



Foliar mineral content of five shrub species with nutritional potential for small ruminants in semiarid regions in northeastern Mexico

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ABSTRACT: This study was conducted to determine the monthly composition of the minerals Ca, P, K, Mg, Cu, Fe, Mn and Zn in five shrub species that are consumed by small ruminants in the semi-arid regions of northeastern Mexico. Leaves samples of shrub species; *Celtis pallida*, *Croton suaveolens*, *Forestiera angustifolia*, *Guaiaacum angustifolium* and *Parkinsonia aculeata* were randomly collected during twelve consecutive months from July 2018 to June 2019 in two sites, located in Linares and Los Ramones counties, in the state of Nuevo Leon, Mexico. Mineral content was analyzed using an atomic absorption spectrophotometer, while phosphorus was measured by the colorimetry method. The Linares county showed the highest content of macro- and micro-minerals. Among species, *C. pallida* showed the highest values of macro-minerals and *P. aculeata* content of micro-minerals was highest. Ca (total mean = 40.0 g kg⁻¹ DM), K (15.4 g kg⁻¹), Mg (3.7 g kg⁻¹), Fe (87.2 mg kg⁻¹), Mn (35.5 mg kg⁻¹) were available in adequate quantities, while P (1.3 g kg⁻¹ DM), Cu (6.4 mg kg⁻¹) and Zn (17.7 mg kg⁻¹) were found deficient. Shrub species in this study can be considered as a good source of Ca, K, Mg, Fe and Mn except in *C. suaveolens*. However, P, Cu and Zn must be supplemented.

Key words: grazing animals, leaves, nutritional requirements.

Conteúdo mineral foliar de cinco espécies de arbustos com potencial nutricional para pequenos ruminantes em regiões semiáridas do nordeste do México

RESUMO: O presente estudo foi realizado com o intuito de determinar os teores dos minerais Ca, P, K, Mg, Cu, Fe, Mn e Zn, ao longo do ano, em cinco espécies de arbustos consumidas por pequenos ruminantes nas regiões semiáridas do nordeste do México. Amostras de folhas de espécies arbustivas; *Celtis pallida*, *Croton suaveolens*, *Forestiera angustifolia*, *Guaiaacum angustifolium* e *Parkinsonia aculeata* foram coletadas aleatoriamente durante doze meses consecutivos, de Julho de 2018 a Junho de 2019, em dois locais, nos municípios de Linares e Los Ramones, no estado de Nuevo Leon, México. O conteúdo mineral foi analisado através de um espectrofotômetro de absorção atômica, enquanto o fósforo foi medido pelo método da colorimetria. O município de Linares apresentou o maior conteúdo de macro e microminerais. Entre as espécies, *C. pallida* apresentou os maiores valores de macrominerais, enquanto o teor de microminerais foi maior na *P. aculeata*. Ca (média = 40.0 g kg⁻¹ MS), K (15.4 g kg⁻¹), Mg (3.7 g kg⁻¹), Fe (87.2 mg kg⁻¹), Mn (35.5 mg kg⁻¹) estavam disponíveis em quantidades adequadas, enquanto P (1.3 g kg⁻¹ MS), Cu (6.4 mg kg⁻¹) e Zn (17.7 mg kg⁻¹) foram encontrados deficientes. As espécies arbustivas deste estudo podem ser consideradas uma boa fonte de Ca, K, Mg, Fe e Mn, exceto na espécie *C. suaveolens*. No entanto, P, Cu e Zn devem ser suplementados.

Palavras-chave: animais em pastagem, folhas, necessidades nutricionais.

INTRODUCTION

The plant species distributed in the northeastern region of Mexico, which are categorized into several groups based on their ecological adaptations and forest use, constitute the type of vegetation

namely, Tamaulipan Thornscrub. It covers about 125,000 km² from the coastal plain of the Gulf of Mexico to the southern riviera of Texas in the United States of America (FOROUGHBAKHCH, 1992; FOROUGHBAKHCH et al., 2005; DOMÍNGUEZ-GÓMEZ et al., 2012). The vegetation of this area,

consists of small trees and shrubs of almost 60 woody species (LUDWIG et al., 1975; DOMÍNGUEZ-GÓMEZ et al., 2012), many of them important in forestry and silvopastoral production (wood, poles, firewood, fodder, charcoal, medicine, etc.), which are the most common known uses as documented by ESTRADA-CASTILLÓN et al. (2018). Livestock production based on grazing occurs mainly in arid and semi-arid regions, on land traditionally considered unsuitable for crop production, containing woody and shrubs plants relevant as potential fodder source (ESTELL et al., 2012), which contain satisfactory levels of protein and minerals for grazing ruminants, while maintaining or improving grassland availability (RAMÍREZ-ORDUÑA et al., 2005; GUERRERO-CERVANTES et al., 2012; HABIB et al., 2016; DERERO & KITAW, 2018). Many trees and shrubs of leguminous species of the semi-arid regions are used as feed especially due to the behavior in extensive grazing by goats and sheep (SANON et al., 2007) and also by wild ruminants, since shrub species remain green and with a relatively high nutrient content throughout the year (GUERRERO-CERVANTES et al., 2008). The shrubs *Celtis pallida* Torr. (Family *Ulmaceae*), *Croton suaveolens* Torr. (Family *Euphorbiaceae*), *Forestiera angustifolia* Torr. (Family *Oleaceae*), *Guaiacum angustifolium* Engelm. (Family *Zygophyllaceae*) and *Parkinsonia aculeata* L. (Family *Leguminosae*) apparently do not contain in their leaves compounds with negative side effects (SCHINDLER et al., 2003; SALEM et al., 2014). However, sometimes they may have imbalanced mineral concentrations, knowledge of their mineral composition and correct supplementation is crucial (HABIB et al., 2016), since they are consumed in different percentages throughout the year (MEYER et al., 1984; RAMÍREZ et al., 1997).

