Tropical and Subtropical Agroecosystems
E-ISSN: 1870-0462
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Universidad Autónoma de Yucatán
México

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Tropical and Subtropical Agroecosystems, vol. 12, núm. 2, mayo-agosto, 2010, pp. 267-281
Universidad Autónoma de Yucatán
Mérida, Yucatán, México

Available in: http://www.redalyc.org/articulo.oa?id=93913070008

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Tropical and Subtropical Agroecosystems, 12 (2010): 267 - 281

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SPATIO-TEMPORAL VARIATIONS OF MACRO AND TRACE MINERAL CONTENTS IN SIX NATIVE PLANTS CONSUMED BY RUMINANTS AT NORTHEASTERN MEXICO

[VARIACIÓN EN ESPACIO Y TIEMPO DEL CONTENIDO DE MACRO Y MICROMINERALES EN SEIS PLANTAS NATIVAS CONSUMIDAS POR RUMIANTES EN EL NORESTE DE MÉXICO]

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SUMMARY

During two consecutive years the Ca, K, Mg, Na, P, Cu, Fe, Mn and Zn contents were determined, seasonally, in foliar tissue of native trees (T) and shrubs (S) from northeastern Mexico such as *Acacia rigidula* (S), *Bumelia celastrina* (T), *Croton cortesianus* (S), *Karwinskia humboldtiana* (S), *Leucophyllum frutescens* (S) and *Prosopis laevigata* (T). Collections were carried out from August 2004 to May 2006 in a subtropical and semiarid region of the State of Nuevo Leon, Mexico at three county (Los Ramones, China and Linares) sites, which are grouped under a similar climatic pattern. Mineral concentrations were quantified using an atomic absorption spectrophotometer, with exception of P content that was estimated using a colorimeter. Mineral data were statistically analyzed using one-way analysis of variance with a multi-factorial arrangement being years (2), sites (3), seasons (4), and plant species (6) the factors. All minerals in all plants were significantly different among years, sites and seasons; however, some interactions were not significant. In general, plants in Linares site had higher mineral content followed by Los Ramores and China; in addition, during the year two, all plants had higher mineral content; moreover, during summer all plants had higher mineral content followed by fall, spring and winter. Yearly and seasonal variations in plant minerals might have been related to seasonal water deficits, excessive irradiance levels during summer and extreme low temperatures in winter that could have affected leaf development and senescence. In spite of these differences, all plant species had suitable levels of Ca, Mg, K, Fe and Mn to satisfy grazing ruminant requirements. However, P, Na, Zn and Cu, showed marginal inadequate concentrations in prolonged periods throughout the year and it might have a negative impact on animal productivity.

Key words: Native plants; northeastern Mexico; macrominerals; microminerals.

RESUMEN

Durante dos años consecutivos, los contenidos de Ca, K, Mg, Na, P, Cu, Fe, Mn y Zn fueron determinados, estacionalmente, en el tejido foliar de árboles (T) y arbustos (S) nativos de la flora del noreste de México tales como: *Acacia rigidula* (S), *Bumelia celastrina* (T), *Croton cortesianus* (S), *Karwinskia humboldtiana* (S), *Leucophyllum frutescens* (S) and *Prosopis laevigata* (T). Las colectas de material vegetal se llevaron a cabo de agosto de 2004 a mayo de 2006 en tres municipios (Los Ramones, China y Linares) del estado de Nuevo León, México localizados en una región subtropical semiárida. Los sitios dentro de cada municipio están agrupados bajo un mismo patrón climático. Las concentraciones de minerales fueron estimadas usando un espectrofotómetro de absorción atómica, con excepción del P que fue estimado usando un colorímetro. Los contenidos de los minerales fueron estadísticamente analizados usando un diseño estadístico completamente al azar con arreglo multifactorial siendo años (2), sitios (3), estaciones (4) y las especies de plantas (6) los factores. Todos los minerales, de todas las plantas fueron significativamente diferentes entre años, sitios y estaciones; sin embargo, algunas interacciones no fueron significativas (P<0.05). En general, las plantas en el sitio de Linares tuvieron mayores contenidos de todos los minerales seguido de Los Ramones y China.

Asimismo, durante el segundo año, todas las plantas tuvieron un mayor contenido de todos los minerales; además, durante el verano las plantas resultaron con el mayor contenido de minerales seguido por otoño, primavera e invierno. Las variaciones anuales y estacionales de los minerales pudieran estar relacionadas con los déficits estacionales de humedad, radiación solar excesiva durante el verano y bajas temperaturas durante el invierno que pudieron haber afectado el desarrollo y madurez de las hojas. Aun cuando hubo diferencias en el contenido mineral, todas las plantas tuvieron niveles adecuados de Ca, Mg, K, Fe y Mn para cubrir los requerimientos de rumiantes en pastoreo. Sin embargo, todas las plantas, en períodos prolongados durante el año, tuvieron niveles marginalmente bajos de P, Na, Zn and Cu, lo que pudiera causar un impacto negativo en la productividad animal.

Palabras clave: Plantas nativas; noreste de México; macrominerales; microminerales.

INTRODUCTION

Range livestock need minerals for skeletal growth, milk production, and the maintenance of body fluids and enzyme systems. Voluntary intake and mineral concentrations of forages determines the level of mineral consumption and determines if animal will meet mineral requirements. Factors that reduce forage intake (e.g. low protein, high degree of lignification) also reduce total mineral consumption (Haenlein and Ramirez, 2007). The concentration of minerals in plants is dependent upon interactions among a number of factors including soil type, plant species, stage of maturity, dry matter yield, grazing management and climate. Although total concentration of a mineral in forage is important, the biological availability of the mineral is equally important. Biological availability (absorption and utilization) of minerals varies substantially among animal species and breeds within a species, as well as among forages. The combination of all of these factors makes it extremely difficult for range nutritionists to determine mineral status of the range ruminant animal.

