Chemical composition and dry matter digestion of some native and cultivated grasses in Mexico

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ABSTRACT: The objective of the study was to quantify differences in nutritive value, over four seasons, of native grasses such as *Bouteloua curtipendula*, *Bouteloua trifida*, *Brachiaria fasciculata*, *Chloris ciliata*, *Digitaria insularis*, *Leptochloa filiformis*, *Panicum hallii*, *Panicum obtusum*, *Paspalum unispicatum*, *Setaria grisebachii*, *Setaria macrostachya*, *Tridens eragrostoides*, *Tridens muticus* and naturalized *Cenchrus ciliaris* and *Rhynchelytrum repens* that are used as forages for grazing beef cattle. *Cenchrus ciliaris* was included as a reference grass of good nutritional quality. Plants were collected in autumn 2001 and in winter, spring and summer 2002. The nutritive value was assessed in terms of nutrient content, effective rumen degradable dry matter (EDDM), metabolizable energy (ME) and metabolizable protein (MP). Most grasses had crude protein (CP) content comparable to the reference *C. ciliaris* grass (grand mean = 120 g/kg) and some of them had a higher content (140 g/kg). Cell wall (NDF) and lignin contents were lower in *C. ciliaris* (650 g/kg, 30, respectively) than in the other grasses (mean = 700 g/kg, 60, respectively). All grasses had less EDDM (mean = 420 g/kg) than *C. ciliaris* (470 g/kg). All grasses had the ME content (mean = 5.6 MJ/kg DM) that was lower for maintenance requirements of growing beef cattle. Conversely, mean MP values (67 g/kg DM) were sufficient. Lower content of P (annual mean = 120 g/kg DM), Na (0.3) and Cu (40 mg/kg DM) was detected in all grasses to meet the requirements of growing cattle. All grasses, in all seasons, had sufficient CP and MP content to meet the maintenance requirements of growing beef cattle. Higher levels of EDDM occurred in summer and autumn. Because of their good nutritional quality, grasses such as *B. fasciculata*, *C. ciliata*, *P. hallii*, *P. obtusum*, *S. grisebachii*, *S. macrostachya* and *T. eragrostoides* can be considered as good forages for ruminants.

Keywords: native grasses; chemical composition; nutritive value; rumen degradability

Native grass species are important forage sources for grazing ruminants because they are well adapted, drought-resistant, provide dependable forage production, have an extensive root system, increase soil fertility and require low input costs. These characteristics make them very suitable for inclu-

Supported by PAICYT-UANL Programa de Apoyo a la Investigación Científica y Tecnológica, Universidad Autónoma de Nuevo León (Project No. CN1307-06).

sion in a balanced and sustainable grazing system, particularly in low rainfall areas. Moreover, many native grasses are well adapted to survive the heat and lack of moisture typical of many areas of northeastern Mexico and South Texas, U.S. (Ramírez et al., 2004). It has also been found that native grasses have thickened stems at the base for food storage and a corky integument over the roots to protect them against excessive heat. In addition, some species have a different leaf structure from the species adapted to the higher rainfall areas. This leaf structure gives the plant small, thickened leaves or bristle-like leaves that help to reduce the amount of moisture that is transpired from the leaf surfaces. However, high levels of ash in most of the native grasses indicate the presence of high amounts of silica which may reduce digestibility (Van Soest, 1994).

Rhynchelytrum repens and *Cenchrus ciliaris* are cultivated species that were introduced to Mexico with good adaptation. Moreover, *Cenchrus ciliaris*, because of its wide distribution to these semiarid regions, has been considered as a naturalized grass. In addition, it has been mentioned as a south Texas and northeastern Mexico wonder grass (Hanselka, 1988); however, seasonality of rainfall and temperature are major influences on nutritional quality (Ramírez et al., 2003a).

Minerals are required to meet the animal needs for optimum development and health and influence animal productivity as they are essential nutrients and affect animal performance (McDowell, 2003). Range grasses may be important sources of inorganic nutrients for ruminants; however, in some circumstances, they are deficient in one or more essential minerals. The objectives of this study were to determine and compare, seasonally, the chemical composition and the rate and extent of digestion of the forage dry matter of two cultivated and thirteen native grasses growing in northeastern Mexico.

MATERIAL AND METHODS

Study area

The study was carried out at the "Sauces Ranch" of about 900 ha located in General Terán County of the state of Nuevo León, México. It is located at 25°24'26" west longitude and 99°46'33" north latitude, with an altitude of 272 m. The climate is typically subtropical and semi-arid with warm summer. Mean monthly air temperature ranges from 14.7°C in January to 22.3°C in August, although daily high temperatures of 45°C are common during summer. Peak rainfall months are May, June and September. Annual rainfall during the year of the study was about 360 mm distributed as follows; 25 mm in winter, 32 mm in spring, 238 mm in summer and 65 mm in autumn. The main type of vegetation is known as the Tamaulipan Thornscrub or Subtropical Thornscrub Woodlands. The 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. They are characterized by high clay and calcium carbonate contents, pH varies from 7.5 to 8.5 and organic matter content is low (Foroughbakhch, 1992).

Grasses such as *Bouteloua curtipendula* (Gould and Kapadia), *Bouteloua trifida* (Thurber), *Brachiaria fasciculata* (Sw.), *Chloris ciliata* (Swartz.), *Digitaria insularis* (L.), *Leptochloa filiformis* (Lam.) Beauv, *Panicum hallii* (Vasey.), *Panicum obtusum* (H.B.K.) Parodi., *Paspalum unispicatum* (L.), *Setaria grisebachii* (Fourn.), *Setaria macrostachya* (H.B.K.), *Tridens eragrostoides* (Vasey and Scribn.) Nash, *Tridens muticus* (Torr.) Wash, and the cultivated *Cenchrus ciliaris* (L.) and *Rhynchelytrum repens* (Willd.) Hubb, were collected for nutritional studies because they represent an important source of forage for grazing ruminants in northeastern Mexico (Ramírez, 1999). In this study, *C. ciliaris* has been considered as a reference grass of good nutritional quality. The collection of grasses was made during four seasons beginning in autumn 2001 (October 20), followed by winter 2002 (January 21), spring 2002 (April 28) and summer 2002 (July 23). As encountered at four sites, randomly located in the whole ranch, grasses were hand harvested until adequate amounts of material were obtained, and composited by species at each site and in each season. Samples were stored in paper bags in the field and transported to laboratory. The sites of collection were grazed by livestock. Partial dry matter (DM) was determined subjecting samples to oven at 55°C during 72 h, then they were ground in a Wiley mill (1 mm) and stored in plastic containers for further analyses.

