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Growth rate, leaf:stem ratio, and height of crotalaria (*Crotalaria juncea* L.) at different planting densities

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ABSTRACT

Objective: To evaluate growth rate, leaf:stem ratio, and height of crotalaria (*Crotalaria juncea* L.) plants sown at different densities, in the dry tropics of the state of Guerrero, Mexico.

Design/Methodology/Approach: The treatments consisted of four planting densities: 400,000, 200,000, 100,000 plants ha^{-1}, and overseed. A growth analysis was also carried out at 30, 38, 45, 52, 60, 68, and 75 days of growth, when the pod was fully developed. The variables evaluated were: growth rate, leaf:stem ratio, plant height, and their correlation.

Results: The best growth rate (577 kg DM ha^{-1} d^{-1}) was obtained at a 400,000 plants ha^{-1} planting density, at 75 days of development. Likewise, the best plant height rate was obtained with this planting density (281 cm). Meanwhile, the leaf:stem ratio had a different behavior, obtaining its highest rate at 30 days. Regardless of the age of the plant, the following descending order was recorded: 100,000 > overseed > 200,000 > 400,000 plants ha^{-1}, with 0.65, 0.60, 0.59, and 0.55 ($p<0.05$), respectively.

Study Limitations/Implications: This is a very important study for future researches, because the crotalaria variables studied in this research have never been evaluated before and they are fundamental for forage production.

Findings/Conclusions: The recommended planting density is 400,000 plants ha^{-1}. Acceptable leaf:stem ratio and growth rate were reported at 45 days of development; the plant height reached 186 cm.

Keywords: Growth rate, height, leaf:stem, densities.

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INTRODUCTION

Cattle raising faces challenging environmental conditions in the dry tropics of Mexico (Castro-Rincón *et al.*, 2018). Livestock production is a major activity, as a result of its

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contribution to food production (SIAP, 2019). Currently, society requires food security and must produce more with less resources (FAO, 2020; SIAP, 2021); this includes the search for a solution to water shortage. This situation demands the acceleration of productive systems, through the search for alternatives that improve livestock feed efficiency (Burbano-Erazo *et al.*, 2019), using affordable technology that enables the sustainable development of rural communities (García *et al.*, 2018). Although pulses are beneficial, in most of the livestock systems their use as green manure or feed is rare (Castro *et al.*, 2017; Russelle *et al.*, 2007; Peters and Lascano, 2003). Crotalaria (*Crotalaria juncea* L.) is mainly used as vegetable coverage, green manure, environmental nitrogen-fixing plant, and as biological control for soil nematodes (Wang *et al.*, 2002; Timossi *et al.*, 2016). This genus is a pulse with a strong and bush-type development (Pereira, 2006). It is an annual crop and, on its early stages, it can regrow after its cut. The stems are fibrous and semi-woody; it has erect habits and narrow leaves, with seeds of different color, contained in pods (Silva *et al.*, 2016). In the different areas of the state of Guerrero, there are periods of food shortage. The alternative is the use of different species which —provided at different concentrations (mainly as flour)— allows producers to supplement better-quality food during the different seasons of the year. Additionally, growing crotalaria significantly improves soil quality (Lemaire et al., 2014). Therefore, the objective of this study was to evaluate growth rate, leaf:stem ratio, and plant height of crotalaria, at different planting densities, in the dry tropics of the state of Guerrero.

MATERIALS AND METHODS

Experimental plot location

The study was carried out from July to October, 2020, in an experimental plot in Tecuescontitlán, Tepecuacuilco de Trujano, Guerrero, Mexico (18° 08’ N and −99° 33’ W, a 782 m.a.s.l). The climate is subhumid warm with summer rains (790 mm annual average rainfall) and a 26 °C average temperature (García, 2004).

The soil has a 7.3 pH, 0.3 dS m^{-1}, and 2.1 % organic matter. Figure 1 shows the maximum, medium, and minimum temperatures, as well as the weekly rainfall accumulation