The following native shrubs and trees grow in the Tamaulipan Thornscrub or Subtropical Thornscrub Woodlands of northeastern Mexico: 1) *Acacia rigidula* Benth. (Fabaceae), 2) *Bumelia celastrina* Kunth (Sapotaceae), 3) *Croton cortesianus* Kunt (Euphorbiaceae), 4) *Karwinskia humboltiana* J.A. Schultes) Zucc (Rhamnaceae), 5) *Leucophyllum frutenscens* (Berl.) I.M. Johnst. (Scrophulariaceae) and 6) *Prosopis leavigata* (Willd.) M. Johnston (Fabaceae) (Everitt *et al*., 2002) are important feed resources for range ruminants and white-tailed deer (Ramírez, 1999). They also provide high quality fuel wood and timber for fencing and construction, and are widely distributed in combination with other species (scattered), or are found in pure stands (Fulbright and Ortega-S, 2006). However, they are affected by climatic conditions and probably causing differences in the concentrations of macro and trace minerals when considering effects in space (sites) and weather (seasonality). Thus, the objectives of this study were to determine and compare, seasonally, throughout two consecutive years, Ca, K, Mg, Na, P, Cu, Fe, Mn and Zn contents of six native plants that are consumed by range ruminants.

MATERIAL AND METHODS

This study was carried out at three sampling sites situated in the state of Nuevo Leon, Mexico. The first site was located at “El Abuelo” ranch in Los Ramones county (25º 40' N; 99º 27' W) with an elevation of 200 m. The second site was located at “Zaragoza” ranch in China county (25º 31' N and 99º 16' W). It has an elevation also of 200 m. The third site was located at the Experimental Station of Facultad de Ciencias Forestales, Universidad Autónoma de Nuevo León (24º 47' N; 99º 32' W; elevation of 350 m) located at Linares county. Vegetation of the three sites is composed by browse plants that are consumed by range livestock (cattle, sheep and goats) and wildlife (white tailed deer), and is representative of the central part of the state of Nuevo León, Mexico (Everitt *et al*., 2002). In general, the three sites are grouped under a similar climatic pattern (subtropical and semiarid with warm summer) with an annual precipitation that ranges from 650 to 800 mm with a bimodal distribution (peaks rainfall are during May, June and August, September). Monthly mean air temperature of the region ranges from 14.7^{o} C in January to 22.3^{o} C in August, although daily high temperatures of 45^{o} C are common during summer (González-Rodríguez *et al*., 2004). Los Ramones and China sites have not registered livestock activities in the last five years, and Linares since the last 25 years. In this study, seasonal rainfall and mean air temperatures that were recorded by land meteorological stations, located in each site, are shown in Table 1. The main type of vegetation of the area is known as the Tamaulipan Thornscrub or Subtropical Thornscrub Woodlands (SPP-INEGI, 1986). Dominant soils are deep, dark-gray, lime-gray, lime-clay Vertisols, with montmorillonite, which shrink and swell noticeably in response to changes in soil moisture content.

Table 1. Seasonal mean temperatures (°C) and accumulated rainfall (mm) registered in the three sites of study.

	Sites					
	Los Ramones		Linares		China	
Seasons	Temperature	Rainfall	Temperature	Rainfall	Temperature	Rainfall
First year						
Summer 2004	23.6	457	23.6	447	22.8	429
Autumn 2004	19.4	131	22.1	97	17.7	96
Winter 2005	11.3	31	13.4	35	10.1	28
Spring 2005	18.2	140	20.5	123	16.5	96
		759		702		649
Second Year						
Summer 2005	24.5	486	23.4	465	23.1	422
Autumn 2005	19.5	301	19.2	316	17.2	294
Winter 2006	11.5	14	9.7	9.0	8.7	24
Spring 2006	19.9	102	19.6	172	18.8	158
		903		962		898

Plant species such as *Acacia rigidula* Benth. (Fabaceae, shrub), *Bumelia celastrina* H. B. K. (Sapotaceae; tree), *Croton cortesianus* Kunt. (Euphorbiaceae; shrub), *Karwinskia humboldtiana* Roem et Schult. (Rhamnaceae; shrub), *Leucophyllum frutescens* Berl. (Scrophulariaceae; shrub) and *Prosopis laevigata* (Willd) M.C. Johnst. (Fabaceae; tree) are representative of the native vegetation of the northeastern Mexico and the subtropical savanna ecosystems of southern Texas, USA (Everitt *et al*., 2002) and are consumed by range ruminates (Ramírez-Lozano, 2009) were selected for mineral analysis.

Terminal shoots with fully expanded leaves from four different plants per species were randomly chosen (Cochran, 1977) from a 50 m x 50 m representative and undisturbed thornscrub plot located in each site. Collections were undertaken, seasonally during two consecutive years: in summer, 2004 (August 28); fall, 2004 (November 28); winter, 2005 (February 28); spring, 2005 (May 28); summer, 2005 (August 28); fall, 2005 (November 28); winter, 2006 (February 28) and spring, 2006 (May 28). Shoots were excised and sampled (about 800 g) from the middle side of four plants (replications) of each species. Leaves were placed into paper bags and stored; then samples were transferred to laboratory for mineral analyses.

Quadruplicate samples of each plant species were used for analyses. Partial dry matter (DM) was determined subjecting samples to oven at 55° C during 72 h, then were ground in a Wiley mill (1 mm) and stored in plastic containers for further analyses. Mineral content was estimated by incinerating samples in a muffle oven at 550° C, during 5 hours. Ashes were digested in a solution containing HCl and HNO_3, using the wet digestion technique (Cherney, 2000). Concentrations of Ca and Mg (oxide nitrous/acetylene flame), K, Na, Cu, Fe, Mn, and Zn (air/acetylene flame) were determined by atomic absorption spectrophotometry using a Varian spectrophotometer (model SpectrAA-200; Varian Australia Pty Ltd., Mulgrave, Victoria, Australia); whereas, P was quantified spectrophotometrically using a Perkin-Elmer spectrophotometer (model Lamda 1A; Perkin-Elmer Corp., Analytical Instruments, Norwalk, CT, USA) (AOAC, 2000). Cobalt and selenium were not determined because were considered that Co, as part of Cyanocobalamin, is not a limited mineral for range ruminants in these regions, and Se in soils and plants does not represent a toxic problem.