Chemical analyses

In each season and at each site, by duplicate, samples were analyzed for DM, organic matter (OM), crude protein (CP; AOAC, 1997) and neutral detergent fibre (NDF), cellulose and acid detergent lignin (ADL; Van Soest et al., 1991). Indigestible neutral detergent fibre (INDF) content in grasses was predicted using the following equation: INDF = –86.98 + 1.542 NDF + 31.63 ADL (Jančík et al., 2008).

Metabolizable energy content was estimated by the *in vitro* gas production technique, in which 200 mg sample of each grass was incubated in rumen liquor *in vitro* and calculated according to Menke and Steingass (1988) equation: ME (MJ per kg DM) = (2.20 + 0.136 gas production in 24 h + 0.057 crude protein + 0.0029 crude fat^2)/4.184. Metabolizable protein content was determined using the PDI system principles (Verite et al., 1987). The main variables used to calculate the metabolizable protein (MP) content were: CP content, effective degradability of CP, *in vitro* OM digestibility (Daisy II ANKOM Technology, Macedon NY USA), forage fat content and organic matter fermented in the rumen. It was assumed that intestinal protein digestibility of bypass protein varied from 0.65 to 0.75 (Verite et al., 1987). Because 56% of samples were energy deficient (grasses such as *B. curtipendula*, *B. trifida*, *P. hallii*, *P. unispicatum*, *S. grisebachii* and *T. muticus* mostly during winter and spring with less than 20 g of intestinal digestible proteins derived from energy/kg of organic matter fermented in the rumen) the following equation was used: MP = undegraded protein (UDP) + microbial protein from feed energy (MPFE). Where UDP = 1.11 × CP (1-degradability) × degradability in small intestine and MPFE = 0.093 × organic matter fermented in the rumen (Verite et al., 1987). For the other 44% of non-deficient energy samples (> 20 g of intestinal digestible proteins derived from energy/kg of organic matter fermented in the rumen) the equation was: MP = UDP +microbial protein from feed nitrogen (MPFN). Where MPFN = 0.64 × CP × (degradability – 0.10; Verite et al., 1987).

Mineral content was estimated by incinerating the samples in a muffle at 550°C, during 5 hours. Ashes were digested in a solution containing HCl and HNO_3, using the wet digestion technique (Diaz-Romeau and Hunter, 1978). Concentrations of Ca and Na (nitrous oxide/acetylene flame), K, Mg, 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 (Lamda 1A model; Perkin-Elmer Corp., Analytical Instruments, Norwalk, CT, USA) (AOAC, 1997).

In situ digestibility analyses

The rate and extent of DM loss was estimated using the nylon bag technique. Four rumen cannulated Pelibuey × Rambouillet sheep (45 ± 3.5 kg of body weight) were used to incubate the nylon bags (5 × 10 cm, 53 µm of pore size), which contained ground (4 g) samples of each grass species. During the trial, sheep were fed lucerne hay *ad libitum*. Incubation periods were 4, 8, 12, 24, 36 and 48 hours. Upon removal from the rumen, bags were washed in cold water. Zero time disappearance was obtained by washing unincubated bags in a similar fashion, and then bags were dried at 55°C in an oven for 48 hours. Disappearance of DM for each incubation period was calculated by:

DM disappearance (%) = (initial weight-final weight)/(initial weight) × 100

Degradation (digestion) characteristics of DM were calculated using the equation of Ørskov and McDonald (1979):

$$p = a + b(1 - e^{-ct})$$

where:

p = disappearance rate of DM at time t

a = intercept representing the portion of DM solubilized at the beginning of incubation (time 0)

b = portion of DM that is slowly degraded in the rumen

c = rate constant of disappearance of fraction b and t is the time of incubation

The nonlinear parameters *a, b* and *c* and effective degradability of DM (EDDM) were calculated using the Neway computer program (McDonald, 1981)

$$\text{DM (EDDM)} = a + (bc/(c + k))(1 - e^{-(c + k)t})$$

k = estimated rate of rumen outflow

t = time lag

The EDDM of samples were estimated assuming a rumen outflow rate of 0.05/h.

Statistical analyses

Data were statistically analyzed using a factorial design where grasses and seasons are the study fac-

Table 1. Seasonal and annual means of crude protein, neutral detergent fibre, cellulose and acid detergent lignin in grasses (g/kg DM))

