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MINERAL CONTENT IN FOUR BROWSE SPECIES FROM NORTHEASTERN MEXICO

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Abstract

The aim of the present study was to determine and compare macro (Ca, K, Mg, Na and P) and micro (Cu, Fe, Mn and Zn) nutrient foliar content in *Acacia amentacea* (DC.), *Celtis pallida* (Torr.), *Forestiera angustifolia* (Torr.) and *Parkinsonia texana* (A. Gray). Leaf samples were collected monthly from January throughout December 2009 in China, Linares and Los Ramones counties in the state of Nuevo Leon, Mexico. All nutrients were significantly different among sites, months and species; double and triple interactions were also significant. Among sites, samples from Los Ramones County showed the higher macronutrient content, followed by China and Linares. As for species, *Celtis pallida* showed the highest values while *A. amentacea* had the lowest macronutrient content. Micronutrient content showed the following decreasing order: China>Los Ramones>Linares. *Parkinsonia texana* was characteristically the most abundant in micronutrient content, while, *A. amentacea* was the poorest in this respect. Regardless of species, site or timing, Ca (total mean = 30 g kg^{-1}), K (15; except *A. amentacea*), Mg (5.2; except *A. amentacea*), Na (1.9; only *F. angustifolia*), Fe (100 mg kg^{-1}), Mn (51; only *F. angustifolia*) and Zn (35; except *A. amentacea*) were determined to be present in suitable amounts to meet nutritional requirements of range ruminants, while Na (1.9; except *F. angustifolia*), P (1.3 g kg^{-1}) and Cu (6 mg kg^{-1}) were marginally deficient throughout the year.

Introduction

The Tamaulipan Thornscrub (TT) vegetation that belongs to the semiarid region of the state of Nuevo Leon in northeastern Mexico is mainly composed by native plant species that consist by diverse perennial and deciduous shrubs and small trees (Reid *et al*., 1990). The plants are characterized by a wide range of growing patterns, leaf longevity, growing dynamic and contrasting phenological development (McMurtry *et al*., 1996, González-Rodriguez *et al.*, 2010). Most plant species provide habitat to wildlife (González-Rodriguez & Cantu-Silva, 2001) and offer good quality forage, high in protein, fiber, vitamins and essential fatty oils for domestic and range small ruminants (Moya-Rodríguez *et al*., 2002).

Browse shrubs *Acacia amentacea* DC., *Parkinsonia texana* (A. Gray) S. Watson, *Forestiera angustifolia* Torr., and *Celtis pallida* Torr., are important components of TT (Ramírez-Lozano, 2012). They are known to be well adapted to water stress by means of tissue dehydration avoidance mechanisms, and by the power to seasonally adjust their morpho-physiological traits (as evidenced, for example, by leaf folding and retention) in order to cope successfully with changes in soil water availability, thus allowing them to avoid internal desiccation and, consequently, to maintain high water potential values under drought conditions (González-Rodriguez & Cantu-Silva, 2001; Fardous *et al.*, 2011). In addition, these shrubs contribute to maintain relatively high ecosystem productivity coefficients through active nitrogen fixation and considerable photosynthetic activity, as shown by high photosynthetic pigment concentrations (Uvalle-Sauceda *et al*., 2008). In addition, these natural resources represent important animal feed resources which are consumed by range livestock, particularly by range small ruminants, and wildlife (Ramírez-Lozano, 2012); yet, little is known about their mineral content. Therefore, the objective of this study was to determine the monthly macro- (Ca, K, Mg, Na and P) and micro-nutrient (Cu, Fe, Mn and Zn) concentrations from foliar tissue of 4 native shrubs during a whole year in three different Counties of the state of Nuevo Leon, in northeastern Mexico.