The present study hypothesized that leaves of native shrubs of northeastern Mexico represent an important feed and mineral resource for small ruminants such as goats, sheep and white-tailed deer, under extensive production systems when pastures have poor quality due to seasonal variation. The leaves of these plants may be an alternative that has not been studied sufficiently and could represent a valuable emergency feed resource.

The aim of this study was to determine the monthly foliar concentration of Ca, P, K, Mg, Cu, Fe, Mn and Zn of five native shrubs, throughout the year at two study sites in northeastern Mexico and to estimate if they have the potential to meet the mineral requirements of small ruminants.

MATERIALS AND METHODS

The studied vegetation was sampled at two sites located in the state of Nuevo Leon, Mexico, in the municipalities of Linares and Los Ramones, whose physical characteristics are: Site 1, Linares; the area of study was established within the Experimental Campus of the College of Forest Sciences of the Autonomous University of Nuevo Leon, located in Linares municipality (24° 47' 45'' N; 99° 32' 31'' W; 350 meters above sea level). The climate is subtropical and semi-arid with a warm summer (GONZÁLEZ-RODRÍGUEZ et al., 2004). The monthly average ambient temperature recorded during the experimental period ranged from 14.1 °C in January to 30.4 °C in August. Annual registered rainfall was 554 mm.

Site 2, Los Ramones; the area of study was established in "El Abuelo Ranch" in Los Ramones municipality, with an area of 100 ha and an altitude of 200 meters above sea level. The geographical location is 25° 39' 46'' N; 99° 27' 51'' W. Climate is semi-arid with warm summer (GONZÁLEZ-RODRÍGUEZ et al., 2004). The average monthly ambient temperature during the study varied from 14.3 °C in January to 31.5 °C in August. The annual recorded rainfall was approximately 667 mm.

Experimental plots (50 m x 50 m) representative of each study site, were established without disturbance. Leaf tissue samples from five randomly selected individuals representative of each of the five species of shrub plants in this study were sampled: *Celtis pallida*, *Croton suaveolens*, *Forestiera angustifolia*, *Guaiacum angustifolium* and *Parkinsonia aculeata* were collected at a height of 1 m to 1.5 m from the ground, at monthly intervals from July 2018 to June 2019.

The collected material was dried for 24 h at 55 °C in a forced air oven (Felisa®, Model FE-292AD, Mexico), in the Laboratory of Chemistry and Plant Physiology of the College of Forest Sciences, the leaves were separated from the branches. Once the foliar samples were identified by month, species and site, they were ground in a Thomas Willey mill (Thomas Scientific Apparatus, Model 3383) using a No. 60 mesh (1 mm x 1 mm), and the ground samples were stored in plastic bags.

Dry matter content (DM) of the leaves samples was determined in quintuplicate, weighing 1.0 g of sample, which was dried at 100 °C for 24 h in a forced air oven (Felisa®, Model FE-292AD, Mexico). The organic matter (MO, %) and ash (%) content was determined by incinerating the

sample at 550 °C for 3 h 30 min by using a furnace (Thermo scientific, Model F48010, U.S.A.). The ashes were used to determine macro-minerals (Ca, Mg and K; g kg⁻¹ DM) and micro-minerals (Cu, Fe, Mn and Zn; mg kg⁻¹ DM) by atomic absorption spectrophotometry (AOAC, 1997), using a spectrophotometer (model PinAAcle 900F, Perkin Elmer). The phosphorus content was measured by the colorimetry method (AOAC, 1997), using a UV-Visible spectrophotometer (model Lambda 1A, Perkin-Elmer).

To measure the influence of temperature and precipitation at each site, automated HOBO sensors (HOBO Pro Temp / RH Series, Forestry Suppliers, Inc., Jackson, MS, USA) were installed to record hourly environmental variables such as temperature of the air (°C) and relative humidity (%). The daily amount of rainfall (mm) was quantified using a Davis brand automated rain gauge, connected to a HOBO Event Onset recorder.

Statistical analysis

The statistical analysis of variance and mean comparison of the observed data for each mineral were analyzed by a completely randomized design with a factorial arrangement, with 5 species, two sites and 12 months as factors, and considering double and triple interactions. Statistical analyses were performed by using the SPSS statistical analysis software (SPSS for Windows, Version 22.0, Chicago, IL, USA).

RESULTS

Macro (Ca, P, K and Mg) and trace minerals (Cu, Fe, Mn and Zn) were significantly different between sites (except Fe), months and species. The double and triple interactions were also significant. Rainfall, relative humidity and temperature recorded during the study are shown in table 1. None of the quantified minerals were significantly correlated, with rainfall, relative humidity and temperature recorded during the period of study.

The Ca content was higher in Linares, compared to Los Ramones. All species showed the highest Ca content in the month of June. *C. pallida* had the highest concentrations, while *C. suaveolens* had the lowest values (Table 2). Los Ramones and the species *P. aculeata* and *G. angustifolium* showed higher and lower concentrations in P, respectively (Table 3). The highest concentration of P was recorded for samples collected in March, while those harvested in July and August were the lowest. Potassium content was higher in leaf samples from Los Ramones site. Regardless of location, the sampled leaves showed the highest K content during April and the lowest level in August. *C. suaveolens* had the highest K content; *G. angustifolium* showed the minimum (Table 4). The magnesium content was higher in leaf samples of the species in Los Ramones. All shrubs showed higher Mg values in November and lower in December. *C. pallida* generally had the highest Mg content, while *P. aculeata* had the lowest (Table 5).

Table 1 - Monthly mean temperature (T, °C), relative humidity (RH, %) and rainfall (mm) registered at the research sites.

