

Profile of the aerial biomass of *Crotalaria pumila* Ort. accumulated in summer

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Abstract

Crotalaria pumila Ort. is a legume native to Mexico with little information about its forage potential based on its profile of accumulation during the summer, so a study was carried out with the aim of determining the total yield and the yield by component during 2021 to generate base information to decide regarding the possibility of the species as a forage species. In an area with spontaneous *C. pumila*, nine weekly samplings were carried out, in which we determined the total yield and yield by components: leaf, stem, flower, and pods, their proportional contribution to the total and number per plant and plant height. The statistical analysis was for a completely randomized design with three repetitions, the independent variable was the number of days elapsed in the summer. As the summer progressed, total and pod yields increased ($p < 0.05$), stem yield remained constant ($p > 0.05$), and leaf yield ($p < 0.05$) and the number of leaves per plant decreased, the increase in pod yield occurred with an increase ($p < 0.05$) in the number of pods per plant. The high pod yield made it possible to ensure a natural reseeding of *C. pumila*. The total yield ranged from 9 to just over 20 t ha⁻¹. The conclusion is that based on the total yield, *Crotalaria pumila* can be a forage species option.

Keywords:

native legume, pods, total yield.



Introduction

Native herbaceous plants can promote the conservation and increase of soil fertility because they show adaptation to the place and positive interaction with macro and microorganisms from this same place (Vázquez *et al.*, 1999); on the other hand, the introduced herbaceous plant species may be limited in this positive function on soil health by showing poor or no adaptation to the place, becoming invasive species and showing negative interactions with other micro and macroorganisms in the ecosystem (Schlaepfer *et al.*, 2011). Pagano (2012) recommended that when applying soil health rehabilitation protocols, the integration of native herbaceous plants into these protocols should always be validated in view of the possible advantages they may have to restore soil health.

In the management of forage areas, the integration of herbaceous or woody legumes is recommended to generate a forage supply with a larger contribution of protein and digestible matter compared to forages formed only with grasses; in addition, legumes have the ability to incorporate nitrogen present in the atmosphere into the livestock ecosystem through the process of symbiotic nitrogen fixation (Coll and Zarza, 1992). Bianco and Cenzano (2018) emphasized that in the protocols for restoring degraded ecosystems in semi-arid and subhumid environments, the integration of native legumes must be validated because they are a unique germplasm adapted to survive in those environments, they maintain biodiversity and even face the effects of climate change.

The integration of nitrogen fixed by legumes into the ecosystem can be as green manure; the legume, when reaching the maximum accumulation of aerial biomass, is cut and left on the soil to be integrated into it by plowing (Alcântara *et al.*, 2000); dead leaf and root tissues that accumulate on the soil surface, the amount of nitrogen integration by this route implies species and management that allow a high accumulation of aerial biomass (Rasmussen *et al.*, 2013); and through the feces of the animal, mainly a ruminant, which ingested legume forage rich in nitrogen content (Alonso *et al.*, 2005).

The incorporation of the nitrogen fixed by the legume into the livestock ecosystem improves the productive behavior of animals, reduces the release of enteric methane, and encourages a higher yield of accompanying forage species or in sequence, so in addition to forage yield, it is indicated to seek strategies to promote that animals reach the highest possible consumption of legume forage (Broderick, 1995; Rodríguez *et al.*, 2015).

Crotalaria pumila Ort. is a legume native to Mexico, with distribution from the south of the United States of America to South America, with presence in 27 of the 32 states of Mexico; it is an erect grass that can reach a height of up to 50 cm, its cycle is annual or perennial of short life, being native, it is not considered with potential to be invasive in the pine-oak vegetation of the Valley of Mexico located within the 2 250 to 2 350 masl. Some common names of this species are tronadora, hierba del cuervo y sonadora (Vibrans, 2009). This species has been recommended for inclusion in protocols aimed at the ecological restoration of subhumid temperate environments in Mexico (Lindig-Cisneros, 2004).