Material and Methods

This study was carried out at three sampling locations in the state of Nuevo Leon, in northeastern Mexico. The first site was ranch "El Abuelo" (100 ha) in Los Ramones County (25º 40' N; 99º 27' W) at 200 masl; climate in the location is semiarid with warm summer; annual mean temperature is 22ºC and annual mean precipitation averages 700 mm. The second site was ranch "Zaragoza" (300 ha) in China County (25º 31' N; 99º 16' W), at 200 masl; weather is dry and warm throughout the year; annual temperature and precipitation average 22ºC and 500 mm, respectively. The third site was located at the Campus of the Faculty of Forest Sciences (500 ha), Universidad Autónoma de Nuevo León (24º 47' N; 99º 32' W) in Linares County, 370 masl; here annual precipitation is 800 mm and annual mean temperature averages 22.3ºC (Reid *et al*., 1990). In general, the three study sites share a similar climatic pattern with similar peaks of maximum rainfall during May, June and September. The main type of vegetation in the area is known as the Tamaulipan Thornscrub or Subtropical Thornscrub Woodlands (SPP-INEGI, 1986). The most abundant species are *Helietta parvifolia, Diospyros palmeri, Prosopis laevigata, Acacia amentacea, A. farnesiana, A. greggii, A. berlandieri, Cordia boissieri, Fraxinus greggii, Forestiera angustifolia, Havardia pallens, Ebenopsis ebano, Leucophyllum texanum, Guaiacum angustifolium,* among others (Alanís *et al.*, 1996). Dominant soils are deep, dark-gray, lime-gray, lime-clay Vertisols, rich in montmorillonite, which shrinks and swells noticeably in response to changes in soil moisture content (INEGI, 2002). During this study, annual precipitation and mean temperature were: at Los Ramones= 205 mm and 23.7ºC; at Zaragoza = 249 mm and 24.1ºC, and at Faculty Campus = 570 mm, 22.8°C, respectively.

Representative and undisturbed experimental plots (50 m x 50 m) were marked at each site. From January through December of 2009 mature leaves and twigs were sampled monthly (800 g/sample) at browse high (1.0 to 1.5 m) from five randomly selected representative plants (Montgomery, 2004) of four shrub species: *A. amentacea*, *P. texana*, *F. angustifolia* and *C. pallida*. Once samples had been dried at room temperature leaves were separated from twigs and grounded in a Thomas Willey mill (Thomas Scientific Apparatus, Model 3383) using a mesh (1 mm x 1 mm); milled material was stocked in labeled plastic vials.

Triplicate samples of each plant species were used for mineral analyses using a wet digestion procedure (Cherney, 2000). Samples were incinerated in a muffle (550ºC) during 5 hours, after which, ashes were digested in a solution of HCl and HNO_3 (10:1; v/v). Contents of Ca, Mg, K, Na, Cu, Fe, Mn and Zn were determined by atomic absorption spectrophotometry using a Varian Spectrophotometer (model SpectrAA-200), while P was quantified spectrophotometrically using a Perkin-Elmer spectrophotometer (model Lamda 1A, AOAC, 1990). Mineral data was statistically analyzed using one-way analysis of variance on a factorial arrangement with 3 sites, 12 months and 4 plant species as factors of variation. Simple linear correlation analyses were performed between mineral content and climate variables. All applied statistical analysis were computed using the Statistical Package for Social Sciences (SPSS; 2004).

Results and Discussion

Macro (Ca, K, Mg, Na, and P) and micro mineral (Cu, Fe, Mn and Zn) content were significantly different among sites, months and species; double and triple interactions were also significant. None of the minerals quantitated significantly correlated with either rainfall or temperature registered during the study. Ca content was higher at Los Ramones, followed by China and Linares, across species. All species showed highest Ca content in October, *P. texana* at the top, followed by *C. pallida, A. amentacea* and *F. angustifolia* (Table 1). Calcium is an essential component of plant cell wall offering support, rigidity and vigor to plant tissues. It seems that regardless of location, species or month, foliar Ca content exceeded metabolism requirements of range sheep, goats and white-tailed deer (5.1, 3.0, 5.3 g of Ca kg^{-1} of diet DM, respectively, NRC, 2007). Similar findings were reported by Hussain & Durrani (2008) in shrubs from Pakistan, and by Guerrero-Cervantes *et al*., (2012) in native shrubs from northeastern and north Mexico, respectively. In this study, the high content of Ca across species may relate to the high calcium carbonate content and high pH found in soils (Tripathi & Karim, 2008).

Potassium concentration was highest in leaf samples from China County followed by those from Linares and Los Ramones, regardless of species. Similarly, all leaf samples regardless of location showed highest K content values during September, while lowest in December. *Forestiera angustifolia* had the highest K content followed by *P. texana, C. pallida* and *A. amentacea* (Table 2). Although K content varied among sites, species and though the year, this macronutrient was present in sufficient amounts to meet the requirements of growing range small ruminants (6.5, 4.6 and 4.6 g of K kg^{-1} of diet DM, respectively, NRC, 2007). Likewise, Akrout *et al*., (2010) reported high K content in eight shrubs, and argued that all had concentrations above the required dietary level for feeding animals. McDowell (2003) reported that high K concentrations in leaf tissue might be due to the inherent mobility of this mineral and its tendency to accumulate in young leaf tissue when it is absorbed. In this study, K foliar content was generally 10 times the requirement by range small ruminants (NRC, 2007); an important observation that must be considered as a potential problem, since K interferes with Na retention and with absorption and utilization of Mg (McDowell, 2003).