Grasses	Seasons[1] w	sp	su	au	M	SEM	Sig	Seasons w	sp	su	au	M	SEM	Sig
	CP							NDF						
B. curtipendula	91	82	119	137	107	2	***	719	721	733	792	741	1	***
B. trifida	79	79	148	130	109	1	***	750	701	758	756	741	2	***
B. fasciculata	108	100	163	184	139	1	***	715	634	622	596	649	3	***
C. ciliaris	97	98	146	127	117	1	***	724	724	698	712	715	2	***
C. ciliata	117	100	182	146	136	1	***	700	674	652	710	684	0.4	***
D. insularis	113	65	133	132	111	2	***	704	695	739	745	721	1	***
L. filiformis	110	98	120	151	120	2	***	752	671	726	669	704	1	***
P. hallii	106	80	161	176	131	1	***	737	669	677	711	698	2	***
P. obtusum	119	126	165	145	139	1	***	740	553	655	663	653	2	***
P. unispicatum	87	89	134	132	111	1	***	698	643	688	672	675	2	***
R. repens	93	74	112	111	97	2	***	733	690	741	730	723	1	***
S. grisebachii	88	132	171	151	135	1	***	728	806	614	728	691	1	***
S. macrostachya	110	123	155	114	125	1	***	720	678	630	730	688	1	***
T. eragrostoides	124	125	166	111	132	1	***	710	735	724	758	731	1	***
T. muticus	80	83	159	122	111	1	***	760	715	729	780	745	1	***
Seasonal means	101	97	149	138	121			726	687	692	717	704		
SEM	1	1	2	1				4	3	5	6			
Significant level	***	***	***	***				***	***	***	***			
	INDF							Cellulose						
B. curtipendula	39	39	36	40	39	2	NS	290	280	280	280	283	3	NS
B. trifida	44	42	36	39	40	2	*	300	280	300	290	293	2	***
B. fasciculata	42	38	41	34	39	1	*	270	230	230	220	238	2	***
C. ciliaris	33	29	29	29	31	0.4	**	330	320	310	330	323	4	*
C. ciliata	42	35	44	26	37	1	***	350	320	330	320	330	3	*
D. insularis	36	35	39	36	37	2	NS	260	270	260	280	268	1	*
L. filiformis	36	41	39	35	38	1	*	382	290	250	280	250	2	***
P. hallii	36	38	32	31	34	0.1	*	310	280	280	280	300	5	**
P. obtusum	39	39	38	34	38	1	***	280	250	250	250	258	3	***
P. unispicatum	38	35	31	28	33	0.1	**	290	270	290	280	283	2	*
R. repens	45	45	38	45	43	1	***	280	270	290	280	280	4	NS
S. grisebachii	42	40	40	37	39	3	*	280	280	230	280	268	6	***
S. macrostachya	42	41	38	39	40	2	NS	280	270	250	280	270	8	**
T. eragrostoides	35	36	32	35	36	2	NS	300	310	300	320	308	3	*
T. muticus	43	42	39	40	41	0.2	***	280	270	270	290	278	6	**
Seasonal means	39	37	37	36	37			299	279	275	284	282		
SEM	2	4	3	2				4	3	5	4			
Significant level	***	***	***	***				***	***	***	***			

[1]w = winter; sp = spring; su = summer; au = autumn; M = mean; SEM = standard error of the mean; *P < 0.05; **P < 0.01; ***P < 0.001; NS = not significant

tors, with interaction between seasons and grasses. The interaction seasons × grasses was significant ($P < 0.05$), thus analyses of variance were carried out among seasons and among grasses within seasons. In addition, partial correlation coefficients were performed between chemical composition, seasonal precipitation and temperatures and EDDM (Steel and Torrie, 1980).

RESULTS AND DISCUSSION

Chemical composition

The CP content in all grasses was significantly different among seasons and among grasses within seasons. *B. fasciculata*, *C. ciliata*, *P. obtusum* and *S. grisebachii* had a higher content and in *R. repens* it was lower (Table 1). Most of the grasses had CP values higher than *C. ciliaris*. All of the grasses exhibited their most rapid increase in CP content in summer and autumn seasons. These seasonal fluctuations in CP content may be induced by summer (238 mm) and autumn (65 mm) precipitation. Other studies have shown seasonal fluctuations in native grasses. Hendrickson and Briske (1997) reported that *Hilaria berlangeri* had a CP content of 130 g/kg in summer and a lower content nearly by 20 g/kg in winter. Moreover, Dittberner and Olson (1983) showed that *Bouteloua gracilis* (aerial fresh immature), which grows in Wyoming, USA, had CP values of 110 g/kg in summer and 60 g/kg in winter when plants were in a dormant period. Studies carried out in Sonora, Mexico (Martin-Rivera and Ibarra-Flores, 1989) reported that during the spring and summer of 1989 *B. gracilis*, *Aristida* spp. and *S. macrostachya* had CP values of 50 and 100 g/kg, 50 and 90 g/kg, 0.7 and 100 g/kg, respectively. Moreover, Ramírez et al. (2004) found that *C. ciliaris*, *P. hallii*, *B. gracilis* and *S. macrostachya* had higher annual means of CP content in spring and autumn seasons. However, Huston et al. (1981) reported that *P. hallii* growing in Texas, USA, had the CP content of 70 g/kg in both summer and autumn seasons.

CP content in forages serves as a reliable measure of nutritional quality (Ganskoop and Bohnert, 2001). If an 80 g/kg CP level is considered as an adequate forage quality threshold because it falls within the range of values suggested for the maintenance of beef cattle (NRC, 2000), thus in this study, all grasses in most seasons can be considered to be of high nutritional quality for grazing ruminants. However, CP concentration in plants is influenced mainly by the supply of available N in soil and the state of maturity. Studies carried out in the same area (Ramírez et al., 2003a,b; Ramírez et al., 2005) reported that CP content in cultivated grasses such as *Panicum coloratum*, *C. ciliaris*, *Cynodon dactylon* and *Dichanthium annulatum* and in native grasses such as *Aristida longiseta*, *B. gracilis*, *C. incertus*, *H. Berlangeri*, *P. hallii*, and *S. macrostachya* (Ramírez et al., 2004) markedly declined as the plant increased in maturity, possibly because of the relative increase in the cell wall and decrease in the cytoplasm. It is possible that this effect could be manifested in the evaluated grasses of this study in winter and spring, because grasses showed the lowest CP content in these seasons.

The cell wall (NDF) content in all grasses was significantly different among seasons and among grasses within seasons. *T. muticus* resulted with the higher annual mean and *P. unispicatum* was lower. During winter and spring NDF was higher than in the other seasons (Table 1). Similarly, Skládanka et al. (2008) reported higher NDF of grasses at the end of the growing season. In this study, except for *B. curtipendula*, *D. insularis*, *S. macrostachya* and *T. eragrostoides* INDF in all grasses was significantly different among seasons within and among grasses within seasons. During winter (dry season) most grasses had higher INDF than in the other seasons. Similar responses were reported by Jančík et al. (2008), who argued that the INDF content of grasses increased during maturation. With the exception of *B. curtipendula* and *R. repens* all grasses had a significantly different cellulose concentration among seasons and among grasses within seasons. The lignin content in *C. ciliaris*, *S. grisebachii* and *T. muticus* was not significantly different among seasons. However, other grasses were significantly different. *R. repens* was higher and *C. ciliaris* was lower. All grasses had a higher lignin content, on annual mean basis, than *C. ciliaris* (Table 2). Apparently, lignin in grasses plays an important role in the structural integrity of individual cells, tissues and organs. Moreover, the amount of lignin is positively associated with the maturity of plants and the latter characteristic is negatively related with rainfall (Hatfield et al., 1993); however, in this study, even though winter and spring had lower rainfall, the lignin content was very similar when the mean of all grasses was compared among seasons (Table 2).