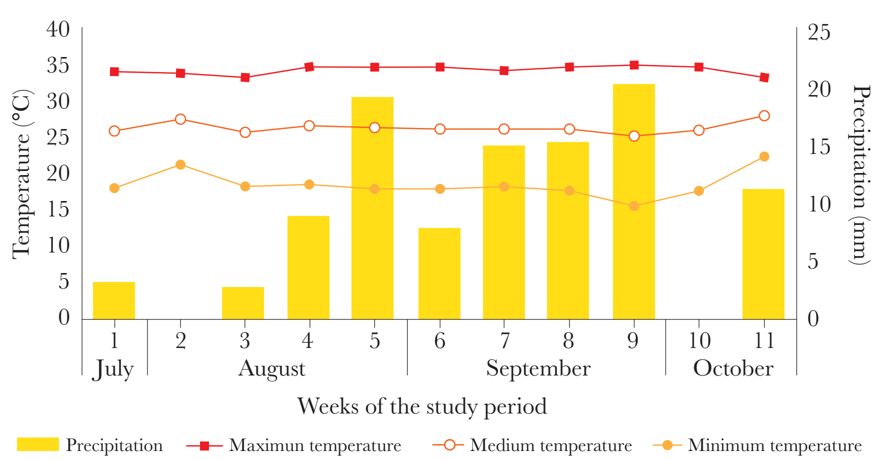

Figure 1. Maximum, medium, and minimum temperatures and weekly rainfall accumulation recorded during the experiment.

during the study period. The data were obtained from weather station 12,092, located in Tonalapa del Sur, 51 km away from the experimental plot.

Plot management

The experimental plot was established on July 30, 2020, during the rainy season. The land was prepared with traditional techniques (fallow, two harrows, and furrow). Sixteen experimental units were used; they were made up of 5 × 5 m plots —randomly distributed and with 3 repetitions. Four planting densities (treatments) were evaluated. The seeds were sown by hand, placing them in the furrows, at a depth that doubled the size of the seed. The distance between furrows was 50 cm and the distance between plants was 5, 10, and 20 cm, resulting in 400,000, 200,000, and 100,000 plants ha^{-1} per each distance. For its part, control was overseed (approximately 380,000 plants ha^{-1}). No irrigation or fertilizers were used and weed control was carried out by hand. From the 30 days after the emergence, samplings were carried out at 8-day intervals, until the plants reached their reproductive stage and had fully developed seeds.

Evaluated variables

Growth rate

Growth rate was determined dividing dry matter yield by the cutting time that passed between cuts.

Leaf:steam ratio

The leaf:stem ratio was determined dividing dry weight (kg ha^{-1} of the morphology fractions of the leaf) by the stem.

Plant height

Plant height was measured one day before each cut, using a wooden rule (cm), from the ground to the highest component of the plant. The height of 20 randomly selected plants was recorded per repetition.

Statistical analysis

The data was analyzed using a completely randomized block design, with a divided plots and three replications arrangement. The PROC GLM of SAS 9.2 (2009) was used and a comparison of the means of the treatments was carried out using the Tukey's Test (α=0.05). Potential simple regressions were carried out, comparing growth rate with the meadow height. The significance of the correlation coefficients ($p<0.05$) was calculated; an analysis of variance and a comparison of means were also carried out (Tukey: $p<0.05$).

RESULTS AND DISCUSION

Growth rate

Table 1 shows the growth rate (GR) of crotalaria, at different planting densities and cutting ages. Regardless of the cutting age, the highest and the lowest rates for this variable were obtained with 400,000 and 100,000 plants ha^{-1} planting densities, recording 317 and 66 kg ha^{-1} d^{-1}, respectively ($p<0.05$). The planting density with the highest GR was 400,000 plants ha^{-1}, at 68 and 75 days, obtaining 556 and 577 kg ha^{-1} d^{-1}, respectively. Overseed also obtained the highest values, recording 546 kg ha^{-1} d^{-1}, at the 75th cutting day. The lowest GR was obtained with the 200,000 and 100,000 plants ha^{-1} planting densities, which recorded 16 and 13 kg ha^{-1} d^{-1}, respectively ($p<0.05$).

Growth rate reflects the dry matter yield, as Tripathi *et al.* (2013) mentioned in their study about crotalaria and different spaces between plants: a higher plant yield can be obtained increasing planting density. These results match the findings of this research. Meanwhile, Richena *et al.* (2020) recorded a higher dry matter yield production and, therefore, a higher growth rate 135 days after the emergence, while pod production started 90 days after the emergence.

Leaf:stem ratio

Table 2 shows the leaf:stem ratio of crotalaria crops, at different planting densities and cutting ages. Regardless of the cutting age, this variable behaved in the following order (from highest to lowest): 100,000 > overseed > 200,000 > 400,000 plants ha^{-1}, with 0.65, 0.60, 0.59, and 0.55, respectively ($p<0.05$). Thirty days after the cutting, the highest leaf:stem ratio was obtained (1.69 average). This average diminished 86% (0.23) when the forage was cut at 75 days ($p<0.05$). The highest and the lowest leaf:stem ratio were obtained with a 100,000 plants ha^{-1} planting density, in the 30th and 75th days after the cutting, recording 2.00 and 0.13 ratios, respectively ($p<0.05$). This leaf:stem ratio trend has been recorded for several tropical pulses (Sosa *et al.*, 2008). A 1.2 average was recorded for these pulses, depending on the cutting and the season of the year. Meanwhile, Rojas-García *et al.* (2017) reported that several alfalfa varieties had a 0.88-1.55 leaf:stem ratio. Something similar happened with this tropical species, at early stages.