Month	-----Linares-----			-----Los Ramones-----		
	T (°C)	RH (%)	Rainfall (mm)	T (°C)	RH (%)	Rainfall (mm)
July-2018	30.1	61.3	16.8	31.0	59.4	50.5
August	30.4	59.2	7.6	31.5	55.1	0.0
September	26.7	79.8	230.5	27.8	77.2	304.0
October	21.5	90.0	24.8	22.8	82.4	23.6
November	15.9	86.2	8.3	16.4	77.9	7.4
December	14.4	80.4	23.4	15.3	69.7	8.9
January-2019	14.1	81.9	35.1	14.3	77.2	20.8
February	18.2	73.8	5.1	18.6	69.2	0.3
March	19.5	76.5	58.4	19.8	73.9	42.7
April	24.0	61.9	2.8	24.4	60.6	1.0
May	27.2	76.3	85.3	27.8	74.9	171.7
June	29.6	68.8	56.6	30.3	69.8	36.1
			554.7*			667.0*

*Accumulated rainfall (mm).

Table 2 - Monthly foliar Ca content (g kg⁻¹ dry matter) in five shrubs species from northeastern Mexico sampled at two study sites from July 2018 to June 2019. Data represents the mean (n=5).

Site	-----Linares-----					-----Los Ramones-----						
Month	<i>C. p.</i>	<i>C. s.</i>	<i>F. a.</i>	<i>G. a.</i>	<i>P. a.</i>	<i>C. p.</i>	<i>C. s.</i>	<i>F. a.</i>	<i>G. a.</i>	<i>P. a.</i>	Mean	SEM
July	62.5	11.2	12.8	45.0	25.0	40.3	11.4	8.7	31.5	16.2	26.5	0.9
August	52.5	9.7	10.6	45.8	19.5	48.8	11.2	16.3	53.4	24.8	29.3	0.9
September	113.3	13.3	16.7	83.5	34.2	94.5	15.1	16.9	50.9	27.5	46.6	0.9
October	73.0	19.9	19.4	89.3	26.4	80.5	15.8	15.2	78.9	18.5	43.7	0.9
November	86.4	16.8	19.6	91.7	27.0	101.6	14.7	16.0	63.2	15.9	45.3	0.9
December	58.5	22.6	24.9	61.4	36.0	65.0	19.5	19.5	53.2	16.2	37.7	0.9
January	64.6	25.3	24.7	52.6	30.0	62.6	22.6	23.2	54.9	17.9	37.8	0.9
February	64.6	25.1	17.2	58.1	24.1	57.8	17.4	22.5	52.4	17.0	35.6	0.9
March	91.2	20.5	23.3	52.3	17.5	73.6	33.5	47.0	54.2	32.4	44.6	0.9
April	80.7	19.7	10.9	40.5	7.3	65.2	13.6	12.7	58.1	7.4	31.6	0.9
May	132.6	19.0	13.0	53.2	18.9	130.9	14.0	12.6	71.7	19.4	48.5	0.9
June	120.4	23.5	18.1	77.2	37.6	121.8	16.2	15.9	79.1	20.1	53.0	0.9
Mean	83.4	18.9	17.6	62.6	25.3	78.6	17.1	18.9	58.5	19.4	40.0	
SEM	0.9	0.8	0.8	0.9	0.8	0.9	0.8	0.8	0.8	0.8		
Site mean	-----41.5-----					-----38.5-----						
SEM	-----0.3-----					-----0.3-----						
Factors	---Month (A)---	Site (B)		--Species (C)--		A x B	-----A x C-----	-----B x C-----		----A x B x C----		
p	-----***-----	***		-----***-----		***	-----***-----	-----***-----		-----***-----		

C. p.; *Celtis pallida*, *C. s.*; *Croton suaveolens*, *F. a.*; *Forestiera angustifolia*, *G. a.*; *Guaiacum angustifolium*, *P. a.*; *Parkinsonia aculeata*.

SEM, standard error of the mean.

***Significant at 0.001 level, **significant at 0.01 level.

Table 3 - Monthly foliar P content (g kg⁻¹ dry matter) in five shrubs species from northeastern Mexico sampled at two study sites from July 2018 to June 2019. Data represents the mean (n=5).

Site	-----Linares-----					-----Los Ramones-----						
Month	<i>C. p.</i>	<i>C. s.</i>	<i>F. a.</i>	<i>G. a.</i>	<i>P. a.</i>	<i>C. p.</i>	<i>C. s.</i>	<i>F. a.</i>	<i>G. a.</i>	<i>P. a.</i>	Mean	SEM
July	1.06	1.09	0.94	0.79	1.42	1.33	1.35	1.00	0.78	1.54	1.13	0.01
August	0.84	1.30	0.79	0.97	1.36	1.09	0.92	0.91	0.66	1.21	1.00	0.01
September	0.99	1.24	0.84	0.78	1.07	1.19	1.65	1.09	0.76	1.88	1.15	0.01
October	1.46	1.64	1.08	0.95	2.00	1.48	1.37	1.19	0.81	2.00	1.40	0.01
November	1.43	1.28	0.98	0.89	1.59	1.17	1.05	1.01	0.82	1.63	1.18	0.01
December	1.21	1.29	0.90	0.82	1.25	1.18	1.04	1.26	0.90	1.74	1.16	0.01
January	1.18	1.39	1.08	0.80	1.49	1.19	1.06	1.08	0.83	1.54	1.16	0.01
February	1.35	1.52	1.64	0.71	1.49	1.28	1.25	1.75	0.72	1.60	1.33	0.01
March	0.87	2.02	1.38	1.77	2.46	1.57	1.43	1.63	1.61	2.80	1.75	0.01
April	1.73	1.76	1.03	1.50	2.52	1.80	1.77	1.39	1.09	2.02	1.66	0.01
May	1.34	1.76	0.99	1.06	1.97	1.59	1.99	1.14	0.80	1.77	1.44	0.01
June	1.20	1.49	1.04	0.95	1.39	1.46	1.26	1.00	0.70	1.75	1.22	0.01
Mean	1.22	1.48	1.06	1.00	1.67	1.36	1.34	1.20	0.87	1.79	1.30	
SEM	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01		
Site mean	-----1.29-----					-----1.31-----						
SEM	-----0.01-----					-----0.01-----						
Factors	Month (A)	Site (B)		Species (C)		A x B	-----A x C-----	-----B x C-----		----A x B x C----		
p	-----***-----	**		-----***-----		***	-----***-----	-----***-----		-----***-----		