Table 2. Seasonal and annual means of acid detergent lignin, metabolizable energy, metabolizable protein and Ca content in grasses (g/kg DM)

Grasses	Seasons[2]				M	SEM	Sig	Seasons				M	SEM	Sig
	w	sp	su	au				w	sp	su	au			
	ADL							ME[1] (MJ/kg DM)						
B. curtipendula	60	60	50	60	58	1	*	6.2	6.1	6.7	6.6	6.4	0.04	***
B. trifida	70	70	50	60	63	1	*	6.3	5.1	6.1	6.1	5.9	0.2	**
B. fasciculate	70	60	70	50	63	2	**	6.8	6.4	6.9	5.5	6.4	0.1	***
C. ciliaris	40	30	30	30	33	4	NS	7.5	6.3	7.6	7.3	7.2	0.1	***
C. ciliata	70	50	80	20	55	4	***	6.5	6.9	6.4	6.6	6.6	0.6	NS
D. insularis	60	50	60	50	55	3	**	6.9	6.8	6.6	7.1	6.8	0.1	**
L. filiformis	50	70	60	50	58	4	**	7.8	7.8	6.7	7.9	7.4	0.1	***
P. hallii	50	60	40	30	45	5	***	6.5	5.7	6.8	6.3	6.3	0.1	***
P. obtusum	60	70	60	50	60	6	***	7.2	7.2	7.0	7.5	7.2	0.2	NS
P. unispicatum	20	40	50	60	43	3	***	6.7	5.9	7.6	6.8	6.7	0.5	***
R. repens	80	60	80	80	100	6	**	7.1	6.9	6.3	5.9	6.7	0.1	***
S. grisebachii	70	60	60	60	63	2	NS	7.1	6.2	7.1	6.7	6.8	0.2	**
S. macrostachya	60	70	60	70	65	6	**	6.5	6.1	6.7	4.9	6.1	0.2	***
T. eragrostoides	50	50	40	60	50	3	***	6.7	7.1	7.7	6.2	6.9	0.1	***
T. muticus	70	60	70	70	68	2	NS	6.2	5.5	6.9	6.2	6.2	0.1	***
Seasonal means	59	57	57	53	58			6.8	6.2	6.9	6.5	6.5		
SEM	2	2	2	1				0.1	0.1	0.4	0.1			
Significant level[2]	**	**	**	**				0.001	0.001	0.01	0.001			
	MP							Ca						
B. curtipendula	59	57	57	80	63	4	***	4	4	5	3	4	0.3	***
B. trifida	50	50	53	77	55	1	***	3	5	7	5	5	0.2	***
B. fasciculata	63	64	75	72	72	1	***	7	8	6	7	7	0.1	***
C. ciliaris	56	59	88	78	70	2	***	6	4	5	7	6	0.1	***
C. ciliata	70	63	77	71	70	2	***	9	7	6	7	7	0.2	***
D. insularis	71	69	65	74	70	2	**	3	4	4	4	4	0.2	***
L. filiformis	71	73	74	78	74	2	*	5	5	4	6	5	0.5	***
P. hallii	64	47	86	75	66	5	***	6	7	6	5	6	0.3	***
P. obtusum	73	76	72	82	76	2	**	9	9	5	7	7	0.3	***
P. unispicatum	50	53	82	79	66	4	***	7	5	8	6	7	0.3	***
R. repens	52	45	68	63	59	1	***	6	8	6	6	6	0.2	***
S. grisebachii	57	60	71	64	63	4	**	4	4	4	5	5	0.2	***
S. macrostachya	70	67	70	53	65	3	***	3	4	5	3	4	0.3	***
T. eragrostoides	72	54	78	69	74	2	**	4	4	5	5	4	0.3	***
T. muticus	53	52	74	58	59	2	***	5	5	5	5	5	0.1	***
Seasonal means	63	59	73	73	67			6	5	5	5			
SEM	3	2	3	2				0.1	0.7	0.1	0.1			
Significant level[2]	0.001	0.001	0.001	0.001				***	***	***	***			
Requirement[4]								4.5 g of Ca/kg of grasses DM						

M = mean; SEM = standard error of the mean; Sig = significant level

[1]ME calculated as: (2.20 + 0.136 gas $prod_{24h}$ + 0.057 crude protein + 0.0029 crude fat^2)/4.184

[2]w = winter; sp = spring; su = summer; au = autumn; SEM = standard error of the mean; NS = not significant; *$P < 0.05$; **$P < 0.01$; ***$P < 0.001$

3 MP calculated as: PDIA = 1.11 × PC (1 – degradability) × degradability in small intestine; PDIMN = 0.64 × PC × (degradability at 48 h –0.10); PDIME = 0.093 × organic matter fermented in the rumen

[4]required by growing beef cattle (McDowell, 2003)

Except for *C. ciliata* and *P. obtusum*, the ME content in all grasses was significantly different among seasons and among grasses within seasons (Table 2). The ME values of the grasses calculated using the gas method were lower than those reported by Getachew et al. (2005), who evaluated 17 grass samples with values that ranged from 7.7 to 13.6 MJ/kg DM. Nonetheless, the mean values obtained in this study indicated that the energy requirements for the maintenance of growing beef cattle (8.8 MJ/kg DM; NRC, 2000) would not be satisfied.