Magnesium content was similar in leaf samples across species in China and Linares Counties and higher than those from any shrub in Los Ramones county. All shrubs showed highest Mg values in January and lowest in December. *Parkinsonia texana* was generally the highest in Mg content, followed by *F. angustifolia, C. pallida* and *A. amentacea* (Table 3). Except for December, all species contained enough foliar Mg through the year to meet metabolic requirements (NRC, 2007) of adult range sheep, goats and white-tailed deer (1.5, 1.6, 1.6 g of Mg kg^{-1} of diet DM, respectively). Similar results were reported by Moya-Rodriguez *et al*., (2002) for eight native shrub species from northeast Mexico, as well as by Barnes *et al*., (1990) for eighteen shrubs in Texas, USA, and by Cerrillo-Soto *et al*., (2004), who reported on esophageal samples of range goats browsing in semiarid lands of north Mexico. The low Mg content in winter might be due to low temperature (range from 1.5°C to 15°C), particularly in December; McCoy *et al*., (1993) have shown that as winter sets in, Mg is translocated from senescent foliar tissue through the phloem and, consequently foliar concentration drops. In addition, Mayland & Wilkinson (1989) observed that high K concentration inhibits Mg translocation to upper parts of the plant.

Sodium content in all shrub species was higher in China County followed by Linares and Los Ramones counties. Highest and lowest foliar Na content across species was recorded in January and December, respectively. In general, *Forestiera angustifolia* showed highest Na content followed by *P. texana, C. pallida* and *A. amentacea* (Table 4). Except for *F. angustifolia* (in Los Ramones and China), all shrubs in all locations and months were marginally deficient in Na to meet metabolic requirements of adult range ruminants (1.0, 0.8, 1.1 g of Na kg^{-1} of diet DM for sheep, goats and white-tailed deer, respectively; NRC, 2007). Each plant species has the ability to absorb and transport sodium (Tester & Davenport, 2003). In this study, except for *F. angustifolia*, all plants can be considered as non-Na accumulators. In this latitude, Na is considered as the most limiting mineral ion for animal needs (Whitehead, 2000).

Table 1. Monthly content of Ca (g kg^{-1} DM) in four shrub species in three county sites in 2009.

Month	Counties												Mean	SEM
	China				Linares				Los Ramones					
	a.a.	c.p.	f.a.	p.t.	a.a.	c.p.	f.a.	p.t.	a.a.	c.p.	f.a.	p.t.		
January	23	66	27	33	19	80	29	27	21	70	25	26	37	1.5
February	19	56	25	31	10	56	9	21	23	60	20	25	29	2.9
March	12	42	25	35	11	60	11	32	8	48	23	24	28	2.7
April	15	32	15	26	18	46	12	21	20	31	27	36	25	1.7
May	17	42	14	31	19	49	13	31	17	53	10	32	27	2.4
June	23	47	15	25	20	68	14	27	20	40	13	39	29	2.7
July	16	31	12	32	23	68	12	30	20	41	20	36	28	2.6
August	14	34	10	29	25	56	14	29	19	36	10	36	26	2.2
September	13	43	17	17	17	48	20	30	21	44	15	28	26	2 .0
October	15	69	12	24	24	94	20	32	14	67	15	25	34	2.1
November	30	78	14	33	23	84	25	40	25	71	17	48	41	2.1
December	21	52	13	25	22	93	21	24	22	62	29	27	34	2.3
Mean	18	49	17	28	19	67	17	29	19	52	19	32	30	1.7
SEM	0.8	2.3	1.1	1.2	0.9	2.5	1.0	0.8	0.8	2.9	1.0	0.9		
Effects	Sites (A)		Months (B)		Species (C)	A x B		A x C	B x C		A x B x C			
Probability	<0.001		<0.001		<0.001	<0.001		<0.001	<0.001		<0.001			

a.a. = *Acacia amentacea;* c.p. = *Celtis pallida;* f.a. = *Forestiera angustifolia*; p.t. = *Parkinsonia texana;* SEM= standard error of the mean

Table 2. Monthly means of K (g kg^{-1} DM) concentration in four shrub species in three county sites in 2009.