C. p.; *Celtis pallida*, *C. s.*; *Croton suaveolens*, *F. a.*; *Forestiera angustifolia*, *G. a.*; *Guaiacum angustifolium*, *P. a.*; *Parkinsonia aculeata*.

SEM, standard error of the mean.

***Significant at 0.001 level, **significant at 0.01 level.

Table 4 - Monthly foliar K content (g kg⁻¹ dry matter) in five shrubs species from northeastern Mexico sampled at two study sites from July 2018 to June 2019. Data represents the mean (n=5).

Site	-----Linares-----					-----Los Ramones-----						
Month	<i>C. p.</i>	<i>C. s.</i>	<i>F. a.</i>	<i>G. a.</i>	<i>P. a.</i>	<i>C. p.</i>	<i>C. s.</i>	<i>F. a.</i>	<i>G. a.</i>	<i>P. a.</i>	Mean	SEM
July	13.9	14.8	24.4	5.0	11.9	20.3	21.0	16.1	6.1	11.8	14.5	0.4
August	14.4	12.2	13.7	5.8	13.3	16.6	16.0	15.6	6.6	11.7	12.6	0.4
September	13.4	13.3	13.8	4.6	11.3	15.9	20.9	16.0	7.7	12.2	12.9	0.4
October	22.5	25.9	16.3	4.1	13.7	14.1	23.7	21.7	6.9	14.7	16.4	0.4
November	16.5	19.9	11.8	4.1	12.1	12.7	24.0	23.0	7.1	16.5	14.8	0.4
December	22.5	23.7	13.9	4.6	11.4	17.3	23.1	21.5	10.0	17.8	16.6	0.4
January	19.6	18.1	18.5	8.9	14.9	14.2	15.4	18.0	12.4	15.7	15.6	0.4
February	22.6	15.0	19.4	8.7	12.9	17.0	15.7	17.4	8.6	17.0	15.4	0.4
March	19.7	19.7	20.9	11.2	14.9	14.2	18.2	17.5	14.1	16.9	16.7	0.4
April	19.8	22.9	18.2	11.2	15.8	18.4	23.2	22.8	11.1	14.3	17.8	0.4
May	18.0	17.6	16.4	7.8	14.0	19.4	20.7	15.0	10.5	12.8	15.2	0.4
June	21.8	20.9	21.5	7.5	15.2	17.5	21.7	18.9	9.2	12.0	16.6	0.4
Mean	18.7	18.6	17.4	7.0	13.5	16.5	20.3	18.6	9.2	14.5	15.4	
SEM	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3		
Site mean	-----15.0-----					-----15.8-----						
SEM	-----0.1-----					-----0.1-----						
Factors	Month (A)	Site (B)	Species (C)	A × B	A × C	B × C	A × B × C					
p	***	***	***	***	***	***	***					

C. p.; *Celtis pallida*, *C. s.*; *Croton suaveolens*, *F. a.*; *Forestiera angustifolia*, *G. a.*; *Guaiacum angustifolium*, *P. a.*; *Parkinsonia aculeata*.

SEM, standard error of the mean.

***Significant at 0.001 level, **significant at 0.01 level.

Table 5 - Monthly foliar Mg content (g kg⁻¹ dry matter) in five shrubs species from northeastern Mexico sampled at two study sites from July 2018 to June 2019. Data represents the mean (n=5).

Site	-----Linares-----					-----Los Ramones-----						
Month	<i>C. p.</i>	<i>C. s.</i>	<i>F. a.</i>	<i>G. a.</i>	<i>P. a.</i>	<i>C. p.</i>	<i>C. s.</i>	<i>F. a.</i>	<i>G. a.</i>	<i>P. a.</i>	Mean	SEM
July	6.5	2.7	2.4	4.4	3.3	6.8	3.8	2.7	3.9	2.2	3.9	0.1
August	6.0	2.3	2.4	4.6	2.0	7.9	3.5	3.3	4.5	1.9	3.9	0.1
September	7.2	2.7	2.7	5.8	2.8	8.1	3.9	2.8	4.3	2.1	4.2	0.1
October	6.7	4.4	3.2	5.5	2.2	8.1	3.9	3.0	4.8	2.4	4.4	0.1
November	5.9	4.2	3.7	5.8	2.5	8.4	3.3	3.3	5.1	2.2	4.4	0.1
December	3.4	2.5	2.5	4.1	1.7	7.1	2.4	2.3	3.4	1.5	3.1	0.1
January	5.8	2.5	2.0	2.3	1.6	6.8	2.6	3.4	3.8	1.9	3.3	0.1
February	4.6	3.3	1.8	3.4	1.5	5.8	2.7	3.1	3.7	1.4	3.1	0.1
March	5.8	2.5	1.7	3.0	1.6	6.9	3.4	2.5	2.3	1.8	3.1	0.1
April	5.5	2.7	1.5	2.3	1.5	6.9	3.9	2.4	3.4	1.5	3.2	0.1
May	6.2	2.8	1.2	2.7	1.6	8.2	3.3	1.6	3.7	2.1	3.3	0.1
June	6.3	2.8	2.4	3.9	2.0	8.0	3.9	2.7	4.7	2.3	3.9	0.1
Mean	5.8	2.9	2.3	4.0*	2.0*	7.4	3.4	2.8	4.0*	1.9*	3.7	
SEM	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1		
Site mean	-----3.4-----					-----3.9-----						
SEM	-----0.0-----					-----0.0-----						
Factors	Month (A)	Site (B)	Species (C)	A × B	A × C	B × C	A × B × C					
p	***	***	***	***	***	***	***					