Authors such as Calderón and Rzedowski (2005) refer to *C. pumila* Ort. as an annual species commonly distributed in the Valley of Mexico associated with grassland vegetation between 2 250 and 2 350 masl. In some regions of Oaxaca, this species is used for human consumption (Manzanero-Medina *et al.*, 2020), while in Africa, the use of the genus *Crotalaria* as green manure or for intercropping has been suggested (Fischler *et al.*, 1999).

In Mexico and Central America, *C. longirostrata*, whose common name is chipilín, is a species close to *C. pumila* and is commonly used for human consumption (Schrei, 2020), so it could be expected that *C. pumila* could generate foliage of good nutritional value. The research objective was to analyze the profile of the aerial biomass, total and by component, accumulated in summer by *Crotalaria pumila* Ort.

Materials and methods

The field phase was carried out in plot J-134 Loma de San Juan, Experimental Field of the Chapingo Autonomous University, located at 19° 29' 45.8" north latitude, 98° 51' 06.1" west longitude, and 2 250 masl. The climate is Cbw₀(w)(i') g, temperate with long cool summer, the driest of the subhumids, with rains in summer, little temperature oscillation, and the hottest month occurs before the summer solstice (García, 2004).

In the mentioned plot of approximately 1 ha, three areas with similar spontaneous densities of *Crotalaria pumila* were located, each of these three areas had an approximate area of 60-70 m², the identification of the species was made based on information from USDA (2022). One sampling was carried out in each area in 2021, for a total of nine samplings, the sampling was by means of a 20 x 20 cm (0.04 m²) frame placed on a previously established zigzag trajectory to avoid placing the frame somewhere previously sampled.

In each sampling, three plants rooted within the frame were randomly collected, each one was measured height (cm), and number of leaves, stems, flowers, and pods, and these components were placed in paper bags. All *C. pumila* plants rooted within the frame were then harvested at ground level. The harvested components and plants were dried in a forced air oven at 65 °C for 72 h and weighed. For the components: leaves, stems, flowers, and pods, the contribution of each to the total dry basis yield expressed as a percentage was calculated.

The statistical analysis was through the analysis of variance (Witte, 2015) of 14 dependent variables: plant height (cm), number of leaves, stems, flowers, and pods per plant, dry basis yield in total and by component, and percentage of contribution of each component to the total yield, the independent variable was number of days elapsed since the beginning of summer (June 21), the statistical model was for a completely randomized experimental design with three repetitions, the experimental unit was each of the three areas previously identified. The summer days elapsed were calculated by subtracting 172 (Julian day of June 21) from the Julian day of the sampling date.

In the statistical analysis, the average of the three plants was used for the variable plant height; the total of the three plants was used for the variables number of leaves, stems, flowers, and pods; however, to present the values of these variables in the section of results, they were expressed per plant, which was the average of the three plants for each variable. Total yield and yield by component were analyzed as g 0.04 m⁻² (20 x 20 cm), to present them in the results, they were converted to kg ha⁻¹. In case of significant effect ($p < 0.05$), the means were separated by Tukey at $\alpha = 0.05$. Calculations were made using PROC GLM of SAS (SAS, 2011).

Results

Of the 14 dependent variables, 11 had an effect ($p < 0.05$) from the summer days elapsed (Table 1).

Table 1. Statistics on the effect of the number of days elapsed in the summer on agronomic variables of *Crotalaria pumila*.