Month	Counties												Mean	SEM
	China				Linares				Los Ramones					
	a.a.	c.p.	f.a.	p.t.	a.a.	c.p.	f.a.	p.t.	a.a.	c.p.	f.a.	p.t.		
January	6	13	37	12	6	13	11	10	6	11	47	13	15	2.1
February	7	19	53	8	10	14	19	12	5	14	43	13	18	2.4
March	10	15	43	13	11	12	19	13	13	15	49	13	19	2.1
April	8	15	20	12	9	17	15	16	8	16	46	11	16	1.6
May	7	9	14	10	9	16	14	12	8	12	14	10	11	0.5
June	6	9	17	11	7	13	15	13	7	18	58	12	16	2.2
July	8	17	35	10	8	24	15	14	7	15	15	13	15	1.3
August	7	11	12	10	7	14	12	9	9	13	24	7	11	0.8
September	9	19	48	16	8	15	12	15	5	14	44	17	19	2.2
October	8	18	20	18	9	15	15	19	8	16	12	15	14	0.7
November	9	19	17	16	7	12	13	9	9	19	20	11	14	0.8
December	6	15	13	11	6	16	9	12	7	16	11	10	11	0.6
Mean	8	15	27	12	8	15	14	13	8	15	32	12	150	0.5
SEM	0.4	0.5	2.8	0.5	0.2	0.6	2.4	0.5	0.3	0.5	0.5	0.5		
Effects	Sites (A)		Months (B)		Species (C)	A x B		A x C	B x C		A x B x C			
Probability	<0.001		<0.001		<0.001	<0.001		<0.001	<0.001		<0.001			

a.a. = *Acacia amentacea;* c.p. = *Celtis pallida;* f.a. = *Forestiera angustifolia*; p.t. = *Parkinsonia texana;* SEM= standard error of the mean

Table 3. Monthly concentrations of Mg (g kg^{-1} DM) in four shrub species in three county sites in 2009.

Month	Counties												Mean	SEM
	China				Linares				Los Ramones					
	a.a.	c.p.	f.a.	p.t.	a.a.	c.p.	f.a.	p.t.	a.a.	c.p.	f.a.	p.t.		
January	1.5	10.3	22.0	5.1	1.0	5.5	4.7	4.8	1.8	13.1	16.8	3.5	7.5	1.1
February	1.0	10.1	18.4	6.7	0.9	9.0	1.9	2.7	1.7	10.8	13.3	3.1	6.6	0.9
March	1.2	6.4	12.5	4.7	1.1	5.0	1.9	2.6	1.2	6.7	13.5	6.2	5.3	0.7
April	1.8	5.9	2.9	6.6	0.9	7.0	2.2	3.2	1.5	8.1	14.7	6.4	5.1	0.6
May	1.6	8.1	3.4	9.6	1.2	10.3	2.3	4.1	1.1	9.0	2.0	6.1	4.9	0.6
June	1.8	6.4	2.7	8.2	1.1	9.5	2.8	5.4	1.5	9.2	10.3	8.6	5.6	0.6
July	2.0	7.5	10.4	8.7	1.1	7.2	1.9	4.6	1.3	8.6	3.6	9.7	5.6	0.6
August	1.0	6.4	1.9	8.1	1.2	7.6	2.3	5.4	0.6	7.5	6.6	5.1	4.5	0.6
September	1.7	10.1	13.6	6.6	1.0	5.4	2.8	9.0	1.4	9.1	10.8	5.9	6.5	0.6
October	1.2	7.8	2.1	4.8	0.9	7.0	1.9	5.0	1.0	5.8	2.3	4.5	3.7	0.7
November	1.0	9.7	2.2	5.6	0.7	6.9	2.0	6.2	1.2	6.9	2.5	4.1	4.1	0.4
December	0.6	4.7	1.5	3.9	0.8	4.1	2.1	3.1	0.8	3.9	1.3	3.9	2.6	0.5
Mean	1.4	7.8	7.8	6.5	1.0	7.0	2.4	4.7	1.3	8.2	8.1	5.6	5.2	0.3
SEM	0.1	0.4	0.9	0.3	0.1	0.3	1.2	0.3	0.03	0.4	0.1	0.3		
Effects	Sites (A)		Months (B)		Species (C)	A x B		A x C	B x C		A x B x C			
Probability	<0.001		<0.001		<0.001	<0.001		<0.001	<0.001		<0.001			

a.a. = *Acacia amentacea;* c.p. = *Celtis pallida;* f.a. = *Forestiera angustifolia*; p.t. = *Parkinsonia texana;* SEM= standard error of the mean

Table 4. Monthly contents of Na (g kg^{-1} DM) in four shrub species in three county sites in 2009.