Mineral data were statistically analyzed using one-way analysis of variance with a multi-factorial arrangement being years (2), sites (3), seasons (4) plant species (6) the factors. Where the F-test was significant ($P<0.05$), differences were validated using the Tukey´s honestly significant difference. Assumptions of normality of data were tested using the Kolmogorov-Smirnov test. Pearson correlation coefficients were performed between mineral content, and rainfall and temperature values registered during the two-year study (Steel and Torrie, 1980). All applied statistical methods were computed using the SPSS package (Version 9).

RESULTS AND DISCUSSION

All plants species had Ca, P, Mg, Na and concentrations that were significantly different among sites, years and seasons. The interactions: site*year, site*season, year*season and site*year*season were significant ($P<0.001$). In general, Linares site resulted with the highest macromineral contents. Moreover, all plants during second year in summer season had the highest records. However, China site in first year and during winter season had the lowest values.

The Ca content was higher in *Prosopis laevigata* (total mean = 24 g kg^{-1} DM) and *L. frutescens* (16 g kg^{-1} DM) was lower (Table 2). Rainfall (r = 0.64; P<0.001) and temperature (r = 0.66; P<0.001) registered during the two-year study were positively related to Ca content in all plants.

Table 2. Seasonal means of Ca content (g kg^{-1} DM) in native plants from northeastern Mexico.

Sites	Seasons	*A. rigidula*	*B. celastrina*	*C. cortesianus*	*K. humboldtiana*	*L. frutensces*	*P. laevigata*
Los Ramones	Summer 2004	25	23	21	25	17	33
	Autum 2004	23	22	18	22	16	27
	Winter 2005	14	17	13	16	11	12
	Spring 2005	22	20	16	21	12	17
	Summer 2005	27	28	20	27	18	36
	Autum 2005	24	25	17	24	16	30
	Winter 2006	13	19	12	17	12	14
	Spring 2006	23	23	15	22	14	25
Linares	Summer 2004	26	31	22	28	24	33
	Autum 2004	21	30	20	24	22	25
	Winter 2005	15	20	15	18	15	10
	Spring 2005	19	27	18	24	18	16
	Summer 2005	27	33	21	30	25	42
	Autum 2005	26	31	19	27	23	29
	Winter 2006	19	23	14	20	17	18
	Spring 2006	22	28	17	25	20	28
China	Summer 2004	22	20	23	23	16	30
	Autum 2004	21	18	21	20	14	25
	Winter 2005	14	14	15	15	10	10
	Spring 2005	19	17	19	19	11	16
	Summer 2005	24	23	26	25	17	35
	Autum 2005	22	20	24	23	15	27
	Winter 2006	17	15	16	16	11	12
	Spring 2006	20	21	21	21	12	22
	Grand Mean	21	23	18	22	16	24
	SEM	0.2	0.5	0.3	0.8	0.2	0.8
	Effects	*P*<	*P*<	*P*<	*P*<	*P*<	*P*<
	Year (A)	<0.001	<0.001	0.01	<0.001	<0.001	<0.001
	Site (B)	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
	Season (C)	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
	A x B	<0.001	0.05	<0.001	0.63	<0.001	<0.001
	A x C	<0.001	0.10	<0.001	0.03	0.001	0.001
	B x C	<0.001	<0.001	0.93	0.26	<0.001	<0.001
	A x B x C	<0.001	0.20	0.01	0.11	0.01	0.02

SEM = standard error of the mean; n = 4; *P*< = probability.

During wet seasons, of both years, with higher temperatures (summer and autumn), the mineral content was higher compared to dry seasons. Seasonal inter species variation that occurred in this study, was also reported by Grenne *et al*. (1987) who found a highly variable Ca content and extremely difficult to interpret relative to seasonal dynamics. In this study, in spite of spatio-temporal differences, it appears that evaluated plants had substantial amounts of Ca, throughout the year, to meet requirements of adult range ruminants (4.6, 5.1 and 3.0 g of Ca kg^{-1} of diet DM for beef cattle, sheep and goats, respectively; McDowell, 2003). In addition, Barnes *et al*. (1990) in south Texas, USA and Ramirez *et al*. (2001), Cerrillo-Soto *et al*. (2004), Ramirez-Orduña *et al*. (2005), Ramirez *et al*. (2006), Haenlein and Ramirez (2007), Guerrero-Cervantes (2009) in north Mexico and Norton and Poppi (1995) in wet regions, reported that native shrubs and trees growing in semiarid and tropical regions had enough Ca for optimal white-tailed deer, range goats, sheep and cattle performance, respectively. High pH in the soils of these regions may be the cause why shrubs are high in Ca content (Spears, 1994). It has been proposed that an average of five g kg^{-1} DM of Ca, in the aerial parts of higher plants, is considered to be adequate (Salisbury and Ross, 1994). Most plants in this study had Ca content above 16 g kg^{-1}.

All species had P content (Table 3) that varied from 0.7 to 2.8 g kg^{-1} (Figure 1). Similar ranges were reported by Barnes *et al*. (1990) (0.8-2.8), Ramirez *et al*. (2001) (0.7-2.6) and Moya *et al*., (2002) (0.5-2.2). However, a higher range (1.6 to 4.0 kg^{-1}) was reported by Khanal and Subba (2001) in cultivated trees from Nepal and by Guerrero-Cervantes (2009) (1.0-3.8) in native shrubs growing in north Mexico. In this study, most plants, in all sites, years and seasons, had P contents that were not sufficient to meet adult range ruminant requirements (2.3, 2.7 and 2.8 g of P kg^{-1} of diet DM for beef cattle, sheep and goats, respectively; McDowell, 2003), especially during dry seasons (winter and spring; Table 1). In this study, rainfall ($r = 0.72$; $P<0.001$) and temperature ($r = 0.74$; $P<0.001$) registered during the two-year study were positively related to P content in all plants. During wet seasons, of both years, with higher temperatures (summer and autumn), the mineral content was higher compared to dry seasons. Low P and high Ca concentration resulted in an unusually wide Ca:P ratios (from 9:1 to 22:1). Similar wide Ca:P ratios had been reported by Kallah *et al*. (2000). However, it seems that browsing small ruminants (goats, sheep and white-tailed deer) can sustain these high Ca:P ratios without being affect their P metabolism (Ramirez, 1999).

