Rev Mex Cienc Pecu 2017;8(4):437-443

http://dx.doi.org/10.22319/rmcp.v8i4.4197

# Macro-mineral concentrations in soil and forage in three grassland sites at Zacatecas

# Concentración de macro minerales en el suelo y forraje de tres sitios en Zacatecas

M. Márquez-Madrid[ab], H. Gutiérrez-Bañuelos[a], R. Bañuelos-Valenzuela[a], A. Muro-Reyes[a], R. David Valdez-Cepeda[bc*]

## ABSTRACT

**Mineral concentration in forage is an important factor for extensive livestock production. Therefore, a study was performed in order to evaluate the soil mineral contents and their relationships with forage mineral concentrations taking into account three grassland sites located at Zacatecas state, México. Soil organic matter (OM) content and pH as well as soil and forage contents of Ca, P, Mg, Na and K were estimated. Soil OM contents were not different (*P*>0.05) among sites averaging 2.99 %. Soil pH of site 2 was higher (*P*≤0.05) than those of sites 1 and 3. Soil of site 2 had higher P, Ca and Mg concentrations than the minimum contents used as references. Soil contents of Na and K were lower than the reference contents suggesting deficiencies in all three sites. Considering requirements for growing cattle, P, Ca and Na were at insufficient levels in forage from all three sites. Significant correlations (r Pearson) suggest a positive effect of soil P content on forage P and Mg concentrations. Soil P content could affect forage Ca concentration and Ca:P ratio. Other correlations suggest soil Ca negative effects on forage Ca concentration and Ca:P ratio.**

**KEY WORDS: Phosphorus, Calcium, Magnesium, Sodium, Potassium.**

## RESUMEN

**La concentración de los minerales en el forraje es un factor importante en la ganadería extensiva. Por consiguiente, un estudio se realizó para evaluar los contenidos de minerales en el suelo y sus relaciones con las concentraciones de los minerales en el forraje, al involucrar tres sitios de pastizales en el estado de Zacatecas, México. Se estimó el contenido de materia orgánica (MO) y el pH del suelo, así como las concentraciones de Ca, P, Mg, Na y Mg en suelo y forraje. Los contenidos de MO en el suelo no fueron diferentes (*P*>0.05) entre sitios con un promedio de 2.99 %. El pH del suelo del sitio 2 fue mayor (*P*≤0.05) que el pH de los suelos de los sitios 1 y 3. Las concentraciones de P, Ca y Mg en el suelo del sitio 2 fueron mayores que los contenidos de referencia. Los contenidos de Na y K en los suelos de los tres sitios fueron menores que los valores de referencia, lo cual sugiere deficiencias. Al considerar los requerimientos del ganado vacuno en crecimiento, P, Ca y Na estuvieron a niveles de insuficiencia en el forraje de los tres sitios. Correlaciones significativas (r Pearson) sugieren un efecto positivo del P en el suelo sobre P y Mg en el forraje. El P del suelo puede afectar al Ca y a la proporción Ca:P del forraje. Otras correlaciones sugieren efectos negativos del Ca en el suelo sobre el Ca y la proporción Ca:P en el forraje.**

**PALABRAS CLAVE: Fósforo, Calcio, Magnesio, Sodio, Potasio.**

Recibido el 20 de julio de 2016. Aceptado el 20 de marzo de 2017.

[a] Universidad Autónoma de Zacatecas, Unidad Académica de Medicina Veterinaria y Zootecnia, Programa de Doctorado en Ciencias Pecuarias. CP 98500. Calera de V.R., Zacatecas, México. E-mails: ac10279@chapingo.mx (MM-M), gtzbahector@hotmail.com (HG-B), apozolero@hotmail.com (RB-V), amurey@hotmail.com (AM-R).

[b] Universidad Autónoma Chapingo, Centro Regional Universitario Centro-Norte. CP 98053. Km 24.5 Carretera Zacatecas-Fresnillo. Morelos, Zacatecas, México.

[c] Universidad Autónoma de Zacatecas, Unidad Académica de Matemáticas. Paseo la Bufa, Calzada Solidaridad. CP 98060. Zacatecas, Zac., México.