The MP content in all grasses was significantly different among seasons and among grasses within seasons (Table 2). The highest MP contents in the studied grasses were observed in summer and autumn (mean = 70 g/kg DM), probably as a consequence of the important rainfall registered during this period of the year. It is to notice that MP of *P. obtusum* was always higher than 70 g/kg DM throughout the year, whereas in the other grasses the MP content varied from 50 to 90 g/kg DM. The lowest MP contents were recorded during winter and spring (60 g/kg DM), whereas during summer and autumn the MP content increased up to 70 g/kg DM, probably as a consequence of higher CP contents registered in this period. These variations in MP content in grasses throughout the year are in agreement with the fact that grazing pastures undergo important nutrient fluctuations along the seasons which may affect the animal performance (Bouquier et al., 1988). *P. obtusum*, *S. macrostachya. T. eragrostoides* had a higher MP content in winter and spring than *C. ciliaris* used as a reference good quality grass. A similar pattern was observed in *P. unispicatum*, *B. curtipendula*, *P. obtusum*, and *L. filiformis* in summer and autumn. Mean MP values (67 g/kg DM) in this study indicate that the consumption of grasses might fulfil the maintenance requirements of 70 g/kg growing beef cattle (Bouquier et al., 1988). In that study, the animals mainly selected a mixture of native grasses. It is important to notice that, according to the PDI system (INRA, 1987), CP concentrations above 120 g/kg might indicate that the energy content of grasses becomes the limiting factor; on the contrary, when the CP concentration is below 110 g/kg, nitrogen limits the growth of rumen microbiota. In the present study, most grasses reflected the latter scenario. Therefore, the MP content of grasses estimates the nutritional value of forages more accurately than other simple chemical determinations.

Mineral content

In general, all grasses had Ca (Table 2), P, Mg and Na concentrations that were significantly different among seasons (Table 3). Growing beef cattle require about 4.5 g of Ca/kg DM in their diets (McDowell, 2003). It seems that most of the grasses during dry seasons (winter and spring) had insufficient Ca to meet these requirements. It appears that P requirements of growing beef cattle are 3.0 g/kg in the DM of their diet. In this study, none of the grasses had sufficient P to meet the requirements. Martin-Rivera and Ibarra-Flores (1989), Dittberner and Olson (1983) and Huston et al. (1981) also found lower values of Ca and P in native grasses collected in Texas, USA. Moreover, Ramírez et al. (2004) in northeastern Mexico and Ganskoop and Bohnert (2001) in north Texas, USA, reported inadequate levels of P in native grasses to meet the growing cattle needs. With the exception of *B. curtipendula* and *B. trifida* all grasses in most seasons had marginal sufficient levels of Mg to meet the needs (1.0 g/kg DM; McDowell, 2003) of growing beef cattle. Similar results to this study were reported by González and Everitt (1982) and Pinchak et al. (1989) in native grasses growing in south Texas, Ganskoop and Bohnert (2001) in north Texas, USA and Ramírez et al. (2004) in northeastern Mexico. Conversely, Kalmbacher (1983) reported that four native grasses from Florida, USA, had insufficient amounts of Mg, in all seasons, to meet the needs of cattle.

With the exception of *B. curtipendula*, *B. trifida* and *T. muticus* (in winter), all grasses had sufficient K to meet the requirements of growing beef cattle (6.0 g/kg DM; McDowell, 2003). Native grasses with adequate levels of K for growing beef cattle needs were also reported in several species growing in south (González and Everitt, 1982; Pinchak et al., 1989) and north Texas, USA (Ganskoop and Bohnert, 2001), northeastern Mexico (Ramírez et al., 2004) and Florida, USA (Kalmbacher, 1983). In this study, high levels of K (Table 3) may cause Mg deficiency because Mg is absorbed from the rumen by two active processes against an electrochemical gradient; the process is inhibited by K (Dua and Care, 1995). In this study, in all seasons, all grasses had insufficient amounts of Na to meet the requirements. It appears that all grasses can be considered as Na non-accumulators because they contain less that 0.2 g Na/kg DM (Youssef, 1988). High K content in evaluated grasses (Table 3) could

Table 3. Seasonal and annual means of P, Mg, K and Na in cultivated grasses *Cenchrus ciliaris* and *Rhynchelytrum repens* and thirteen native grasses growing in northeastern Mexico (g/kg DM)