The Mg content (Table 4) was higher in *Croton cortesianus* (total mean = 8 g kg^{-1} DM) and lower in *K. humboldtiana* (1 g kg^{-1} DM). The Mg content in all plants augmented as rainfall ($r = 0.67$; $P<0.001$) and temperature ($r = 0.66$; $P<0.001$) increased, being summer and autumn, of both years, higher than winter and spring. It seems that all tested plants, in all seasons, had Mg concentrations to meet adult range ruminant requirements (1.0, 1.5 and 1.6 g of Mg kg^{-1} of diet DM for beef cattle, sheep and goats, respectively; McDowell, 2003). Barnes *et al*. (1990) reported a very similar range (1.1 to 8.0 g kg^{-1} DM) in 18 shrubs that growth in Texas, USA. Norton and Poppi (1995) found that some commonly used tropical legumes had Mg concentrations that meet ruminant requirements. Moreover, other studies have found that diets, from esophageal samples by range goats growing in north Mexico (Cerrillo-Soto *et al*., 2004), or browse plants from northeastern (Ramirez *et al*., 2001; Moya-Rodriguez *et al*., 2002; Ramirez *et al*., 2006) and northwestern Mexico (Ramirez-Orduña *et al*., 2005) had sufficient amounts of Mg to meet requirements of adult small ruminants.

Sodium content (Table 5) resulted higher in *K. humboldtiana* (2.4 g kg^{-1} DM) and was lower in *C. cortesianus* (0.5 g kg^{-1} DM). It appears that most plants can be considered as Na non-accumulators because they contain less that 2 g Na kg^{-1} DM (Youssef, 1988). In this study, rainfall ($r = 0.73$; $P<0.001$) and temperature ($r =0.76$; $P<0.001$) influenced mineral content in all plants. During dry seasons (winter and spring; Table 1) most plants had lower Na content to meet the needs (0.7, 1.0 and 0.8 g of Na kg^{-1} of diet DM for beef cattle, sheep and goats, respectively; McDowell, 2003) of growing adult range ruminants. High K content (range = 8-31 g kg^{-1} DM) in evaluated plants (Table 6) could reduce Na absorption of range ruminants feeding these plants because it has been reported that elevated dietary K may decrease ruminal concentration and absorption of Na in sheep and steers (Spears, 1994). In this study, all evaluated shrubs and trees had K concentrations that increased as rainfall ($r =0.63$; $P<0.001$) and temperature ($r = 0.64$; $P<0.001$) augmented. During summer all plants had higher K than in other seasons (Table 6). Seasonal variation in K content might be related to water availability, because K absorption by the root is linked to the soil moisture (McDowell, 2003). It seems that adult range ruminants consuming these plants could acquire substantial amounts of K to meet their requirements of K in all seasons (6.0, 6.5 and 4.6 g of K kg^{-1} of diet DM for beef cattle, sheep and goats, respectively). Similar findings were reported by Greene *et al*. (1987), Ramirez *et al*. (2001), Moya-Rodríguez *et al*. (2002), Cerrillo-Soto *et al*. (2004), Ramirez *et al*. (2006), Ramirez-Orduña *et al*. (2005) and Guerrero-Cervantes (2009) who evaluated K content in browse species growing in arid and semiarid regions of the world.

Table 3. Seasonal variation of P concentration (g kg^{-1} DM) in native plants.

Sites	Seasons	*A. rigidula*	*B. celastrina*	*C. cortesianus*	*K. humboldtiana*	*L. frutensces*	*P. laevigata*
Los Ramones	Summer 2004	1.6	1.4	1.3	1.4	1.6	2.5
	Autum 2004	1.5	1.2	1.2	1.2	1.5	1.8
	Winter 2005	1	0.7	0.8	0.8	0.8	0.8
	Spring 2005	1.4	1	1	1.1	1.2	1.3
	Summer 2005	1.8	1.5	1.4	1.5	1.8	2.6
	Autum 2005	1.6	1.4	1.3	1.4	1.6	2.1
	Winter 2006	1.3	0.8	0.9	0.9	0.9	1
	Spring 2006	1.5	1.1	1.2	1.3	1.3	1.6
Linares	Summer 2004	1.6	1.4	1.4	2	1.9	2.6
	Autum 2004	1.5	1.4	1.2	1.7	1.7	2.2
	Winter 2005	1.3	0.9	0.8	0.9	0.9	1
	Spring 2005	1.4	1.3	1.1	1.3	1.6	1.7
	Summer 2005	1.9	1.9	1.6	2.5	2	2.8
	Autum 2005	1.8	1.6	1.4	2	1.9	2.3
	Winter 2006	1.4	1.2	0.9	1.2	1	1.1
	Spring 2006	1.5	1.4	1.2	2.6	1.7	1.6
China	Summer 2004	1.7	1.3	1.4	1.3	1.4	2
	Autum 2004	1.2	1	1.2	1.2	1.1	0.2
	Winter 2005	0.8	0.8	0.8	0.6	0.5	0.8
	Spring 2005	1.2	0.9	1.1	0.9	0.7	1
	Summer 2005	1.7	1.4	1.6	1.5	1.6	2.2
	Autum 2005	1.5	1.3	1.4	1.2	1.4	1.9
	Winter 2006	0.8	0.9	0.9	0.6	0.7	0.9
	Spring 2006	1.3	1.1	1.2	1.1	0.9	1.4
	Grand Mean	1.4	1.2	1.2	1.3	1.3	1.6
	SEM	0.02	0.05	0.04	0.06	0.01	0.02
	Effects	*P*<	*P*<	*P*<	*P*<	*P*<	*P*<
	Year (A)	<0.001	<0.001	0.01	<0.001	<0.001	<0.001
	Site (B)	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
	Season (C)	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
	A x B	<0.001	0.10	<0.001	<0.001	<0.001	<0.001
	A x C	<0.001	<0.001	0.12	0.03	<0.001	<0.001
	B x C	<0.001	<0.001	0.08	<0.001	<0.001	<0.001
	A x B x C	<0.001	<0.001	0.49	0.40	<0.001	<0.001

SEM = standard error of the mean; n = 4; *P*< = probability.