*Corresponding Author: name. E-mail: vacrida@hotmail.com

Mineral elements are essential nutrients for animals and have effects on livestock performance[1]. In fact, minerals represent 5 % of the body weight[1]. Most of this weight corresponds to seven macro-minerals or macronutrients, which play important roles in the animal body. For instance, Calcium (Ca) and phosphorus (P) are structural components of bones and teeth[2]. Potassium (K) is important in acid-base balance, regulation of osmotic pressure, water balance, muscle contractions, nerve impulse transmission and certain enzyme reactions[2]. Magnesium (Mg) activates more than 300 enzymes[3]. Sodium (Na) and Chlorine (Cl) are involved in maintaining osmotic pressure, controlling water balance, and regulating acid-base balance[2]. Sulfur (S) is a component of methionine, cysteine, B-vitamins, and other organic compounds[2]. Therefore, ensuring an adequate supply of mineral nutrients to livestock is essential for maintaining their growth, health and reproduction[4]. In that context, forage nutrient target values have been proposed to provide growing cattle and lactating cow requirements[1,2].

There is widely recognized that the main source of minerals for animals is forage. Forage is plant material (mainly plant leaves and stems) eaten by grazing livestock. Forage yield and its mineral composition varies among grassland areas and perhaps within each of them. Forage yield and its mineral composition depend on soil and climate factors, botanical composition, and plants age, among other issues. For instance, low availability of P and Na could be the primary reason for mineral deficiencies in grazing animals[5]. That is, grasslands could provide insufficient quantities of macronutrients to meet animal requirements[6].

There is known insufficiency of at least one of the macronutrients may affect animal growth, and its health and reproductive functions[7]. This type of situations may be improved through mineral supplementation[2,4]. Nonetheless, many managers of grasslands do not know current forage composition and its relationships with limitative factors. This is the case of Zacatecas state, Mexico ranchers. This state has 494,203 ha of natural grasslands[8], which are mainly managed under the called cow-calf production system. Along these grasslands, dominant species belong to perennial and yearly grasses of the genus *Bouteloua*, *Aristida*, *Lycurus* and *Muhlenbergia*[9]. Then, knowledge on such a topic might be useful to make decisions towards improving the use of the resources involved in the production system, mainly during summer and early autumn when there is maximum forage yield due to rainfall distribution. Therefore, the aim of this research work was to evaluate the soil mineral contents and their relationships with forage mineral concentrations taking into account three grassland sites located at Zacatecas state, México.

A fieldwork was carried out during the end of the rainy season (October, 2013) throughout three beef cattle sites within the territory of Zacatecas state, Mexico. All three sites were managed under the called cow-calf production system. Site 1 is located between the coordinates 23º 40′ and 23º 39′ N, and between 103º 28′ and 103º 27′ W at an altitude of about 2,250 m; it corresponds to an open medium size grassland; this site is within an area of 406 ha, which maintained 45 animal units during all year. Site 2 is between 23º 18′ and 23º 17′ N, and between 102º 46′ and 102º 47′ W at an altitude of about 2,110 m; this site belongs to an open medium size shrub-grassland associated with cactus; it is within an area of 482 ha, which maintained 35 animal units during the four seasons. Site 3 is allocated between 23º 29′ and 23º 27′ N, and between 103º 42′ and 103º 4′ W at 2,240 m; it corresponds to an open medium size grassland within an area of 170 ha, which maintained 32 animal units during summer and autumn. Climate of all three sites is classified as semi-dry ($BS_1kw$), with annual mean temperature and yearly mean rainfall of 16 to 18 °C and 400 to 500 mm, respectively[10]. In all three sites, dominant grass species included *Bouteloua gracilis* (blue grama), *Bouteloua curtipendula* (Sideoats grama), *Lycurus phleoides* (common wolf tail), *Aristida arizonica* (Arizona three-awn grass) and *Aristida divaricata* (poverty three awn), *Muhlenbergia porter* (bush muhly), and *Microchloa kunthii* (Kunth's smallgrass).