Month	Counties												Mean	SEM
	China				Linares				Los Ramones					
	a.a.	c.p.	f.a.	p.t.	a.a.	c.p.	f.a.	p.t.	a.a.	c.p.	f.a.	p.t.		
January	0.2	1.6	11.0	0.7	0.2	0.3	0.1	0.4	0.2	5.7	30.3	1.5	4.4	0.4
February	0.2	0.8	4.2	1.3	0.2	0.8	0.3	0.5	0.3	4.1	33.2	1.5	4.0	0.4
March	0.2	0.5	6.8	0.6	0.2	0.2	0.2	0.5	0.3	1.4	15.2	0.5	2.2	0.5
April	0.2	0.8	0.3	0.8	0.2	0.3	0.1	0.5	0.2	0.9	22.4	0.8	2.3	0.3
May	0.3	1.8	0.8	1.1	0.1	0.6	0.2	0.4	0.3	0.7	0.2	0.7	0.6	0.1
June	0.1	1.7	0.4	0.9	0.5	0.8	0.2	0.4	0.2	2.1	8.8	0.5	1.4	0.4
July	0.2	0.6	4.2	1.5	0.2	0.5	0.3	0.3	0.3	1.2	0.1	0.3	0.8	0.2
August	0.7	1.7	0.4	1.0	0.1	1.5	0.2	2.0	0.2	1.3	36.4	1.7	3.9	0.3
September	0.1	0.5	2.8	0.3	0.2	0.2	0.1	0.2	0.1	1.3	10.1	0.3	1.4	0.5
October	0.3	0.3	0.2	0.3	0.1	0.3	0.2	0.2	0.2	0.2	0.4	0.3	0.3	0.3
November	0.1	0.5	0.2	0.3	0.2	0.4	0.1	2.3	0.1	2.6	7.3	0.2	1.2	0.2
December	0.1	0.4	0.1	0.1	0.1	0.2	0.1	0.2	0.1	0.5	0.2	0.2	0.2	0.1
Mean	0.2	0.9	2.6	0.7	0.2	0.5	0.2	0.7	0.2	1.8	13.7	0.7	1.8	0.2
SEM	0.02	0.3	2.2	0.1	0.03	0.1	0.6	0.1	0.02	0.1	0.02	0.1		
Effects	Sites (A)		Months (B)		Species (C)	A x B		A x C	B x C		A x B x C			
Probability	<0.001		<0.001		<0.001	<0.001		<0.001	<0.001		<0.001			

a.a. = *Acacia amentacea;* c.p. = *Celtis pallida;* f.a. = *Forestiera angustifolia*; p.t. = *Parkinsonia texana;* SEM= standard error of the mean

Table 5. Monthly concentrations of P (g kg^{-1} DM) in four shrub species in three county sites in 2009.

Month	Counties												Mean	SEM
	China				Linares				Los Ramones					
	a.a.	c.p.	f.a.	p.t.	a.a.	c.p.	f.a.	p.t.	a.a.	c.p.	f.a.	p.t.		
January	1.0	1.1	1.1	1.4	1.0	1.1	0.8	1.5	0.9	1.2	0.9	1.5	1.1	0.03
February	1.1	1.2	0.8	1.2	1.0	0.9	1.2	1.1	1.2	1.3	1.1	1.4	1.1	0.03
March	1.6	1.8	1.4	1.4	1.5	1.4	1.4	1.7	1.5	1.6	1.1	1.3	1.5	0.03
April	1.6	1.7	1.5	1.7	1.4	1.4	0.9	1.8	1.3	1.7	0.9	1.6	1.5	0.04
May	1.8	1.9	1.6	1.7	1.5	1.5	1.2	1.8	1.4	1.8	1.0	1.8	1.6	0.04
June	1.2	1.5	1.1	1.5	1.3	1.3	0.9	1.4	1.1	1.5	1.3	1.5	1.3	0.03
July	1.4	1.8	1.8	1.4	1.1	1.2	0.8	1.4	1.1	1.5	1.0	1.4	1.3	0.01
August	1.3	2.1	1.2	1.5	1.1	1.1	0.8	1.2	1.2	1.7	1.1	1.3	1.3	0.02
September	1.5	1.8	1.7	2.1	1.4	1.5	1.2	1.7	1.3	1.7	1.5	1.5	1.6	0.03
October	1.4	1.5	1.6	1.6	1.3	1.6	0.9	1.6	1.3	1.4	1.0	1.1	1.4	0.02
November	1.2	1.5	1.3	1.4	1.2	1.4	1.1	1.6	1.2	1.7	1.2	1.4	1.4	0.03
December	1.1	1.4	1.2	1.4	1.2	1.1	1.2	1.6	1.1	1.4	1.2	1.4	1.3	0.01
Mean	1.3	1.6	1.3	1.5	1.2	1.3	1.0	1.5	1.2	1.5	1.1	1.4	1.3	0.04
SEM	0.03	0.04	0.03	0.03	0.04	0.05	0.05	0.04	0.03	0.04	0.03	0.04		
Effects	Sites (A)		Months (B)		Species (C)	A x B		A x C	B x C		A x B x C			
Probability	<0.001		<0.001		<0.001	<0.001		<0.001	<0.001		<0.001			