All plants had Cu, Fe, Mn and Zn contents that were significantly different among sites, years and seasons. The interactions site*year, site*season, year*season and site*year*season were significant (P<0.001). In general, Linares site resulted with the highest micromineral concentrations. Moreover, all plants during second year in summer season had the highest numbers. However, China site in first year and during winter season had the lowest records. Copper content (Table 7) was higher in *B. celastrina*, *L. frutescens* and *P. laevigata* (8 mg kg^{-1} DM) and the lower in *A. rigidula* (6 mg kg^{-1} DM). Rainfall (r = 0.69; P<0.001) and temperature (r = 0.67; P<0.001) registered during the two-year study positively influenced Cu content in all plants. Apparently, most evaluated plants, only during summer and autumn in Linares and Los Ramones sites, had Cu levels that could meet adult range ruminant requirements (11, 9 and 9 mg of Cu kg^{-1} of diet DM for beef cattle, sheep and goats, respectively; McDowell, 2003). Low Cu concentrations in dry seasons (winter and spring; Table 1) are also reported in shrubs and trees from semiarid regions (Barnes *et al*., 1990; Ramirez *et al*., 2001; Cerrillo-Soto *et a*l., 2004; Moya-Rodriguez *et al*., 2002; Ramirez *et al*., 2006; Ramirez-Orduña *et al*., 2005) and in tropical native legumes (Norton and Poppi, 1995). Low Cu levels in plants might be caused because the high pH of the soils of these regions (Spears, 1994) which are about from 7.5 to 8.5. High dietary fiber (Spears, 1994; Ramirez *et al*., 2000; Guerrero-Cervantes, 2009) during dry seasons might have also reduced availability of Cu.

Table 4. Seasonal content of K (g kg^{-1} DM) in browse plants.

Sites	Seasons	*A. rigidula*	*B. celastrina*	*C. cortesianus*	*K. humboldtiana*	*L. frutensces*	*P. laevigata*
Los Ramones	Summer 2004	17	14	16	22	20	18
	Autum 2004	13	13	14	20	18	14
	Winter 2005	9	10	12	13	13	9
	Spring 2005	12	13	13	17	15	11
	Summer 2005	19	16	17	24	22	20
	Autum 2005	15	14	15	21	18	16
	Winter 2006	11	12	12	14	15	10
	Spring 2006	13	13	14	18	17	13
Linares	Summer 2004	17	16	19	25	22	19
	Autum 2004	14	14	17	23	19	15
	Winter 2005	11	12	13	15	16	10
	Spring 2005	13	13	15	18	17	12
	Summer 2005	18	17	18	26	26	21
	Autum 2005	17	16	16	24	21	16
	Winter 2006	12	13	12	16	17	11
	Spring 2006	16	15	14	21	20	14
China	Summer 2004	15	14	16	20	18	16
	Autum 2004	14	13	14	18	17	14
	Winter 2005	9	12	11	12	12	8
	Spring 2005	12	13	13	16	14	11
	Summer 2005	15	15	17	22	19	17
	Autum 2005	13	14	16	19	18	14
	Winter 2006	11	12	12	14	13	8
	Spring 2006	12	13	14	16	16	12
	Grand Mean	14	14	15	19	18	14
	SEM	0.3	0.4	0.6	0.3	0.2	0.3
	Effects	*P*<	*P*<	*P*<	*P*<	*P*<	*P*<
	Year (A)	<0.001	<0.001	0.01	<0.001	<0.001	<0.001
	Site (B)	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
	Season (C)	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
	A x B	0.01	0.001	0.004	0.31	0.02	<0.001
	A x C	0.10	0.05	0.93	0.25	0.02	<0.001
	B x C	<0.001	0.11	<0.001	<0.001	<0.001	<0.001
	A x B x C	0.02	0.01	0.99	0.01	0.002	0.44

SEM = standard error of the mean; n = 4; *P*< = probability.

Iron content (Table 8) was higher in *L. futenscens* (mean = 201 mg kg^{-1}) and *B. celastrina* was lower (98 mg kg^{-1} DM). Temperature (r = 0.39; P<0.001) and rainfall (r = 0.43; P<0.001) registered during the two-year study positively influenced Fe content in all plants. Wet seasons (summer and autumn) were higher than dry seasons. All plants, in all seasons and in both years, contained Fe levels in substantial amounts to meet adult range ruminant requirements (45, 45 and 45 mg of Fe kg^{-1} of diet DM for beef cattle, sheep and goats, respectively; McDowell, 2003). Similar findings were reported by Ramirez *et al*. (2001), Moya-Rodriguez *et al*. (2002), Ramirez *et al*. (2006), Ramirez-Orduña *et al*. (2005) and Guerrero-Cervantes (2009) who evaluated the Fe contained in shrubs and trees that grow in semiarid regions of Mexico. They sustained that Mexican browse species had Fe levels in substantial amounts to meet the Fe requirements of adult range small ruminants. Iron deficiency seldom occurs in browsing and grazing ruminants due to generally adequate pasture concentrations and contaminants of plants by soil. Soil contamination of forages and direct soil consumption often provide excess quantities of dietary Fe (McDowell, 2003).

Table 5. Magnesium content (g kg^{-1} DM) in native plants throughout two-year study.