Grasses	Seasons[1]				M	SEM	Sig	Seasons				M	SEM	Sig
	w	sp	su	au				w	sp	su	au			
	P							Mg						
B. curtipendula	0.8	1.3	0.6	0.9	0.9	0.1	**	0.7	0.9	0.7	0.7	0.8	0.1	*
B. trifida	0.7	1.0	0.8	0.4	0.7	0.02	***	0.6	0.9	1.0	0.8	0.8	0.02	***
B. fasciculata	0.9	1.2	1.5	1.4	1.3	0.02	*	2.2	1.1	3.1	3.7	2.5	0.03	***
C. ciliaris	1.1	1.2	1.5	1.1	1.2	0.1	*	1.1	1.8	1.2	1.9	1.5	0.30	NS
C. ciliata	1.1	1.2	1.5	1.4	1.3	0.03	**	1.8	1.8	1.8	1.9	1.8	0.1	NS
D. insularis	1.0	1.4	1.0	1.1	1.1	0.04	**	0.7	2.1	1.1	1.1	1.2	0.04	***
L. filiformis	1.2	1.0	1.8	1.8	1.5	0.03	***	1.6	0.8	1.6	2.1	1.5	0.1	***
P. hallii	1.1	0.6	1.2	1.3	1.1	0.1	***	1.3	0.7	2.8	3.2	2.0	0.1	***
P. obtusum	1.4	1.1	1.4	1.7	1.4	0.1	*	2.1	1.5	1.6	1.6	1.7	0.1	***
P. unispicatum	0.9	1.6	1.7	1.3	1.4	0.02	**	1.5	2.5	3.4	2.0	2.6	0.04	***
R. repens	0.8	0.6	0.9	0.8	0.8	0.02	*	2.0	2.0	3.0	2.0	1.8	0.1	***
S. grisebachii	0.9	1.1	1.3	1.7	1.3	0.1	***	2.0	1.1	2.0	2.5	2.0	0.1	***
S. macrostachya	1.5	1.1	1.5	1.7	1.5	0.1	***	1.2	1.2	2.8	1.3	1.6	0.1	***
T. eragrostoides	1.1	1.3	1.0	1.1	1.1	0.05	*	1.3	1.2	1.2	1.3	1.3	0.04	NS
T. muticus	0.5	1.3	0.6	0.4	0.7	0.01	***	0.7	2.2	1.3	1.0	1.3	0.02	***
Seasonal means	1.0	1.1	1.2	1.2	1.1			1.4	1.5	1.9	1.8			
SEM	0.02	0.01	0.01	0.02				0.02	0.03	0.03	0.1			
Significant level	***	***	***	***				***	***	***	***			
Requirement[z]	3.0 g of P/kg of grasses DM							1.0 g of Mg/kg of grasses DM						
	K							Na						
B. curtipendula	3	7	6	4	5	0.8	***	0.1	0.1	0.2	0.2	0.2	0.1	**
B. trifida	2	4	4	2	3	0.1	***	0.2	0.1	0.2	0.2	0.2	0.04	*
B. fasciculata	6	2	33	18	15	0.4	***	0.1	0.2	0.4	0.2	0.2	0.1	***
C. ciliaris	16	29	16	24	21	0.3	***	0.6	1.0	0.7	1.4	0.9	0.1	***
C. ciliata	10	7	21	15	13	0.7	***	0.4	0.2	0.5	0.4	0.4	0.1	***
D. insularis	7	16	19	9	13	0.3	***	0.2	0.2	0.2	0.2	0.2	0.1	NS
L. filiformis	4	1	10	9	6	0.5	***	0.1	0.1	0.3	0.3	0.2	0.1	***
P. hallii	5	2	19	13	10	0.6	***	0.1	0.3	0.3	0.2	0.2	0.1	NS
P. obtusum	13	11	27	17	17	0.7	***	0.3	0.1	0.2	0.3	0.2	0.1	NS
P. unispicatum	7	21	16	13	14	0.3	***	0.2	0.4	0.2	0.2	0.3	0.2	NS
R. repens	7	7	12	8	9	0.7	***	0.1	0.2	0.1	0.2	0.2	0.1	NS
S. grisebachii	8	7	33	19	17	0.8	***	0.1	0.2	0.2	0.1	0.2	0.1	NS
S. macrostachya	19	11	40	29	25	2.8	***	0.3	0.2	1.1	0.4	0.5	0.04	***
T. eragrostoides	14	19	11	13	14	1.3	***	0.2	0.1	0.2	0.3	0.2	0.03	***
T. muticus	2	6	7	4	5	0.3	***	0.2	0.1	0.1	0.2	0.2	0.03	***
Seasonal means	8	10	18	13	12			0.2	0.2	0.3	0.3	0.3		
SEM	0.4	0.4	0.3	0.4				0.01	0.02	0.02	0.01			
Significant level	***	***	***	***				***	***	***	***			
Requirement[2]	6.0 g of K/kg of grasses DM							0.8 g of Na/kg of grasses DM						

M = mean; SEM = standard error of the mean; Sig = significant level

[1]w = winter; sp = spring; su = summer; au = autumn; SEM = standard error of the mean; Sig = significance *$P < 0.05$; **$P < 0.01$; ***$P < 0.001$; NS = not significant

[2]required by growing beef cattle (McDowell, 2003)

Table 4. Seasonal and annual means of Cu, Fe, Mn and Zn in cultivated grasses *Cenchrus ciliaris* and *Rhynchelytrum repens* and thirteen native grasses growing in northeastern Mexico (mg/g DM)

Grasses	Seasons[1]				M	SEM	Sig	Seasons				M	SEM	Sig
	w	sp	su	au				w	sp	su	au			
	Cu							Fe						
B. curtipendula	2	2	1	2	2	0.3	NS	56	66	92	84	74	6.0	***
B. trifida	3	2	2	2	2	0.2	**	79	78	189	75	105	20.1	***
B. fasciculata	3	4	8	2	4	0.2	***	100	128	153	175	139	5.8	***
C. ciliaris	5	10	8	9	8	0.2	***	114	164	120	176	144	8.1	***
C. ciliata	3	3	6	4	4	0.2	***	119	198	150	165	158	10.4	***
D. insularis	2	6	3	2	3	0.3	***	58	108	143	191	125	12.5	***
L. filiformis	6	5	2	3	4	0.4	***	118	120	126	124	122	18.4	***
P. hallii	3	2	6	3	3	0.2	***	188	126	188	180	170	5.7	***
P. obtusum	6	5	3	4	5	0.3	***	188	176	188	181	183	8.5	***
P. unispicatum	4	6	4	4	4	0.2	***	116	135	152	185	147	6.0	***
R. repens	3	4	6	4	4	0.2	***	53	77	135	97	91	5.5	***
S. grisebachii	2	3	7	3	4	0.2	***	104	90	147	122	116	7.8	***
S. macrostachya	2	3	8	3	4	0.5	***	91	75	155	99	105	11.4	***
T. eragrostoides	4	5	3	3	4	0.4	***	148	108	173	110	135	13.9	***
T. muticus	2	2	2	2	2	0.1	NS	117	96	137	113	115	4.6	***
Seasonal means	3	4	5	3	4			110	116	150	138	129		
SEM	0.1	0.1	0.1	0.1				4.7	6	6	4			
Significant level	***	***	***	***				***	***	***	***			
Requirement[z]	10 mg of Cu/kg of grasses DM							50 mg of Fe/kg of grasses DM						
	Mn							Zn						
B. curtipendula	46	40	49	47	45	1.2	***	31	45	64	50	48	4.5	***
B. trifida	38	30	38	36	36	0.8	***	15	25	29	27	24	3.8	***
B. fasciculata	54	31	78	89	63	2.0	***	46	45	64	55	52	3.1	***
C. ciliaris	27	44	33	39	36	1.4	***	41	52	43	71	52	1.5	***
C. ciliata	70	67	80	76	88	2.8	***	31	51	46	45	43	1.3	***
D. insularis	28	27	23	33	27	1.4	***	61	47	74	60	60	2.8	***
L. filiformis	25	24	29	22	25	1.9	***	49	43	62	61	53	3.8	***
P. hallii	46	38	45	45	43	1.0	***	29	29	58	29	37	2.3	***
P. obtusum	34	32	34	38	35	0.8	***	32	44	58	52	46	3.4	***
P. unispicatum	25	46	48	42	40	0.7	***	66	53	82	76	69	2.1	***
R. repens	30	24	29	27	28	1.5	***	50	51	39	43	46	2.7	***
S. grisebachii	31	29	35	30	31	1.2	***	55	57	69	59	60	5.4	***
S. macrostachya	31	36	40	33	35	1.5	***	59	59	57	43	55	5.6	NS
T. eragrostoides	38	31	44	40	38	2.1	***	50	64	66	53	58	4.4	***
T. muticus	22	29	30	28	27	0.6	***	29	38	31	37	34	1.4	***
Seasonal means	36	35	42	42	40			43	47	56	51	49		
SEM	0.8	1.7	0.8	0.8				1.3	0.8	0.4	1.0			
Significant level	***	***	***	***				***	***	***	***			
Requirement[2]	20 mg of Mn/kg of grasses DM							30 mg of Zn/kg of grasses DM						