a.a. = *Acacia amentacea;* c.p. = *Celtis pallida;* f.a. = *Forestiera angustifolia*; p.t. = *Parkinsonia texana;* SEM= standard error of the mean

Table 6. Monthly content of Cu (mg kg^{-1} DM) in four shrub species in three county sites in 2009.

Month	Counties												Mean	SEM
	China				Linares				Los Ramones					
	a.a.	c.p.	f.a.	p.t.	a.a.	c.p.	f.a.	p.t.	a.a.	c.p.	f.a.	p.t.		
January	8	8	10	11	11	12	11	12	4	9	6	12	9	0.4
February	6	4	4	5	2	4	8	16	7	9	10	13	7	0.5
March	4	8	3	8	7	11	9	9	4	7	5	8	7	0.4
April	5	6	5	8	6	9	6	11	5	11	6	10	7	0.4
May	6	6	5	5	6	8	4	8	4	6	4	8	6	0.3
June	4	3	5	5	4	7	5	7	4	8	7	6	5	0.3
July	2	6	5	3	5	6	3	4	4	5	3	4	4	0.3
August	4	7	5	6	6	7	3	6	3	8	5	4	5	0.2
September	4	7	5	6	6	7	7	7	3	5	5	7	6	0.2
October	5	7	6	5	7	9	4	15	5	7	4	5	7	0.4
November	3	4	5	4	6	4	5	6	3	6	5	7	5	0.2
December	2	4	4	4	6	7	7	10	3	5	5	3	5	0.1
Mean	4	6	5	6	6	8	6	9	4	7	5	7	6	0.1
SEM	0.2	0.3	0.3	0.5	0.3	0.3	0.3	0.4	0.3	0.4	0.4	0.6		
Effects	Sites (A)		Months (B)		Species (C)	A x B		A x C	B x C		A x B x C			
Probability	<0.001		<0.001		<0.001	<0.001		<0.001	<0.001		<0.001			

a.a. = *Acacia amentacea;* c.p. = *Celtis pallida;* f.a. = *Forestiera angustifolia*; p.t. = *Parkinsonia texana;* SEM= standard error of the mean

Table 7. Monthly content of Fe (mg kg^{-1} DM) in four shrub species in three county sites in 2009.

Month	Counties												Mean	SEM
	China				Linares				Los Ramones					
	a.a.	c.p.	f.a.	p.t.	a.a.	c.p.	f.a.	p.t.	a.a.	c.p.	f.a.	p.t.		
January	141	194	447	448	120	125	142	240	140	222	170	188	215	2.8
February	314	373	188	307	159	163	146	287	306	244	367	231	257	3.1
March	187	369	120	244	105	187	144	248	136	190	293	212	203	2.3
April	178	399	184	444	118	166	122	142	167	485	185	391	249	2.4
May	148	313	249	415	125	167	74	165	142	249	320	292	222	3.0
June	240	320	374	261	182	303	142	112	144	164	80	195	210	1.4
July	98	258	253	268	74	112	81	114	130	137	84	132	145	1.7
August	376	386	131	492	87	182	108	482	145	335	127	357	267	4.1
September	85	276	152	258	299	128	456	146	249	282	274	184	232	1.6
October	104	146	435	165	97	230	98	106	120	157	105	160	160	1.3
November	130	85	92	193	124	133	108	200	87	108	74	188	127	3.1
December	160	384	320	417	119	112	491	161	402	213	368	381	294	1.2
Mean	180	292	245	226	134	167	176	200	181	232	204	243	207	1.5
SEM	4.9	3.6	2.6	4.6	4.4	3.1	2.0	3.0	4.7	3.0	2.9	2.2		
Effects	Sites (A)		Months (B)		Species (C)	A x B		A x C	B x C		A x B x C			
Probability	<0.001		<0.001		<0.001	<0.001		<0.001	<0.001		<0.001			

a.a. = *Acacia amentacea;* c.p. = *Celtis pallida;* f.a. = *Forestiera angustifolia*; p.t. = *Parkinsonia texana;* SEM= standard error of the mean

Table 8. Monthly Mn concentrations (mg kg^{-1} DM) in four shrub species in three county sites in 2009.