Agronomic variable	p-value	Standard error of the mean	Coefficient of variation (%)
Total yield (g 0.04 m ⁻²)	0.0247	24.25	42.78
Percentage of leaf	<0.0001	5	19.4
Leaf yield (g 0.04 m ⁻²)	0.0384	5.09	33.99
Percentage of stem	0.0014	5	12.36
Stem yield (g 0.04 m ⁻²)	0.1395	10.76	43.95
Percentage of flower	0.0005	2	76.1
Flower yield (g 0.04 m ⁻²)	0.0006	1.19	66.18
Percentage of pod	<0.0001	7	35.7

Agronomic variable	p-value	Standard error of the mean	Coefficient of variation (%)
Pod yield (g 0.04 m ⁻²)	0.0014	11.9	77.11
Plant height	0.148	9.79	18.46
Stems per plant	0.1094	1.29	51.33
Leaves per plant	0.0351	56.1	35.35
Flowers per plant	0.0312	8.08	58.69
Pods per plant	0.0012	13.86	53.11

The proportion of the variables analyzed that showed an effect was 78%, which allows us to indicate that there were changes in the profile of the accumulation of aerial biomass in *C. pumila* as the summer progressed. The three variables that showed no change ($p > 0.05$) during the study period were: stem yield, plant height, and number of stems per plant.

The three variables associated with the impact of the stem on the profile of aerial biomass accumulation, as these characteristics of the stem remain constant throughout the summer, it can consequently be affirmed that changes in total yield throughout the summer were not associated with quantitative changes in the stem component.

Having not registered changes in the height of the plant throughout the summer and considering that this variable is partly a consequence of the elongation of the stem, it can be pointed out that this elongation reached its maximum before the beginning of summer, and with this favor the competitive ability of *C. pumila*, in relation to other plant species, for the solar energy capture factor.

The variables yield and percentage of flower and pod contribution showed wide variability coefficients of variation (Table 1), which reveals the possibility of selecting individuals with higher yield and thus generating a more productive population under the edaphic and climatic conditions in which this research was carried out. In contrast to the constant behavior of the variables associated with the stem component, the three variables associated with the leaf component did show changes ($p < 0.05$) as the summer progressed, therefore, the leaf component was one of those that determined the changes in the accumulation profile of the aerial biomass of *C. pumila* throughout the summer.

The variable of dry base total yield showed a tendency to increase while the leaf yield showed a contrary trend, it decreased as the summer progressed, the leaf yield decreased almost 50% of the measurement made towards the first third compared to that made at the end of the summer (Table 2). The proportional reduction in leaf yield, which was 50%, as the summer progressed, was greater than the proportional increase in total yield, which was 35%, during the same period.

Table 2. Total yield and yield by components of *Crotalaria pumila* throughout the summer.

Days*	Total	Leaf	Stem	Flower	Pod
	(kg ha ⁻¹)				
43	9185b	4030ab	5 060	53b	40c
50	10993ab	4538ab	5 913	223b	300c
57	11733ab	4143ab	5 195	1393a	975c
64	7128b	2695ab	3 105	135b	1175bc
71	12433ab	3838ab	5 330	475b	2775abc
78	13728ab	3763ab	7 565	20b	2375abc
85	27175a	6105a	10 438	785ab	9850a
92	19738ab	2348b	7 388	343b	9650ab
99	15453ab	2273b	5 115	520b	7525abc

*= the number of summer days elapsed was calculated based on Julian days, the sampling date in Julian days was subtracted 172, which is the Julian day of June 21, the beginning of summer; a, b, c= means in the same column with at least one letter in common are not different (Tukey, $\alpha = 0.05$)

The pod yield was the variable with the greatest variation in the study period, it was almost 250 times higher towards the last third of the summer compared to what was recorded in the first third, which could be interpreted as a strategy of the species to ensure its survival and growth in the next rainy season through seed production. The high total yield recorded at the end of the summer was associated with the high pod yield, while the stem yield remained without major changes throughout the study period (Table 2).

The total yield throughout the summer, as already indicated, showed a tendency to increase, associated with a substantial increase in pod yield, a reduction in leaf yield, and no change in stem yield. The set of these trends in the yields of the leaf, stem, and pod components allows us to point out that *C. pumila* allocates much of the energy obtained to a component associated with the reproduction and maintenance of the species, which is the pod component where the seed is found, which is, in turn, the component that allowed the persistence of the species in this environment.