M = mean; SEM = standard error of the mean; Sig = significant level

[1]w = winter; sp = spring; su = summer; au = autumn; SEM = standard error of the mean; Sig = significance *$P < 0.05$; **$P < 0.01$; ***$P < 0.001$; NS = not significant

[2]required by growing beef cattle (McDowell, 2003)

Table 5. Seasonal and annual means of the DM *in situ* digestibility parameters and effective degradability of DM in grasses

Grasses	Seasons[1] w	sp	su	au	M	SEM	Sig	Seasons w	sp	su	au	M	SEM	Sig
	a (DM)							*b* (DM)						
B. curtipendula	0.16	0.19	0.18	0.2	0.18	0.002	***	0.27	0.24	0.26	0.24	0.25	0.003	**
B. trifida	0.16	0.21	0.23	0.21	0.2	0.002	***	0.24	0.21	0.2	0.25	0.22	0.004	**
B. fasciculata	0.18	0.19	0.36	0.21	0.23	0.003	***	0.28	0.23	0.32	0.32	0.29	0.004	***
C. ciliaris	0.19	0.26	0.32	0.23	0.25	0.003	***	0.29	0.28	0.31	0.36	0.31	0.005	***
C. ciliata	0.22	0.21	0.32	0.25	0.25	0.002	***	0.23	0.24	0.25	0.19	0.23	0.002	***
D. insularis	0.26	0.23	0.26	0.23	0.24	0.001	***	0.18	0.28	0.29	0.32	0.27	0.003	***
L. filiformis	0.18	0.19	0.20	0.23	0.20	0.002	***	0.27	0.29	0.34	0.34	0.31	0.005	***
P. hallii	0.18	0.21	0.26	0.24	0.22	0.002	***	0.21	0.24	0.34	0.29	0.27	0.005	***
P. obtusum	0.20	0.35	0.31	0.26	0.28	0.001	***	0.20	0.20	0.45	0.31	0.29	0.004	***
P. unispicatum	0.16	0.21	0.26	0.26	0.22	0.002	***	0.27	0.20	0.24	0.29	0.25	0.002	***
R. repens	0.19	0.25	0.25	0.23	0.23	0.002	***	0.25	0.21	0.19	0.23	0.22	0.002	***
S. grisebachii	0.18	0.25	0.32	0.23	0.24	0.002	***	0.27	0.19	0.44	0.28	0.29	0.004	***
S. macrostachya	0.18	0.21	0.27	0.22	0.22	0.001	***	0.21	0.22	0.40	0.24	0.27	0.005	***
T. eragrostoides	0.24	0.23	0.24	0.19	0.22	0.001	***	0.23	0.23	0.32	0.25	0.26	0.006	**
T. muticus	0.16	0.21	0.25	0.21	0.21	0.001	***	0.24	0.2o	0.36	0.22	0.26	0.003	***
Seasonal means	0.19	0.23	0.27	0.23	0.23			0.24	0.23	0.31	0.27	0.26		
SEM	0.003	0.003	0.004	0.001				0.003	0.003	0.004	0.001			
Significant level	*	**	***	**				***	**	***	**			
	c (h)							EDDM (DM)						
B. curtipendula	0.05	0.04	0.06	0.06	0.05	0.002	***	0.35	0.38	0.36	0.38	0.37	0.002	***
B. trifida	0.05	0.05	0.06	0.06	0.06	0.002	*	0.33	0.37	0.38	0.39	0.37	0.001	***
B. fasciculata	0.05	0.06	0.04	0.06	0.05	0.001	***	0.38	0.36	0.58	0.45	0.44	0.003	***
C. ciliaris	0.06	0.07	0.03	0.06	0.06	0.002	***	0.39	0.47	0.53	0.50	0.47	0.002	***
C. ciliata	0.06	0.07	0.04	0.07	0.06	0.001	***	0.39	0.40	0.50	0.4	0.42	0.001	***
D. insularis	0.04	0.06	0.07	0.05	0.06	0.001	***	0.38	0.44	0.48	0.46	0.44	0.002	***
L. filiformis	0.05	0.04	0.04	0.06	0.05	0.001	***	0.38	0.4	0.44	0.49	0.43	0.004	***
P. hallii	0.06	0.05	0.04	0.06	0.05	0.002	**	0.36	0.39	0.49	0.45	0.43	0.003	***
P. obtusum	0.05	0.07	0.02	0.05	0.05	0.002	***	0.35	0.41	0.59	0.49	0.46	0.002	***
P. unispicatum	0.05	0.06	0.05	0.06	0.06	0.001	**	0.35	0.36	0.43	0.47	0.40	0.001	***
R. repens	0.05	0.06	0.06	0.05	0.06	0.001	***	0.38	0.41	0.41	0.39	0.40	0.001	***
S. grisebachii	0.06	0.06	0.03	0.06	0.05	0.001	***	0.38	0.39	0.62	0.43	0.42	0.002	***
S. macrostachya	0.05	0.06	0.03	0.05	0.05	0.001	***	0.33	0.37	0.54	0.40	0.41	0.003	***
T. eragrostoides	0.05	0.05	0.03	0.05	0.04	0.001	***	0.41	0.41	0.44	0.38	0.41	0.002	***
T. muticus	0.05	0.06	0.04	0.05	0.05	0.001	***	0.34	0.36	0.51	0.37	0.39	0.002	***
Seasonal means	0.05	0.06	0.04	0.05	0.05			0.37	0.4	0.49	0.43	0.42		
SEM	0.007	0.001	0.001	0.001				0.002	0.003	0.005	0.003			
Significant level	*	***	***	**				***	***	***	***			

M = mean; SEM = standard error of the mean; Sig = significant level

[1]w = winter; sp = spring; su = summer; au = autumn; SEM = standard error of the mean; Sig = significance; *$P < 0.05$; **$P < 0.01$); ***$P < 0.001$

a = intercept representing the portion of DM solubilized at the beginning of incubation (time 0); *b* = portion of DM that is slowly degraded in the rumen; *c* = rate constant of disappearance of fraction *b*

EDDM = effective degradability of DM assuming an outflow rate of 0.05/h reduce the Na absorption of sheep feeding on these grasses because it has been reported that elevated dietary K may decrease the ruminal concentration and absorption of Na in ruminants (Spears, 1994). However, sodium deficiencies can be alleviated by supplementing common salt.