Sites	Seasons	*A. rigidula*	*B. celastrina*	*C. cortesianus*	*K. humboldtiana*	*L. frutensces*	*P. laevigata*
Los Ramones	Summer 2004	5	5	5	3	4	5
	Autum 2004	4	4	4	3	3	4
	Winter 2005	2	2	2	1	2	2
	Spring 2005	3	4	3	2	3	3
	Summer 2005	5	7	4	4	5	5
	Autum 2005	5	5	3	4	4	5
	Winter 2006	2	3	1	2	2	3
	Spring 2006	3	4	2	3	4	4
Linares	Summer 2004	5	7	8	5	5	6
	Autum 2004	4	6	6	4	5	5
	Winter 2005	3	3	4	2	2	3
	Spring 2005	4	4	5	4	4	5
	Summer 2005	6	8	6	6	6	7
	Autum 2005	5	6	5	5	5	6
	Winter 2006	3	4	3	3	3	4
	Spring 2006	4	5	4	4	5	5
China	Summer 2004	4	6	6	3	4	4
	Autum 2004	3	4	6	2	3	3
	Winter 2005	2	3	4	1	2	2
	Spring 2005	3	4	4	2	3	3
	Summer 2005	5	7	5	3	4	4
	Autum 2005	4	5	4	2	4	4
	Winter 2006	2	3	3	1	2	2
	Spring 2006	3	4	4	2	3	3
	Grand Mean	4	5	4	3	4	4
	SEM	0.1	0.3	0.1	0.1	0.1	0.2
	Effects	*P*<	*P*<	*P*<	*P*<	*P*<	*P*<
	Year (A)	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
	Site (B)	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
	Season (C)	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
	A x B	<0.001	0.41	0.01	0.32	<0.001	<0.001
	A x C	0.16	0.97	<0.001	0.40	0.005	0.89
	B x C	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
	A x B x C	<0.001	0.10	0.01	0.16	<0.03	<0.001

SEM = standard error of the mean; n = 4; *P*< = probability.

Manganese content (Table 9) was higher in *P. laevigata* (41 mg kg^{-1} DM) and *K. humboldtiana* (24 mg kg^{-1} DM) was lower. Rainfall (r = 0.59; P<0.001) and temperature (r = 0.60; P<0.001) registered during the two-year study positively influenced Mn content in all plants. Dry seasons (winter and spring) were lower than wet seasons. It seems that all plants only in all summer and autumn had Mn concentrations to meet the requirements of adult range ruminants (30, 30 and 30 mg of Mn kg^{-1} of diet DM for beef cattle, sheep and goats, respectively; McDowell, 2003). Conversely, Barnes *et al*. (1990) reported that with exception of fruits from shrubs *Acacia berlandieri*, *Acacia tortuosa* and *Prosopis glandulosa,* all evaluated browse plants from south Texas, USA, had low levels of Mn to meet the requirements of grazing ruminants. Low Mn levels, in dry seasons, of native shrubs and trees growing in different rangelands of Mexico were also reported by Ramirez *et al*. (2001), Cerrillo-Soto *et al*. (2004), Ramirez-Orduña *et al*. (2005) Ramirez *et al*. (2006) and Cervantes-Guerrero (2009). They found that high levels of Ca in Mexican shrubs and small trees may increase Mn requirements, possible due to obstruction of Mn assimilation (McDowell, 2003), and accessibility of Mn may be compromised when high quantity is located in the cell wall (Spears, 1994; Ramirez *et al*., 2002). Even though, Mn deficiency has been generated under research conditions, causing effects on skeletal development and reproductive traits in ruminants, doubt has been expressed whether these deficiencies arise in practical conditions. However, contrary to this study, Mn scarcity for ruminants under grazing conditions has been reported in USA and other countries (McDowell, 2003).

Table 6. Seasonal concentrations of Na (g kg^{-1} DM) in native plants.

Sites	Seasons	*A. rigidula*	*B. celastrina*	*C. cortesianus*	*K. humboldtiana*	*L. frutensces*	*P. laevigata*
Los Ramones	Summer 2004	1.8	1.5	1.5	1.9	1.6	1.6
	Autum 2004	1.4	1.2	1.4	1.6	1.5	1.4
	Winter 2005	0.8	0.8	0.7	1	0.9	0.8
	Spring 2005	1.1	1.1	1.1	1.4	1.2	1.3
	Summer 2005	2	1.6	1.6	2.1	1.8	1.7
	Autum 2005	1.7	1.4	1.4	1.8	1.7	1.5
	Winter 2006	0.6	0.9	0.8	1.1	1	1
	Spring 2006	1.1	1.3	1.2	1.9	1.2	1.5
Linares	Summer 2004	1.6	1.7	1.6	2.4	1.8	1.7
	Autum 2004	1.4	1.4	1.4	2.3	1.7	1.6
	Winter 2005	0.8	1.1	0.9	1.1	1	1.1
	Spring 2005	1.2	1.3	1.2	1.8	1.5	1.3
	Summer 2005	2	1.9	1.8	2.7	2	1.9
	Autum 2005	1.8	1.6	1.5	2.4	1.8	1.7
	Winter 2006	0.9	1.2	1.1	1.3	1.2	1.3
	Spring 2006	1.3	1.4	1.3	1.8	1.7	1.5
China	Summer 2004	1.6	1.4	1.4	1.6	1.5	1.4
	Autum 2004	1.5	1.2	1.2	1.4	1.4	1.4
	Winter 2005	0.5	0.8	0.5	0.8	0.8	0.7
	Spring 2005	0.7	1.1	1.1	1.3	0.9	1.2
	Summer 2005	1.7	1.6	1.5	1.7	1.6	1.6
	Autum 2005	1.3	1.4	1.2	1.5	1.5	1.5
	Winter 2006	0.7	0.9	0.7	0.9	0.9	1
	Spring 2006	1.1	1.1	1.1	1.4	1	1.3
	Grand Mean	1.3	1.3	1.2	1.6	1.4	1.4
	SEM	0.01	0.02	0.01	0.03	0.01	0.02
	Effects	*P*<	*P*<	*P*<	*P*<	*P*<	*P*<
	Year (A)	0.001	<0.001	<0.001	<0.001	<0.001	<0.001
	Site (B)	0.03	<0.001	<0.001	<0.001	<0.001	<0.001
	Season (C)	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
	A x B	0.16	0.32	0.33	0.51	0.02	0.004
	A x C	0.004	0.43	0.34	0.83	0.47	<0.001
	B x C	0.001	0.06	<0.001	<0.001	<0.001	<0.001
	A x B x C	<0.001	0.59	<0.001	0.47	0.04	<0.001

SEM = standard error of the mean; n = 4; *P*< = probability.