C. p.; *Celtis pallida*, *C. s.*; *Croton suaveolens*, *F. a.*; *Forestiera angustifolia*, *G. a.*; *Guaiacum angustifolium*, *P. a.*; *Parkinsonia aculeata*.

SEM, standard error of the mean.

***Significant at 0.001 level, **significant at 0.01 level. *Site factor were not significant between same shrub species.

The Cu content (Table 6) was higher in leaf samples from the site of Linares compared to Los Ramones. Shrubs sampled in March showed the highest Cu content of the year, while concentrations were lower in samples collected in January. *P. aculeata* and *C. suaveolens* had a similar Cu content and were higher than *C. pallida*. The Fe content of *C. suaveolens* exhibited the highest values (Table 7), January leaf samples had the highest while July showed the lowest concentrations. Manganese content was higher in *P. aculeata* followed by *F. angustifolia*, in addition, a higher Mn content was recorded in foliar samples of the Linares site than in the samples of shrubs collected in Los Ramones, which were generally lower. During August, lower values were recorded, while in January they were higher (Table 8). The zinc content was highest in March, while the lowest was recorded in September among the species studied. The highest level of Zn was reported in *F. angustifolia*, while *C. pallida* recorded the lowest levels. Higher concentrations of Zn were observed in foliar samples at Los Ramones site (Table 9).

DISCUSSION

The calcium content was higher in Linares, compared to Los Ramones, this contrasts with that reported by DOMÍNGUEZ-GÓMEZ et al. (2014), also *C. pallida* had highest concentrations in our study. It seems that regardless of location, species or months, the foliar content of Ca (total mean = 40.0 g kg⁻¹) exceeded the requirement recommended by NRC (2007) for adult white-tailed deer, sheep and goats (5.1, 3.0, 5.3 g kg⁻¹ DM for Ca, severally). Probably the high Ca content in these sites is due to the fact that the soil, is a calcisol with high pH (CANTÚ et al., 2018). The high Ca concentrations contained in soil will eventually be reflected in the leaves of the plants (FAN et al., 2019). High calcium content in plants consumed by ruminants in extensive grazing in semi-arid regions were also reported by HABIB et al. (2016) in Pakistan and by GUERRERO-CERVANTES et al. (2012) in northern Mexico.

In the present study regardless of shrub species, sampling month or site the content of P (total mean = 1.3 g kg⁻¹ DM), was insufficient to meet the

Table 6 - Monthly foliar Cu content (mg kg⁻¹ dry matter) in five shrubs species from northeastern Mexico sampled at two study sites from July 2018 to June 2019. Data represents the mean (n=5).

Site	-----Linares-----					-----Los Ramones-----							
Month	<i>C. p.</i>	<i>C. s.</i>	<i>F. a.</i>	<i>G. a.</i>	<i>P. a.</i>	<i>C. p.</i>	<i>C. s.</i>	<i>F. a.</i>	<i>G. a.</i>	<i>P. a.</i>	Mean	SEM	
July	7.4	6.1	3.9	2.4	12.6	4.9	6.7	3.8	3.4	7.6	5.9	0.2	
August	4.5	6.7	3.2	2.6	12.9	5.5	5.5	3.7	4.9	7.8	5.7	0.2	
September	4.6	6.9	4.0	2.7	8.0	4.9	7.8	4.4	3.5	8.1	5.5	0.2	
October	7.7	10.4	5.3	3.2	13.3	5.7	6.4	5.1	3.2	8.4	6.9	0.2	
November	5.6	10.8	5.5	3.2	12.7	6.7	6.4	6.0	6.1	6.0	6.9	0.2	
December	4.3	12.8	4.0	2.6	7.6	5.0	6.0	4.0	4.2	4.2	5.5	0.2	
January	4.7	9.7	3.5	2.2	9.0	4.5	6.1	3.7	5.5	4.2	5.3	0.2	
February	7.0	9.7	5.8	2.0	9.3	4.2	5.3	7.3	4.6	3.7	5.9	0.2	
March	3.8	11.1	5.7	7.0	9.2	7.3	7.8	6.8	10.6	6.7	7.6	0.2	
April	7.9	10.6	4.8	5.0	9.4	9.3	9.1	5.0	7.1	7.3	7.5	0.2	
May	6.0	8.8	4.2	3.7	10.4	8.7	8.7	4.0	7.5	9.5	7.1	0.2	
June	7.4	7.9	3.8	3.4	10.5	7.5	6.9	4.0	5.6	9.6	6.7	0.2	
Mean	5.9	9.3	4.5	3.3	10.4	6.2	6.9	4.8	5.5	6.9	6.4		
SEM	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2			
Site mean	-----6.7-----					-----6.1-----							
SEM	-----0.1-----					-----0.1-----							
Factors	---Month (A)---		Site (B)	---Species (C)---		A × B		-----A × C-----		-----B × C-----		---A × B × C---	
p	-----***-----		***	-----***-----		***		-----***-----		-----***-----		-----***-----	

C. p.; *Celtis pallida*, *C. s.*; *Croton suaveolens*, *F. a.*; *Forestiera angustifolia*, *G. a.*; *Guaicum angustifolium*, *P. a.*; *Parkinsonia aculeata*.