Plant height

Table 3 shows crotalaria height, at different planting densities and cutting ages. Regardless of planting density, the height of the plants had a significant increase during the vegetative development stage ($p<0.05$). At day 75, the 200,000 and 100,000 plants ha^{-1} planting densities recorded the shortest plants (276 and 265 cm, respectively), while

Table 1. Forage yield (kg ha^{-1} d^{-1}) of crotalaria, at different planting densities and cutting ages.

Density (plants ha^{-1})	Age at cut (days after the emergency)							Average
	30	38	45	52	60	68	75	
400,000	22 Af	90 Ae	172 Bd	315 Ac	491 Ab	556 Aa	577 Aa	317 A
200,000	16 BCf	53 Be	78 Ce	143 Bd	193 Cc	236 Cb	270 Ba	141 C
100,000	13 Ce	27 Cde	48 Dcd	64 Cbc	83 Db	113 Da	118 Ca	66 D
Overseed	18 Bg	97 Af	199 Ae	314 Ad	374 Bc	476 Bb	546 Aa	289 B
Average	17 g	67 f	124 e	209 d	285 c	345 b	378 a	

Means with the same lower-case letter in the same column (abcd) and capital letters (ABCD) in the same column are not statistically different (Tukey: $\alpha=0.05$).

Table 2. Leaf:stem ratio of crotalaria, at different planting densities and cutting ages.

Density (plants ha^{-1})	Age at cut (days after the emergency)							Average
	30	38	45	52	60	68	75	
400,000	1.27 ^{Ba}	0.85 ^{Ab}	0.49 ^{ABc}	0.45 ^{Ac}	0.28 ^{Bd}	0.27 ^{Bd}	0.27 ^{Ad}	0.55 ^{C}
200,000	1.66 ^{ABa}	0.80 ^{Ab}	0.44 ^{ABc}	0.36 ^{Bc}	0.32 ^{Ac}	0.33 ^{Ac}	0.25 ^{Ac}	0.59 ^{B}
100,000	2.00 ^{Aa}	0.72 ^{Cb}	0.69 ^{Ab}	0.47 ^{Ac}	0.30 ^{ABcd}	0.26 ^{Bcd}	0.13 ^{Bd}	0.65 ^{A}
Overseed	1.83 ^{Aa}	0.70 ^{Bb}	0.40 ^{Bbc}	0.36 ^{Bbc}	0.32 ^{Ac}	0.32 ^{Ac}	0.28 ^{Ac}	0.60 ^{B}
Average	1.69 ^{a}	0.76 ^{b}	0.50 ^{c}	0.41 ^{c}	0.30 ^{c}	0.29 ^{c}	0.23 ^{d}	

Means with the same lower-case letter in the same column (^{abcd}) and capital letters (^{ABCD}) in the same column are not statistically different (Tukey: α=0.05)

Table 3. Plant height (cm) of crotalaria, at different planting densities and cutting ages.

Density (plants ha^{-1})	Age at cut (days after the emergency)							Average
	30	38	45	52	60	68	75	
400,000	59 ^{Cf}	112 ^{Be}	186 ^{Ad}	239 ^{Ac}	267 ^{Ab}	278 ^{Aa}	281 ^{Aa}	203 ^{A}
200,000	71 ^{Af}	111 ^{Be}	174 ^{Bd}	227 ^{Bc}	235 ^{Cc}	266 ^{Bb}	276 ^{Ba}	194 ^{C}
100,000	68 ^{ABg}	114 ^{Bf}	168 ^{Be}	212 ^{Cd}	239 ^{Cc}	253 ^{Cb}	262 ^{Ca}	188 ^{D}
Overseed	66 ^{Bf}	117 ^{Ae}	185 ^{Ad}	227 ^{Bc}	251 ^{Bb}	271 ^{Ba}	278 ^{Aba}	199 ^{B}
Average	66 ^{e}	113 ^{d}	178 ^{c}	226 ^{bc}	248 ^{b}	267 ^{ab}	274 ^{a}	

Means with the same lower-case letter in the same column (^{abcd}) and capital letters (^{ABCD}) in the same column are not statistically different (Tukey: α=0.05).

the 400,000 plants ha^{-1} and overseed planting densities obtained the tallest plants (281 and 278, respectively, which are statistically equal).