Zinc content (Table 10) was higher in *P. laevigata* (total mean = 41 mg kg^{-1} DM) and *K. humboldtiana* was lower (total mean = 31 mg kg^{-1} DM). Peaks of Zn levels appeared to be related to summer and autumn rainfall (r = 0.66; P<0.001) and temperature (r = 0.72; P<0.001). In this study, all plants had sufficient levels of Zn to meet goat requirements (35, 27 and 45 mg of Zn kg^{-1} of diet DM for beef cattle, sheep and goats, respectively; McDowell, 2003). Some shrubs that occur in Texas, USA and northeastern Mexico (Ramirez *et al*. 2001; Moya-Rodriguez *et al*. 2002) had also Zn levels that varied seasonally, but only a few of them had levels of Zn to meet domestic and white-tailed deer requirements (Barnes *et al*., 1990). Conversely, Cerrillo-Soto *et al*. (2004) and Ramírez-Orduña *et al*. (2005) indicated a relevant potential mineral intake of Zn by range Spanish goats browsing in north and northwestern regions of México, respectively.

Table 7. Copper content (mg kg^{-1} DM) in browse plants throughout two-year study.

Sites	Seasons	*A. rigidula*	*B. celastrina*	*C. cortesianus*	*K. humboldtiana*	*L. frutensces*	*P. laevigata*
Los Ramones	Summer 2004	7	10	8	8	9	11
	Autum 2004	6	8	7	6	8	10
	Winter 2005	3	5	5	4	4	6
	Spring 2005	5	7	6	6	6	7
	Summer 2005	8	11	9	8	10	12
	Autum 2005	7	9	8	7	9	10
	Winter 2006	4	6	6	5	5	7
	Spring 2006	6	8	7	6	7	8
Linares	Summer 2004	8	12	8	8	11	12
	Autum 2004	7	10	7	7	9	10
	Winter 2005	5	7	6	6	6	5
	Spring 2005	6	9	7	7	7	7
	Summer 2005	9	15	10	10	13	13
	Autum 2005	8	13	9	9	11	11
	Winter 2006	6	9	6	6	7	7
	Spring 2006	7	12	8	8	9	9
China	Summer 2004	7	8	7	7	8	7
	Autum 2004	6	7	7	6	7	6
	Winter 2005	3	4	6	4	4	4
	Spring 2005	4	6	7	5	6	5
	Summer 2005	8	9	6	7	9	10
	Autum 2005	7	8	6	7	8	8
	Winter 2006	4	5	5	5	6	5
	Spring 2006	5	7	6	6	7	7
	Grand Mean	6	9	7	7	8	8
	SEM	0.2	0.3	0.2	0.1	0.1	0.1
	Effects	*P*<	*P*<	*P*<	*P*<	*P*<	*P*<
	Year (A)	<0.001	<0.001	0.05	<0.001	<0.001	<0.001
	Site (B)	<0.001	<0.001	0.05	<0.001	<0.001	<0.001
	Season (C)	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
	A x B	0.10	<0.001	0.01	0.51	<0.001	<0.001
	A x C	<0.001	0.01	<0.001	0.83	0.001	<0.001
	B x C	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
	A x B x C	<0.001	0.02	<0.001	0.47	0.02	<0.001

SEM = standard error of the mean; n = 4; *P*< = probability.

Higher mineral content in all plants during the second year of the study may be explained by the fact that the Hurricane Emily occurred in the region registering more rainfall during the summer and autumn of 2005 that the previous year. In addition, higher mineral content in Linares site (undisturbed during the last 25 years) may be related to the higher historical precipitation (600-800 mm) compared to other sites (400-600 mm). Thus, the positive relationships between mineral content and seasonal mean temperatures and rainfall, reflects the plasticity of how native trees and shrubs species deal with seasonal water deficits, extreme temperatures (frost or heat) and excessive irradiance levels as main multiple stresses that may co-occur either during the dry or wet seasons.

Table 8. Seasonal variation of Fe content (mg kg^{-1} DM) in native plants.

Sites	Seasons	*A. rigidula*	*B. celastrina*	*C. cortesianus*	*K. humboldtiana*	*L. frutensces*	*P. laevigata*
Los Ramones	Summer 2004	112	102	162	155	193	91
	Autum 2004	96	95	144	125	143	83
	Winter 2005	87	58	122	63	100	62
	Spring 2005	93	87	137	106	121	74
	Summer 2005	191	107	174	174	292	114
	Autum 2005	152	100	156	148	250	107
	Winter 2006	116	65	136	67	169	73
	Spring 2006	124	92	143	125	192	84
Linares	Summer 2004	110	122	167	176	336	126
	Autum 2004	99	108	149	154	259	104
	Winter 2005	90	70	124	72	121	77
	Spring 2005	95	96	157	131	221	96
	Summer 2005	185	185	177	193	384	289
	Autum 2005	166	156	158	165	323	214
	Winter 2006	114	83	137	81	151	97
	Spring 2006	123	114	148	141	254	194
China	Summer 2004	109	98	127	134	219	90
	Autum 2004	94	88	116	116	158	74
	Winter 2005	86	56	93	55	109	44
	Spring 2005	92	76	111	106	143	63
	Summer 2005	160	96	131	147	224	144
	Autum 2005	152	92	127	127	220	98
	Winter 2006	94	66	101	62	152	53
	Spring 2006	141	81	154	78	196	63
	Grand Mean	120	96	140	121	205	105
	SEM	0.6	1.2	1.3	1.1	3.3	1.5
	Effects	*P*<	*P*<	*P*<	*P*<	*P*<	*P*<
	Year (A)	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
	Site (B)	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
	Season (C)	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
	A x B	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
	A x C	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
	B x C	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
	A x B x C	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001

SEM = standard error of the mean; n = 4; *P*< = probability.