SEM, standard error of the mean.

***Significant at 0.001 level, **significant at 0.01 level.

Table 7 - Monthly foliar Fe content (mg kg⁻¹ dry matter) in five shrubs species from northeastern Mexico sampled at two study sites from July 2018 to June 2019. Data represents the mean (n=5).

Site	-----Linares-----					-----Los Ramones-----						
Month	<i>C. p.</i>	<i>C. s.</i>	<i>F. a.</i>	<i>G. a.</i>	<i>P. a.</i>	<i>C. p.</i>	<i>C. s.</i>	<i>F. a.</i>	<i>G. a.</i>	<i>P. a.</i>	Mean	SEM
July	60.9	73.8	56.0	94.0	94.3	93.9	71.9	55.4	58.6	57.5	71.6	2.4
August	74.8	92.3	50.9	94.0	99.3	81.0	89.7	72.1	94.1	70.4	81.8	2.4
September	74.8	142.6	74.6	92.1	121.6	63.8	109.4	79.4	83.2	68.3	90.9	2.4
October	56.4	59.2	67.7	113.6	124.7	63.6	64.8	79.9	81.2	69.3	78.0	2.4
November	75.9	59.8	65.2	102.3	99.6	61.2	95.6	60.6	97.3	48.1	76.6	2.3
December	72.1	76.0	68.1	94.9	125.3	63.7	129.0	54.5	89.6	53.8	82.7	2.4
January	71.0	136.2	94.7	80.5	116.2	75.8	176.6	96.1	122.0	75.3	104.4	2.6
February	66.8	127.9	72.5	91.5	112.3	78.7	171.4	112.6	108.8	75.3	101.8	2.6
March	99.6	97.5	65.9	130.1	71.5	109.7	135.5	85.2	112.9	78.5	98.6	2.5
April	65.6	96.2	43.9	86.2	74.1	93.1	150.1	68.3	103.0	68.6	84.9	2.3
May	75.2	146.1	64.7	93.6	120.9	94.4	117.0	71.1	96.8	83.4	96.3	2.3
June	74.4	66.2	58.7	139.1	97.3	59.5	48.5	44.1	137.8	65.1	79.1	2.3
Mean	72.3	97.8	65.2	101.0	104.8	78.2	113.3	73.3	98.8	67.8	87.2	
SEM	2.0	2.0	2.1	2.0	2.0	2.0	2.1	2.0	2.0	1.9		
Site mean	-----88.2-----					-----86.3-----						
SEM	-----0.9-----					-----0.9-----						
Factors	---Month (A)---		Site (B)	---Species (C)---		A × B	-----A x C-----		-----B x C-----		--A x B x C--	
p	-----***-----		NS	-----***-----		***	-----***-----		-----***-----		-----***-----	

C. p.; *Celtis pallida*, *C. s.*; *Croton suaveolens*, *F. a.*; *Forestiera angustifolia*, *G. a.*; *Guaiacum angustifolium*, *P. a.*; *Parkinsonia aculeata*.

SEM, standard error of the mean.

***Significant at 0.001 level, **significant at 0.01 level, NS, Not significant.

requirements of mature small ruminants; 2.7, 2.8 and 2.6 g kg⁻¹ DM of P, for sheep, goats and white-tailed deer, severally by NRC (2007) and indicated that there is a problem with the source and use of phosphorus. The low P content in native plants that grow in semi-arid regions of northern Mexico was also reported by GUERRERO-CERVANTES et al. (2012), RAMÍREZ et al. (2010) and DOMÍNGUEZ-GÓMEZ et al. (2014). Thus, according to this situation phosphorus supplementation for small ruminants in semi-arid regions to meet their requirements its recommends by MAHMOOD et al. (2014).

The obtained results derived in a Ca:P ratio of 40:1, was higher compared to wide Ca:P ratios reported by RAMÍREZ et al. (2010). According to WILKENS et al. (2012), there are differences among ruminant species in the mechanisms to maintain Ca homeostasis, whereas small ruminants have mechanisms that help them to adapt diets with low P levels (HUBER et al., 2002). Apparently, goats, sheep and white-tailed deer can adapt to high proportions of Ca:P without being affected in their metabolism (RAMÍREZ, 1999).

Although, the content of K (total mean = 15.4 g kg⁻¹ DM) varied between sites, species and months, this macronutrient was present in enough quantities to meet the growth requirements (6.5, 4.6 and 4.6 g kg⁻¹ DM for K), for goats, sheep, and white-tailed deer, respectively by NRC (2007), except *G. angustifolium* (4.1 g kg⁻¹ DM) during October and November in Linares site. In the present study, the foliar content of K was generally three times the requirement for small ruminants. These results are consistent with those reported by DERERO & KITAW (2018), where potassium was the macro-mineral with the second highest concentration after Ca in fodder tree species in pastoral and agro-pastoral areas in eastern Ethiopia. DOMÍNGUEZ-GÓMEZ et al. (2014), reported similar results in semi-arid regions in northeastern of Mexico and HABIB et al. (2016), in arid and semi-arid rangelands of northern Pakistan and suggested that sodium supplementation, could avoid deficiencies caused by high concentrations of K.

All species, except *P. aculeata* (1.4 g kg⁻¹ DM) in Los Ramones site and *F. angustifolia* (1.2 g

Table 8 - Monthly foliar Mn content (mg kg⁻¹ dry matter) in five shrubs species from northeastern Mexico sampled at two study sites from July 2018 to June 2019. Data represents the mean (n=5).