In general, all grasses had Cu, Fe, Mn and Zn concentrations (Table 4) that were significantly different among seasons. It seems that all grasses, in all seasons, had insufficient Cu to meet the requirements of growing beef cattle (10 mg/kg DM; McDowell, 2003). Low Cu concentrations were also found in native grasses growing in semiarid regions of south Texas, USA (Barnes et al., 1990) and northeastern Mexico (Ramírez et al., 2004). Low Cu in evaluated grasses may be caused by the high pH (7.5–8.5) in soils (Spears, 1994) of these regions. Growing beef cattle requires 50 g/kg of Fe in the DM of their diets (McDowell, 2003). In this study, all grasses in all seasons had Fe in amounts to meet the requirements. Similar findings were reported by Ramírez et al. (2004). They sustained that range grasses had Fe levels in substantial amounts to meet the requirements. Ganskoop and Bohnert (2001), who evaluated Fe content in native grasses growing in north Texas, USA, found levels (> 48 mg/kg) that also exceeded the requirements. In addition, Kalmbacher (1983) reported that native grasses from Florida, USA, had sufficient Fe for the requirements of pregnant beef cattle. Iron deficiency seldom occurs in grazing ruminants due to generally adequate pasture concentrations and contamination of plants by soil. Soil contamination of forages and direct soil consumption often provide excess quantities of dietary Fe (McDowell, 2003). Even though Mn content was lower during winter and spring, all grasses had sufficient amounts, in all seasons, to meet the requirements of growing beef cattle (20 g/kg of DM; McDowell, 2003). Although Mn deficiency has been produced experimentally in ruminants, with effects on skeletal development and reproductive performance, doubt has been expressed whether this deficiency arises under field conditions. However, contrary to our findings, Mn deficiency for ruminants under grazing conditions was reported in the USA and other countries (McDowell, 1985). All grasses had Zn content to meet the requirements of growing beef cattle (30 g/kg DM; McDowell, 2003). Similar findings were reported by Ramírez et al. (2004), who evaluated the Zn content of seven native grasses growing in northeastern Mexico. However, Ganskoop and Bohnert (2001) found that the amount of Zn (mean = 28 g/kg DM) in native grasses growing in north Texas, USA, was insufficient to satisfy the growing cattle requirements. A high level of Ca increases the dietary Zn requirements, so that supplemental Zn is required to prevent parakeratosis in cattle when the diet is high in Ca. However, in this study the Ca levels, especially during dry seasons, were lower, thus Zn deficiency cannot occur.

Effective degradability of dry matter

The fraction of DM solubilized at the beginning of incubation of grasses in the rumen of sheep (a), the fraction of DM that is slowly degraded in the rumen (b) and the rate constant of disappearance of fraction b were significantly different among seasons and among grasses within seasons (Table 5). The same pattern was observed in EDDM. *C. ciliaris* had higher annual mean EDDM and *B. curtipendula* and *B. trifida* were lower. In general, during summer and autumn EDDM was higher than in the other seasons. In all seasons, all native grasses and *R. repens* had lower EDDM than *C. ciliaris* (Table 2). EDDM in all grasses was in the range from 0.33 to 0.62. These values coincide with those reported by Čerešňáková et al. (2007), but they are lower than those reported for forages from legumes (0.63–0.77).

It seems that CP content in evaluated grasses influenced the rumen digestion of DM positively because when CP increased, EDDM also increased (r = 0.67; $P < 0.001$). Seasonal rainfall and temperatures had the same influence ($r = 0.47$, $P < 0.001$; $r = 52$, $P < 0.001$, respectively) on EDDM. Conversely, when lignin increased ($r = -0.50$; $P < 0.001$), EDDM decreased. Positive effects of CP and precipitation on EDDM in the forage of grasses were previously reported by Ganskoop and Bohnert (2001). They found that when CP in seven native grasses, collected in a rangeland of the Estate of Idaho, USA, and rain precipitation increased, *in vitro* dry matter digestibility also increased. These effects were also reported in native grasses such as *B. gracilis*, *P. hallii*, and *S. macrostachya* growing in northeastern Mexico (Ramírez et al., 2004).

CONCLUSIONS

Even though the CP content of grasses was affected by climatic conditions, all grasses, in all seasons, had sufficient CP and MP content to meet the maintenance requirements (70 g/kg) of growing beef cattle; higher levels were observed in summer and autumn. The same pattern occurred in EDDM. Growing beef cattle grazing on these grasses could not require supplementary Mg, K, Fe, Mn and Zn but they must require P, Na and Cu supplementation throughout the year, whereas Ca would be complementary when seasonal rainfall is scarce. Because of their higher CP and mineral content, grasses such as *B. fasciculata*, *C. ciliata*, *P. hallii*, *P. obtusum*, *S. grisebachii*, *S. macrostachya* and *T. eragrosto*ides can be considered to be of good nutritional quality. In this study, *Rhynchelytrum repens* had lower nutritional quality than *C. ciliaris*. However, the ME content of the forages calculated from *in vitro* gas production may not meet the maintenance requirements of beef cattle. Although the MP content confirms the good quality of studied grasses, it was also observed in most grasses that CP content might be the limiting factor for the growth of rumen microbiota and productive purposes.

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Received: 2008–06–03
Accepted after corrections: 2008–11–14

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