CONCLUSIONS

Rainfall and temperature influenced mineral content. Low rainfall and temperature, which occurred during winter and spring, affected mineral content in the evaluated plants. However, most plants had higher levels of the tested minerals during summer and autumn, when rainfall and temperature were high. Calcium, Mg, K, Fe and Mn (in summer and autumn) and Zn contents, in all plants and all seasons, can be sufficient for the requirements of range ruminants, while Na, P, and Cu contents were marginal deficient in most seasons. Diet formulation for range ruminants should include evaluation of the dominant available plants and consideration of their probable mineral contents during certain seasons for ration formulation. Even though, all plants differed in mineral content and followed a seasonal pattern, during adequate or adverse conditions such as extreme temperatures and water shortages, they still could play important roles in maintaining the productivity of dry rangeland ecosystems.

Table 9. Manganese content (mg kg^{-1} DM) in native plants measured seasonally.

Sites	Seasons	*A. rigidula*	*B. celastrina*	*C. cortesianus*	*K. humboldtiana*	*L. frutensces*	*P. laevigata*
Los Ramones	Summer 2004	37	37	34	25	31	50
	Autum 2004	28	34	32	22	29	33
	Winter 2005	22	18	18	17	17	24
	Spring 2005	24	25	22	21	23	29
	Summer 2005	39	38	32	27	38	51
	Autum 2005	34	36	31	24	30	42
	Winter 2006	20	20	20	18	20	29
	Spring 2006	27	26	24	22	26	34
Linares	Summer 2004	36	42	37	30	37	67
	Autum 2004	25	37	34	27	22	53
	Winter 2005	21	17	24	18	22	26
	Spring 2005	23	36	28	24	27	49
	Summer 2005	41	48	41	35	40	70
	Autum 2005	33	41	37	32	31	65
	Winter 2006	26	23	25	24	28	38
	Spring 2006	32	41	30	29	30	51
China	Summer 2004	33	29	28	24	31	39
	Autum 2004	29	27	27	21	27	37
	Winter 2005	19	21	14	18	17	23
	Spring 2005	24	25	20	20	24	33
	Summer 2005	32	34	29	28	34	45
	Autum 2005	31	31	25	25	31	40
	Winter 2006	22	22	13	16	21	28
	Spring 2006	29	26	22	23	25	36
	Grand Mean	29	31	27	24	28	41
	SEM	0.4	0.6	0.5	0.4	0.5	0.4
	Effects	*P*<	*P*<	*P*<	*P*<	*P*<	*P*<
	Year (A)	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
	Site (B)	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
	Season (C)	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
	A x B	<0.001	0.06	<0.001	<0.001	<0.001	<0.001
	A x C	<0.001	<0.001	<0.001	0.01	0.85	<0.001
	B x C	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
	A x B x C	<0.001	0.02	<0.001	<0.001	<0.001	<0.001

SEM = standard error of the mean; n = 4; *P*< = probability.

ACKNOWLEDGEMENTS

Research was funded by PAICYT-UANL (Programa de Apoyo a la Investigación Científica y Tecnológica, Universidad Autónoma de Nuevo León), Project Grant CN1549-07.

Table 10. Zinc content (mg kg^{-1} DM) in native plants throughout two-year study.

Sites	Seasons	*A. rigidula*	*B. celastrina*	*C. cortesianus*	*K. humboldtiana*	*L. frutensces*	*P. laevigata*
Los Ramones	Summer 2004	36	34	39	37	42	45
	Autum 2004	33	31	36	35	38	38
	Winter 2005	21	23	26	20	26	21
	Spring 2005	30	28	35	30	32	34
	Summer 2005	39	35	40	38	42	52
	Autum 2005	34	33	35	36	40	46
	Winter 2006	24	25	26	22	28	23
	Spring 2006	32	30	34	32	35	41
Linares	Summer 2004	35	37	42	40	44	61
	Autum 2004	33	34	37	37	39	51
	Winter 2005	26	27	24	23	28	33
	Spring 2005	31	31	33	33	37	42
	Summer 2005	32	40	44	41	44	67
	Autum 2005	34	38	41	38	40	55
	Winter 2006	28	29	28	24	31	36
	Spring 2006	35	35	36	35	28	49
China	Summer 2004	34	32	39	35	42	41
	Autum 2004	32	29	36	33	35	36
	Winter 2005	26	22	25	17	23	19
	Spring 2005	30	25	33	27	33	32
	Summer 2005	36	35	35	36	42	50
	Autum 2005	33	31	33	34	37	45
	Winter 2006	27	25	22	18	27	21
	Spring 2006	31	28	32	29	33	38
	Grand Mean	31	31	34	31	35	41
	SEM	0.3	0.6	0.4	0.4	0.3	0.4
	Effects	*P*<	*P*<	*P*<	*P*<	*P*<	*P*<
	Year (A)	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
	Site (B)	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
	Season (C)	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
	A x B	<0.001	<0.001	<0.001	0.94	<0.07	<0.001
	A x C	<0.001	0.10	<0.001	0.10	<0.001	<0.001
	B x C	<0.001	<0.001	<0.001	0.001	<0.001	<0.001
	A x B x C	<0.001	0.01	<0.001	0.63	<0.001	<0.001

SEM = standard error of the mean; n = 4; *P*< = probability.

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Submitted xxxxx, xx, 2009 – Accepted xxx, xx 2009
Revised received xxxxx, xxx9