Month	Counties												Mean	SEM
	China				Linares				Los Ramones					
	a.a.	c.p.	f.a.	p.t.	a.a.	c.p.	f.a.	p.t.	a.a.	c.p.	f.a.	p.t.		
January	22	31	116	37	27	65	123	77	26	50	201	36	67	0.8
February	17	40	126	58	19	73	67	66	30	53	188	33	64	0.9
March	21	28	80	53	23	52	72	57	20	32	79	41	47	0.6
April	20	32	42	48	28	31	73	51	28	46	121	51	48	0.6
May	23	25	46	40	20	59	99	54	26	51	22	43	42	0.4
June	27	32	38	43	49	83	100	59	32	51	132	54	58	0.5
July	21	27	69	43	37	69	118	66	39	32	25	48	50	0.5
August	30	35	29	48	41	58	74	53	31	31	75	49	46	0.7
September	16	28	47	33	47	50	146	83	28	33	43	38	49	0.7
October	24	32	42	33	30	52	52	63	29	70	48	38	43	0.7
November	22	29	30	21	40	52	68	45	22	35	26	51	37	0.5
December	14	26	69	22	30	40	110	51	28	31	251	51	60	0.4
Mean	21	30	61	40	33	57	92	60	28	43	101	45	51	0.6
SEM	0.8	2.0	2.6	1.6	0.8	0.7	1.2	1.8	1.7	2.3	0.7	1.8		
Effects	Sites (A)		Months (B)		Species (C)	A x B		A x C	B x C		A x B x C			
Probability	<0.001		<0.001		<0.001	<0.001		<0.001	<0.001		<0.001			

a.a. = *Acacia amentacea;* c.p. = *Celtis pallida;* f.a. = *Forestiera angustifolia*; p.t. = *Parkinsonia texana;* SEM= standard error of the mean

Table 9. Monthly Zn contents (mg kg^{-1} DM) in four shrub species in three county sites in 2009.

Month	Counties												Mean	SEM
	China				Linares				Los Ramones					
	a.a.	c.p.	f.a.	p.t.	a.a.	c.p.	f.a.	p.t.	a.a.	c.p.	f.a.	p.t.		
January	15	12	22	42	14	14	82	79	15	14	21	67	33	0.5
February	21	18	26	67	23	12	60	154	20	14	21	77	43	0.9
March	30	27	19	83	22	21	53	93	32	26	26	70	42	1.3
April	18	18	35	74	16	20	40	114	20	23	21	138	45	0.7
May	15	16	31	47	14	30	33	67	16	20	46	103	37	0.3
June	23	29	43	74	18	26	41	93	19	24	28	104	43	0.9
July	18	23	41	50	17	18	42	72	16	28	36	86	37	0.8
August	17	22	26	49	12	13	18	40	13	20	12	32	23	1.1
September	11	22	23	38	14	16	40	70	15	19	22	56	29	0.4
October	17	29	38	28	16	24	30	137	16	23	31	35	35	0.6
November	15	20	33	29	12	17	30	38	17	18	42	57	27	0.5
December	13	17	28	27	14	20	63	93	14	18	37	23	31	0.9
Mean	18	21	30	51	16	19	44	88	18	21	28	71	35	0.6
SEM	0.9	0.7	1.8	0.5	0.9	0.9	1.4	1.2	0.7	0.9	0.9	0.8		

Effects	Sites (A)	Months (B)	Species (C)	A x B	A x C	B x C	A x B x C
Probability	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001

a.a. = *Acacia amentacea*; c.p. = *Celtis pallida*; f.a. = *Forestiera angustifolia*; p.t. = *Parkinsonia texana*; SEM= standard error of the mean

Phosphorus content was higher in leaf samples from China County than those form Los Ramones or Linares Counties, regardless of species. Highest P concentration was recorded for samples drawn in May, while those harvested in January and February were lowest in P. In general, *Parkinsonia texana* and *C. pallida* had the same content and were higher in P than *A. amentacea* or *F. angustifolia* (Table 5). Marginally insufficient amounts to meet the metabolic requirements of adult range small ruminants (2.7, 2.8 and 2.6 g of P kg^{-1} of diet DM for sheep, goats and white-tailed deer, respectively; NRC, 2007) were observed indistinctly of shrub species, sample timing or location. Low P content in native plants growing in a semiarid region of north Mexico was also reported by Guerrero-Cervantes *et al*., (2012); Rodríguez (1993) judged this situation as critical for ruminant needs during any season of the year, attributable to scarce availability of P because soils in the region have evolved from volcanic ashes and, in this kind of soils, phosphorous is mainly fixed rather than mobile.

