0.05$). Regardless of plant densities, the CP was higher in the first cutting days, from 30 to 43 days, with an average of 15.58 to 10.7%, respectively, and the 56-day cutting frequency showed the lowest percentage, with 8.3% ($p \leq 0.05$).

Table 4. Crude protein, neutral detergent fiber, and acid detergent fiber (%) of crotalaria (*Crotalaria juncea* L.) grown at different densities and cutting ages.

Cutting age (days)	Crude protein (%)			Average
	400 000 (plants ha^{-1})	200 000 (plants ha^{-1})	100 000 (plants ha^{-1})	
30	16.71A a	15.86A a	14.18A a	15.58 a
43	11.2A b	10.95A a	9.94A a	10.7 b
56	8.07A c	8.2A a	8.64A a	8.3 d
70	11.64A b	8.65A a	9.51A a	9.93 c
84	8.92A bc	11.83A a	11.76A a	10.84 b
98	9.72A bc	9.12A a	10.94A a	9.93 c
Average	11.04 A	10.77 B	10.83 B	10.88
		Neutral detergent fiber (%)		
30	50.25A c	53.17A c	51.68A b	51.7 c
43	68.51A b	70.28A ab	68.87A a	69.22 b
56	72.81A ab	74.42A a	71.06A a	72.76 a
70	76.1A a	76A a	72.5A a	74.87 a
84	71.01A ab	65.84A b	63.57A a	66.81 c
98	66.73A b	71.68A ab	68.92A a	69.11 b
Average	67.59 B	68.57 A	66.1 C	67.41
		Acid detergent fiber (%)		
30	35.14A b	36.33A c	34.28A b	35.25 d
43	44.06A ab	53.44A a	53.17A a	50.22 b
56	55.04A a	56.34A a	53.53A a	54.97 a
70	57.07A a	56.11A a	53.84A a	55.67 a
84	51.9A a	46.01A b	44.71A ab	47.54 c
98	48.46A ab	54.24A a	50.88A a	51.19 b
Average	48.61 B	50.41 A	48.4 B	49.14

ABC= means with the same uppercase letter in the same row are not different ($p \leq 0.05$); abc= means with the same lowercase letter in the same column are not different ($p \leq 0.05$).

This could be due to the loss of lower leaves of the plant canopy and the increase in stems, which have a higher percentage of cellulose, hemicellulose, and lignin, which reduces the quality of the plant (Rojas-García *et al*., 2024), as shown in Table 3. Alonzo and Paniagua (2010); Godoy *et al*. (2012); Romero *et al*. (2013); Portillo *et al*. (2019); Lagunes *et al*. (2019); Maldonado-Peralta *et al*. (2023) report that they obtained higher values in percentage of protein in legumes, ranging from 28 to 14% between the cutting stages of 30 to 75 days of age. Nonetheless, Balseca *et al*. (2015) reported an average of 8.26% CP in legumes, similar to the lowest value in this research.

On the other hand, the sowing density with the highest percentage of neutral detergent fiber was 200 000 plants ha^{-1}, with 68.57% (Table 4; $p < 0.05$), and the density of 100 000 plants ha^{-1} was

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the one that showed the lowest percentage, with 66.10%. Cutting days 56 and 70 presented the highest percentage of NDF, with 72.76 and 74.87%, respectively (p< 0.05).

Researchers such as Romero *et al*. (2013); Portillo *et al*. (2019) mention in *Clitoria ternatea*, percentages lower than these results but with the same behavior of increasing as regrowth time passes, with values of NDF of 25 and 40% at 30 and 60 days after sowing, respectively.

On the other hand, Valles-De la Mora *et al*. (2014), in a report carried out on *Cratylia argentea*, obtained an average value of 57.48% of NDF, which is related to day 30 of regrowth in this research, and Lagunes *et al*. (2019); Balseca *et al*. (2015) reported 64.25% and 71% of NDF, respectively, in this same species, which coincides with days 43 to 98 of regrowth.

A similar behavior was obtained in acid detergent fiber, with the sowing density of 200 000 plants ha^{-1} having the highest percentage, with 50.41% (Table 4; p< 0.05), and those with 100 000 and 400 000 plants ha^{-1} had the lowest percentage, with an average of 48.5%. The cutting stages with the highest and lowest percentage of acid detergent fiber were at 70 and 30 days, with 55.67 and 35.25%, respectively.

In a study with *Clitoria ternatea*, Romero *et al*. (2013) reported a trend similar to this research, but lower percentages of ADF, of 18, 25, and 25% at 30, 60, and 75 days of age of the plant, respectively. Valles-De la Mora *et al*. (2014), in the rainy season in *Cratylia argentea*, obtained an average value of 37.35% of ADF. In white clover (*Trifolium repens* L.), red clover (*Trifolium pratense* L.), and vicia (*Vicia sativa* L.) in low rainfall season. Portillo *et al*. (2019) present percentages of ADF ranging from 30.1 to 38.2%. Nevertheless, Lagunes *et al*. (2019) reported a higher average value of 42.25% of ADF, similar to these results.

Conclusions

Crotalaria should be sown at a density of 400 000 plants ha^{-1} and cut after 70 days of growth since this is when the intermediate values of yield and quality are found, and it is also before flower production begins; however, for greater flower production and, therefore, greater seed production, it is at 100 000 plants ha^{-1}. It is necessary to continue studies on crotalaria concerning productive behavior in cattle and nitrogen fixation as soil recovery since it is a legume.

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Production of *Crotalaria juncea* L. at different sowing densities and cutting ages

Journal Information
Journal ID (publisher-id): remexca
Title: Revista mexicana de ciencias agrícolas
Abbreviated Title: Rev. Mex. Cienc. Agríc
ISSN (print): 2007-0934
Publisher: Instituto Nacional de Investigaciones Forestales, Agrícolas y Pecuarias

Article/Issue Information
Date received: 01 July 2024
Date accepted: 01 September 2024
Publication date: 09 October 2024
Publication date: Aug-Sep 2024
Volume: 15
Issue: 6
Electronic Location Identifier: e3338
DOI: 10.29312/remexca.v15i6.3338

Categories

Subject: Articles

Keywords:

Keywords:

crude protein

legume

yield

Counts

Figures: 0

Tables: 4

Equations: 0

References: 35

Pages: 0