In addition to the absolute values in yield of the components, it is interesting to observe the changes in the proportional contribution that these components give to the total yield. The yield of the pod component contributed 47% of the total yield at the end of the study period, that is, at 90 days after the beginning of summer, this change in the contribution of this component to the total yield implied a very relevant change if one considers that at 43 days after the beginning of the summer, the contribution of this component to the total was less than 1% (Table 3).

Table 3. Contribution (%) of each component to the aerial biomass of *Crotalaria pumila* throughout the summer.

Days*	Leaves	Stems	Flowers	Pods
43	44.6 a	54.3 a	0.53 b	0.54 c
50	43.3 a	52.9 ab	1.5 b	2.34 c
57	34.8 ab	44.9 abc	12.66 a	7.66 c
64	39.4 a	44.3 abc	1.85 b	14.48 c
71	31.4 abc	43.1 abc	3.69 b	21.81 bc
78	28.9 abcd	52.5 ab	0.13 b	18.42 bc
85	22.1 bcd	38.3 bc	3.14 b	36.44 ab
92	13 d	38.3 bc	1.66 b	46.99 a
99	17.3 cd	32.9 c	5.64 ab	44.1 a

*= the number of summer days elapsed was calculated based on Julian days, the sampling date on Julian days was subtracted 172, which is the Julian day of June 21, the beginning of summer; a, b, c= means in the same column with at least one letter in common are not different (Tukey, $\alpha= 0.05$).

The stem component had a greater contribution to yield towards the early part of the summer, with more than 50%, compared to the end of the summer when it contributed to the total yield with approximately 30%. The fall in the contribution of the stem to the total yield could be explained by the influence of the pod yield on the total (Table 3).

One possible implication is that *C. pumila* allocated captured energy and carbon dioxide to seed formation as a survival and colonization strategy of the area in the next growing or rainy season. A situation associated with the fact that the contribution of the leaf component, which is the factory of photo-assimilated and supplier of raw material for the formation of plant tissue, to the total yield decreased towards the end of the summer, contributing less than 20% of the total yield.

Throughout the summer, the plant height remained unchanged, with an average of 50 cm, the smallest variation in plant height resulted in stability in the number of stems per plant, 2.5 stems per plant on average (Table 4). This is an indicator that the plants of this species have a limited growth to favor the production of seeds rather than the accumulation of plant tissue in the leaf and stem.

Table 4. Plant height and presence per plant of components of aerial biomass in *Crotalaria pumila* during the summer.

Days*	Height	Leaves	Stems	Flowers	Pods
	(cm)	(number per plant)			
43	48	121.9 b	4.4	11.7 ab	3.9 c
50	47	189.1 ab	3.6	9.1 ab	8.1 c
57	46	139 ab	2.4	15.9 ab	12.7 bc
64	51	110.5 b	1.5	12.3 ab	14.8 bc
71	49	158.2 ab	2.1	16.8 ab	29.6 abc
78	53	173.6 ab	2.6	20.4 ab	28.9 abc
85	60	253.2 a	2.2	24.4 a	57.5 a
92	70	130.9 ab	1.1	5.8 b	33.7 abc
L99	L52	L151.9 ab	L2.7	L7.4 ab	L45.9 ab

*= the number of summer days elapsed was calculated based on Julian days, the sampling date on Julian days was subtracted 172, which is the Julian day of June 21, the beginning of summer; a, b, c= means in the same column with at least one letter in common or without letters are not different (Tukey, $\alpha=0.05$).

The numbers of leaves and flowers per plant varied throughout the summer; however, it is difficult to indicate a definite trend as the summer progressed (Table 4), possibly due to the presence of individuals in different stages of development at the same date, as a strategy of the species to adapt to possible annual and seasonal environmental variations and avoid the risk of extinction of the species.

Unlike the number of leaves and flowers per plant, the number of pods showed a sustained increase from the beginning to the end of summer, increasing almost 15 times from 43 to 85 days after the beginning of summer (Table 4). This strong increase in the number of pods per plant was associated with significant increases in yield and proportional contribution to the total yield (Tables 2 and 3).