Site	-----Linares-----					-----Los Ramones-----						
Month	<i>C. p.</i>	<i>C. s.</i>	<i>F. a.</i>	<i>G. a.</i>	<i>P. a.</i>	<i>C. p.</i>	<i>C. s.</i>	<i>F. a.</i>	<i>G. a.</i>	<i>P. a.</i>	Mean	SEM
July	34.7	13.5	44.2	30.4	57.6	32.4	24.1	19.6	27.4	23.8	30.8	0.9
August	34.8	12.1	30.7	28.4	40.1	25.3	18.3	22.3	34.0	39.3	28.5	0.9
September	43.7	13.1	38.4	40.1	55.4	35.9	25.1	24.3	32.6	52.5	36.1	0.9
October	26.4	21.5	57.3	34.5	48.2	44.9	22.1	29.2	26.2	32.8	34.3	0.9
November	22.9	18.8	78.6	35.6	49.6	29.8	16.7	19.6	32.0	25.3	32.9	1.0
December	32.8	28.3	78.9	47.9	64.2	29.3	25.3	36.9	51.3	38.1	43.3	0.9
January	25.9	25.9	54.3	30.9	70.3	45.7	27.4	46.6	48.7	38.9	41.4	1.0
February	32.9	26.2	58.3	36.3	64.6	35.8	22.5	46.0	59.2	48.1	43.0	1.0
March	52.5	23.4	50.0	36.3	31.8	33.3	22.4	26.4	26.6	31.0	33.4	0.9
April	32.4	21.1	37.8	31.1	40.9	24.2	28.4	22.4	21.6	33.2	29.3	0.9
May	33.6	23.8	33.6	31.4	56.6	27.0	28.0	25.1	34.4	43.8	33.8	0.9
June	29.2	18.5	37.9	41.1	59.9	36.6	28.1	32.3	47.0	55.9	38.6	0.9
Mean	33.5*	20.5	50.0	35.3*	53.3	33.3*	24.0	29.2	36.7*	38.6	35.5	
SEM	0.8	0.8	0.9	0.8	0.9	0.8	0.8	0.8	0.8	0.8		
Site mean	-----38.5-----					-----32.4-----						
SEM	-----0.4-----					-----0.4-----						
Factors	---Month (A)---		Site (B)	---Species (C)---		A × B	-----A × C-----		-----B × C-----		--A × B × C--	
p	***		***	***		***	***		***		***	

C. p.; *Celtis pallida*, *C. s.*; *Croton suaveolens*, *F. a.*; *Forestiera angustifolia*, *G. a.*; *Guaiacum angustifolium*, *P. a.*; *Parkinsonia aculeata*.

SEM, standard error of the mean.

***Significant at 0.001 level, **significant at 0.01 level. *Site factor were not significant between same shrub species.

kg⁻¹ DM) in Linares site during February and May, respectively, contained enough foliar Mg (total mean = 3.7 g kg⁻¹ DM) throughout the year to meet the metabolic requirements by NRC (2007) of adult sheep (1.5 g kg⁻¹ DM of Mg). Otherwise, *P. aculeata* (1.5 g kg⁻¹ DM) in both sites and *F. angustifolia* (1.5 g kg⁻¹ DM) in Linares site during April showed insufficient levels to meet requirements for goats and white-tailed deer (1.6 g kg⁻¹ DM of Mg). Similar results were reported by RAMÍREZ et al. (2001) in 14 native shrubs of northeastern Mexico. RAMÍREZ et al. (2010) and DOMÍNGUEZ-GÓMEZ et al. (2014) for 6 and 4 native shrubs of northeastern Mexico, respectively, also argued that the low Mg content in winter months could be due to the low temperatures. In the present study, the average temperature during December and February ranged from 14.3 °C to 18.2 °C. These lowest monthly temperatures recorded, could explain why the lowest Mg levels were found in these months during the study.

In general, the studied species contained insufficient amounts of foliar Cu (total mean = 6.4 mg kg⁻¹ DM). However, adequate contents were present

unevenly in all the shrubs species throughout the year. The species *C. suaveolens* (Linares site mean = 9.3 mg kg⁻¹ DM) and *P. aculeata* (Linares site mean = 10.4 mg kg⁻¹ DM) showed sufficient levels of foliar Cu to meet the requirements of small ruminants in adult range (9.0 mg kg⁻¹ DM of Cu, for sheep, goats and white-tailed deer), in general by NRC (2007). This result agreed with reports of RAMÍREZ et al. (2010) and GUERRERO-CERVANTES et al. (2012), in native species consumed by small ruminants in semi-arid regions of northeastern and northern Mexico, during the spring months. RAMÍREZ et al. (2001) explained that the highest Cu content observed is based on the seasonal pattern of plant growth, about which growth rates appeared to be higher during the spring season in this region. According to RAMÍREZ-ORDUÑA et al. (2005), low Cu levels in shrubs might be caused because the high pH of soil in semi-arid regions of Baja California Sur, Mexico.

In all shrub species studied, Fe (total mean = 87.2 mg kg⁻¹ DM) concentrations exceeded the requirements by NRC (2007), for grazing ruminants (50 mg kg⁻¹ DM of Fe, for sheep, goats

Table 9 - Monthly foliar Zn content (mg kg⁻¹ dry matter) in five shrubs species from northeastern Mexico sampled at two study sites from July 2018 to June 2019. Data represents the mean (n=5).