Dubeux *et al.* (2019) evaluated planting densities and inoculants for crotalaria and reported heights of 200 and 300 cm, 75 days after the sowing. These values are very similar to those found in this study. Meanwhile, Sosa *et al.* (2008) reported a relationship between plant height, dry matter yield, and the coverage percentage of tropical pulses. These results are also similar to the findings of this study. Finally, Abdul-Baki *et al.* (2001) reported 220-320 cm plant heights, 100 days after sowing. These results are also similar to those recorded in this study.

Growth rate (kg ha^{-1} d^{-1}) regression equations with meadow height (cm)

Figure 2 shows the regression coefficient (R^2), between growth rate (kg ha^{-1} d^{-1}) and crotalaria leaf (%), at different planting densities. This research determined that meadow height is similar to the four associations. However, growth rate has a high variation, which depends on the planting density; in this study, the highest growth rate was recorded with a 400,000 plants ha^{-1} planting density. Overall, all regressions recorded a potential trend and a high ratio. The average R^2 ($p<0.001$) was 0.98. As a reference, a higher growth rate resulted in higher height (and vice versa) for the four planting densities of crotalaria.

These results are similar to those reported by Rojas-García *et al.* (2021), who evaluated the correlation between forage yield and meadow height in white clover with orchard grass

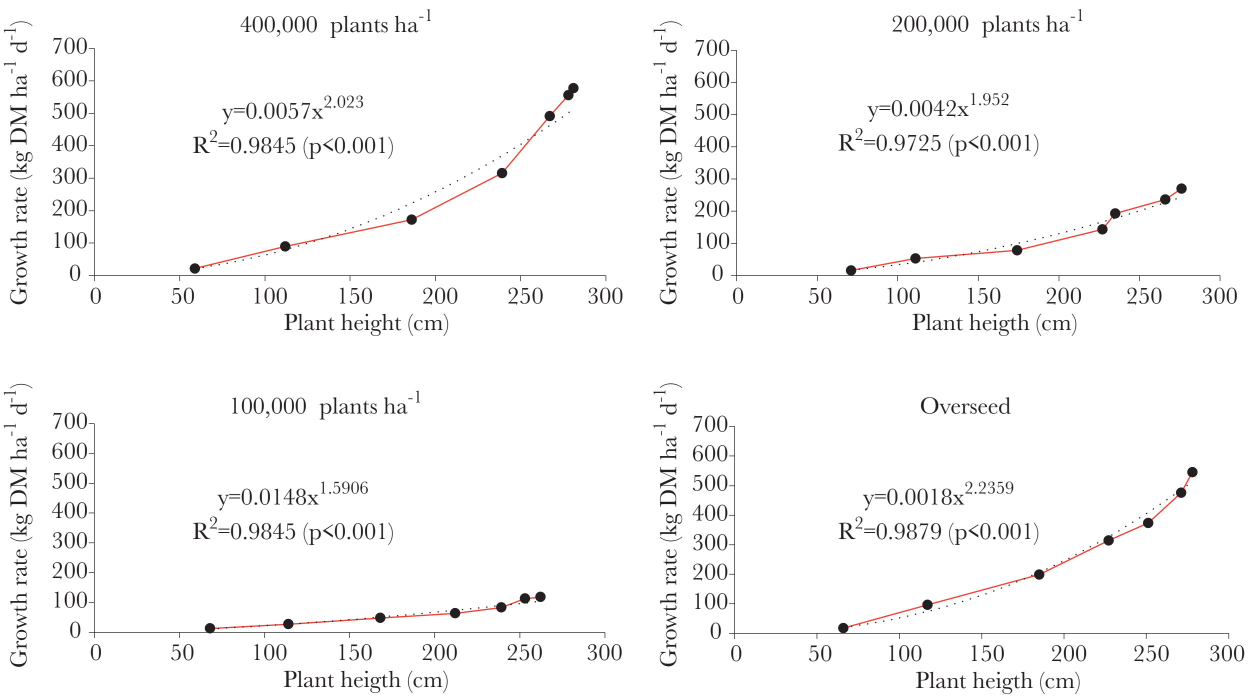

Figure 2. Regression coefficient between growth rate (kg ha^{-1} d^{-1}) and meadow height (cm) of crotalaria, at different planting densities and cutting ages.

and ryegrass. They recorded a high ratio (R^2: 0.805) ($p<0.001$), resulting in a reliable reference to determine the cutting age or grazing guidelines. Several researchers evaluated pulses and grasses and reinforced these references (Rojas *et al*., 2016; Teixeira *et al*., 2007).

CONCLUSION

The 400,000 plants ha^{-1} planting density reported an acceptable leaf:stem ratio and growth rate, at 45 days of development, recording a 186 cm height. Heigh measurement is a reliable method to determine growth rate, as a result of its high correlation.

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