Cooper content (Table 6) was higher in leaf samples from Los Ramones County, followed by those from China and Linares Counties. In January, all shrubs sampled showed the highest Cu content of the year, while these were lowest in samples harvested in July. *Celtis pallida* and *P. texana* had similar P content, and were higher than *A. amentacea* or *F. angustifolia*. Most shrubs contained apparently insufficient amounts of foliar Cu to meet adult range small ruminant requirements (9.0, 9.0 y 9.0 mg of Cu kg^{-1} of diet DM for sheep, goats and white-tailed deer, respectively, NRC, 2007). However, adequate contents were present unevenly in months corresponding to the spring season. Similar results were reported by Ramírez-Lozano *et al*., (2010) and Guerrero-Cervantes *et al*., (2012) during assessment of Cu content in native species browsed by range ruminants in semiarid regions of northeastern and north Mexico, respectively. Ramírez *et al*., (2001) explained the higher Cu content observed on the basis of the plant-growing seasonal pattern, over which growth rates seem to be higher during spring months in this region.

Iron content was higher in Linares County, followed by China and Los Ramones Counties. In general, *C. pallida* exhibited highest values (Table 7). In all shrub species, Fe concentrations measured exceeded requirements by grazing ruminants (50 mg of Fe kg^{-1} of diet DM for sheep, goats and white-tailed deer, respectively; NRC, 2007). Iron satisfactory nutritional levels for grazing ruminants have been also reported by Moya-Rodriguez *et al*., (2002), Ramírez *et al*., (2010) and Guerrero-Cervantes *et al*., (2012). Moreover, Ahmad *et al*., (2012) documented that Fe concentrations in soil and forage are adequate for ruminant nutrition and indeed, an Fe deficiency seldom occurs (McDowell, 2003).

Manganese content was highest in *F. angustifolia* and lowest in *A. amentacea*. Higher Mn content was recorded in foliar samples from Los Ramones County than those from samples collected from shrubs in China and Linares County, which were typically lower. During January, all shrub species registered higher values, while lower in May (Table 8). In general, all species except *A. amentacea*, contain sufficient foliar Mn to satisfy adult small range ruminant requirements (30 mg of Mn kg^{-1} of diet DM for sheep, goats and white-tailed deer, respectively; NRC, 2007). *Acacia amentacea* showed the lowest Mn content among species sampled. Barnes *et al*., (1990) reported similar observations except, fruits of *Acacia berlandieri*, *Acacia tortuosa* and *Prosopis glandulosa*, native plants from semiarid regions of southeast Texas, USA, showed marginally sufficient amounts of Mn to meet requirements by grazing ruminants.

Zinc foliar content was highest in April lowest in August across species studied. Highest Zn was found in *C. pallida,* while *A. amentacea* typically registered the lowest levels. Similarly, highest Zn concentrations were observed in tissue samples from In Los Ramones County, followed by China and Linares counties, irrespective of species (Table 9). *Parkinsonia texana* was the only shrub species in which sufficient Zn to meet requirements of adult range small ruminants was recorded (40, 45 and 45 mg of Zn kg^{-1} of diet DM for sheep, goats and white-tailed deer, respectively; NRC, 2007) Similar values were reported by Ramírez-Lozano *et al*., (2010) in native plants of northeastern Mexico; these authors argued that only some particular species can meet adult ruminant requirements during certain seasons if the year. In contrast, Ramírez-Orduña *et al*., (2008) reported high Zn concentrations in native species from Baja California Sur, Mexico.

Conclusions

Foliar content in Ca, K, Mg, Fe, Mn and Zn (only in *P. texana*) across locations and months were adequate to satisfy metabolic requirements of range small ruminants, while Na, P and Cu levels in foliar tissue were marginal. The high concentration recorded for some of the ion minerals studied here suggests a beneficial role by these ions as mineral supplements in the diet of browsing ruminants. Furthermore, our results may suggest that, monthly pattern variations among shrub species may relate to an important role in supporting the productivity of dry rangeland ecosystems.

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