Site	-----Linares-----					-----Los Ramones-----						
Month	<i>C. p.</i>	<i>C. s.</i>	<i>F. a.</i>	<i>G. a.</i>	<i>P. a.</i>	<i>C. p.</i>	<i>C. s.</i>	<i>F. a.</i>	<i>G. a.</i>	<i>P. a.</i>	Mean	SEM
July	9.6	14.2	23.8	7.7	24.5	11.0	11.4	24.1	14.9	22.4	16.4	0.5
August	6.1	9.7	13.8	6.6	17.2	10.8	7.4	27.5	8.3	15.4	12.3	0.5
September	5.2	8.3	15.4	2.0	9.1	6.4	8.3	20.2	9.8	14.2	9.9	0.5
October	5.7	10.0	22.9	2.1	16.0	6.4	6.2	21.6	7.9	13.4	11.2	0.5
November	7.1	11.8	34.1	1.9	14.0	8.1	5.0	36.5	12.1	17.1	14.8	0.5
December	9.3	17.7	30.4	5.0	14.1	8.6	8.0	37.9	10.7	15.1	15.7	0.5
January	8.4	14.4	30.2	6.8	14.5	8.8	10.2	47.0	19.0	14.1	17.3	0.5
February	11.3	15.7	43.7	5.6	14.0	6.0	9.1	70.3	10.4	15.1	20.1	0.5
March	10.1	31.1	32.8	14.1	40.0	18.5	19.5	48.4	35.1	39.2	28.9	0.5
April	18.8	22.8	28.9	11.2	25.6	20.2	19.3	38.9	16.8	22.8	22.5	0.5
May	17.6	19.5	28.4	10.5	22.6	19.7	23.8	30.2	19.4	27.4	21.9	0.5
June	15.7	16.1	28.1	9.3	20.5	18.7	15.1	36.0	23.9	32.8	21.6	0.5
Mean	10.4	15.9	27.7	6.9	19.4	11.9	11.9	36.5	15.7	20.8	17.7	
SEM	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5		
Site mean	-----16.1-----					-----19.4-----						
SEM	-----0.2-----					-----0.2-----						
Factors	---Month (A)---		Site (B)	---Species (C)---		A × B	-----A x C-----		-----B x C-----		--A x B x C--	
p	-----***-----		***	-----***-----		***	-----***-----		-----***-----		-----***-----	

C. p.; *Celtis pallida*, *C. s.*; *Croton suaveolens*, *F. a.*; *Forestiera angustifolia*, *G. a.*; *Guaiaacum angustifolium*, *P. a.*; *Parkinsonia aculeata*.

SEM, standard error of the mean.

***Significant at 0.001 level, ** significant at 0.01 level.

and white-tailed deer). Satisfactory Iron levels for small ruminants have been reported by RAMÍREZ-ORDUÑA et al. (2005), GUERRERO-CERVANTES et al. (2012) in northern Mexico and by HABIB et al. (2016) in semi-arid rangelands of Pakistan.

All species, with the exception of *C. suaveolens* (Linares site mean = 20.5 Mn mg kg⁻¹ DM and Los Ramones site mean = 24.0 Mn mg kg⁻¹ DM), contain enough Mn content in leaves (total mean = 35.5 mg kg⁻¹) to meet the requirements by NRC (2007) of adult small ruminants (30 mg kg⁻¹ DM of Mn, for sheep, goats and white-tailed deer). GUERRERO-CERVANTES et al. (2012), reported low levels of Mn in shrub leaves of northern Mexico. The low level of Mn in August in this study could be associate to dry season, also reported for native small trees and shrubs growing in different rangelands of Mexico by RAMÍREZ et al. (2006). Also, the high foliar content of Ca may increase Mn requirements, due to the probable obstruction of Mn absorption (RAMÍREZ et al., 2010).

The shrub species of this study did not show consistent concentrations of Zn (total mean =

17.7 mg kg⁻¹ DM) to meet the requirements by NRC (2007), for adult small ruminants (40, 45 and 45 mg kg⁻¹ DM of Zn, for sheep, goats and white-tailed deer, separately). Acceptable concentrations for sheep were registered in *F. angustifolia* in the months of January (Los Ramones site 47.0 mg kg⁻¹ DM), February (Linares site = 43.7 mg kg⁻¹ DM and Los Ramones site = 70.3 mg kg⁻¹ DM) and March (Los Ramones site = 48.4 mg kg⁻¹ DM). In the case of *P. aculeata*, only in March (Linares site 40.0 mg kg⁻¹ DM) acceptable values were registered for sheep, according to our results March showed the highest levels of Zn, previous studies showed that this situation generally occurred in tropical shrubs during spring season (HASSEN et al., 2007). Similar levels of Zn were reported by RAMÍREZ et al. (2010) and DOMÍNGUEZ-GÓMEZ et al. (2014) in native plants of northeastern Mexico. These authors argued that only some species can meet the requirements of adult ruminants during certain seasons of the year. In the same way, HABIB et al. (2016) reported that only certain species contain adequate levels of Zn for grazing small ruminants in semi-arid regions of northern Pakistan.

CONCLUSION

The species *C. pallida* showed the best levels of macro-minerals, while *P. aculeata* had the highest levels of micro-minerals. The shrub species in this study can be considered a good source of Ca, K, Mg, Fe and Mn except in *C. suaveolens*. However, P, Cu and Zn must be supplemented to meet the metabolic requirements of small ruminants in extensive grazing, in areas where they consume these shrubs. Furthermore, feeding and silvopastoral-agroforestry studies are required to select the best shrub species to ensure its efficient adaptability and acceptance by small ruminants in semiarid rangeland of northeastern Mexico.

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DECLARATION OF CONFLICT OF INTERESTS

The authors state that there is no conflict of interest with any financial organization regarding the material discussed in the manuscript.

AUTHORS' CONTRIBUTIONS

HGR and MCE conceived and designed experiments. MCE performed the experiments, carried out the lab analyses and performed statistical analyses of experimental data. MVGM supervised statistical analyzes of experimental data. MCE, ICS, HBB and HGR prepared the draft of the manuscript. All authors critically revised the manuscript and approved of the final version.

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