Discussion

In general, the agronomic characteristics evaluated in *Crotalaria pumila* presented wide variability at the same sampling date, particularly in the components flower and pod, key parts of the species for reproduction and survival in natural conditions, which requires the existence of individuals with different stages of development (Galindo-Pacheco and Clavijo-Porras, 2009).

Flowering was profuse between 60 and 80 days after the beginning of summer, prior to unfavorable conditions for growth, as a strategy to escape conditions of lack of water for the formation and development of the seed (Fuhlendorf and Engle, 2001). The existence of a span with abundant flowering in *C. pumila* is an indicator of the species' strategy to produce enough seed, a seed bank, with relative uniformity in physiological maturity for greater germination potential in the next growing season (Grace *et al.*, 2019).

The total yield increased as the summer progressed, in the first sampling at 43 days after the beginning of the summer, *C. pumila* reached a total yield slightly higher than 9 t ha^{-1} , a level of yield that makes it a forage option if it is considered that in some forage cereals, such as oats and triticale, total yields between 7 and 12 t ha^{-1} have been recorded, in some cases under irrigation conditions (Velasco-López *et al.*, 2020). Absolute data of total yield greater than 15 t ha^{-1} should be taken with caution; Sadeghi *et al.* (2013) warn that in the measurement of agronomic variables, the area of the sampling unit may over or underestimate the real value; however, the data obtained are useful for comparative purposes, considering that the size of the sampling unit is constant for all treatments.

In the monitoring of 9 perennial forage grasses, Faji *et al.* (2022) emphasize the importance of considering, as a criterion of choice between forage species, the total yield and the height of the plant, since the latter is related to the yield, as well as the changes that occur in the components leaf and stem as they influence the quality of the forage and therefore its potential as feed for livestock. The quantitative monitoring throughout the summer of the variables analyzed in this research was pertinent to the process of generating information to determine the forage potential of *C. pumila*.

The profile of accumulation of aerial biomass in *C. pumila* as the summer progressed and, with it, the advance in the maturity of the plants can be considered contrasting to several species commonly used as forages. Kebede *et al.* (2013), when monitoring five species of vetch (legumes) throughout the growing season, found constant increases in plant height and stem contribution as the growing season progressed, the increase in stem implied a strong reduction in the leaf:stem ratio, in the case of *C. pumila* it was found that plant height and contribution of the stem component did not show changes from the beginning to the end of the study period.

To determine the forage potential of *C. pumila*, it remains in the future to measure the quality of the forage produced in terms of crude protein contents, digestibility and fiber, and acceptance by livestock. Being a legume, the concentration and types of tannins in the foliage are also relevant when defining its forage potential, tannins depending on the concentration and type can have a positive effect on the performance of ruminants (Mueller-Harvey *et al.*, 2019), after an extensive review of the subject, highlight that when evaluating legumes as a source of food for ruminant cattle, in addition to measuring the introduction of nitrogen into the ecosystem; through the process of symbiotic fixation of atmospheric nitrogen, the quality of the foliage in contribution of protein and digestibility, the content and type of tannins present in the plant tissue throughout the growing season must be determined since some can have a positive effect on the use of the feed and the health status of the ruminant that ingests the forage.

Conclusions

In this study, *Crotalaria pumila* Ort., a legume native to Mexico, based on the total yield of aerial biomass during the summer and grown under rainfed conditions, showed forage potential for sites in the Valley of Mexico since it reached a yield similar to other forage options such as oats and other small grain cereals, common crops in the area where the study was conducted.

It is also important to highlight that there is the possibility of self-reseeding as it reached a high production of pods, a component that managed to be the one with the largest contribution to the total biomass accumulated towards the end of summer. *Crotalaria pumila* at the end of the summer, the accumulation of stem was less than that of other components, such as the leaf, which allowed us to indicate that in the aspect of quality of the forage, the contribution of stem is not important.

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Profile of the aerial biomass of *Crotalaria pumila* Ort. accumulated in summer

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