For surface soil (0 to 15 cm) samples collection using Rodríguez and Rodríguez[11] procedure. Each site was divided in four sections. A total of 40 samples were collected from each section. Then, these 40 samples were mixed to obtain a composite sample. So, four composite soil samples belonged to each site. As a result and taking into account the three sites, 12 composite soil samples were obtained.

Forage samples were taken following the same sections used for soil sampling. In other words, each site was divided in four sections. Forage samples were collected from each site using the "hand plucking" simulation technique(12). As a result, four forage samples belonged to each site, obtaining a total of 12 forage samples.

All 12 composite soil samples were dried at 60 °C during 48 h, and sieved through a 2 mm screen. Afterwards, soil pH was determined through a pH meter using a supernatant suspension of a mixed soil to water ratio of 1:2. Available P was measured by means of two different techniques: if pH was alkaline, Olsen *et al*(13) method was performed by using 0.5M of $NaHCO_3$ adjusted at 8.5 pH; and when pH was acid, the other technique(14) was carried out by using a extraction solution of HCl and $NH_4F$. Cations Ca, Mg, K and Na were extracted by shaking 3 g of air-dried soil in 30 mL of 1M NH4OAc for 30 min; extracts were centrifuged(15), and the supernatant was decanted and analyzed by spectrometry(16,17). Organic matter of soil was determined through organic carbon content using Walkley and Black approach(18).

All 12 forage samples were dried at 60 °C during 48 h and ground through a 1 mm screen in a Wiley mill. Ash was determined by tissue incineration at 600 °C during 8 h. Hydrochloric and nitric acids were used to degrade resultant ash. Calcium, K, Mg, and Na concentrations were obtained by an atomic absorption spectrophotometry (Varian, AA240FS)(19). Phosphorus concentration was determined by spectrophotometry (UV/VIS Lambda 2, Perkin Elmer). Relationship K/(Ca+Mg) was calculated in miliequivalents, mEq(20).

Soil and forage samples were randomly collected at field. Measured variables were soil available P, Ca, Mg, Na, and K contents, and soil pH and organic matter content (OM). In addition, forage concentrations of these macronutrients (P, Ca, Mg, Na, and K) were measured. Soil mineral contents were contrasted with soil reference contents pointed out by McDowell(21) for P, Ca and K, and Rhue and Kidder(22) for Mg and Na. In addition, estimated forage mineral mean concentrations were compared with cattle mineral requirements(1,2).

Soil and forage variables were analyzed under a completely random design. The analyses of variance were performed using the General Lineal Model(23) and the factor site as main effect. The Tukey test ($P \leq 0.05$) was used to compare mean effects of sites, that is, Ho: site 1=site 2=site 3. In addition, Pearson correlation coefficients (r, $P \leq 0.05$) were computed to identify the degree of linear relationships between soil and forage variables trough the PROC CORR in the Statistical Analysis System(23).

Soil OM contents varied from 2.83 to 3.15 % averaging 2.99 % (Table 1). OM contents from soils

Table 1. Mineral mean concentrations, pH and organic matter (OM) in soil samples collected from three native rangelands (Sites) used for beef cattle in Zacatecas state, Mexico

| | Site | | | Mean | *P* | Soil content |
|---|---|---|---|---|---|---|
| | 1 | 2 | 3 | Standard Error | | suggesting deficiencies[w] |
| P, mg kg$^{-1}$ [u] | 5.58 $^a$ | 92.90 $^b$ | 4.40 $^a$ | 13.10 | <0.001 | <10 |
| Ca, mg kg$^{-1}$ | 41.95 $^a$ | 83.20 $^b$ | 23.65 $^a$ | 7.73 | <0.001 | <70 |
| Mg, mg kg$^{-1}$ | 28.93 $^a$ | 53.93 $^b$ | 23.88 $^a$ | 4.28 | <0.001 | <30 |
| Na, mg kg$^{-1}$ | 5.45 $^a$ | 4.38 $^a$ | 1.10 $^a$ | 0.85 | 0.076 | <62 |
| K, mg kg$^{-1}$ | 27.75 $^a$ | 17.03 $^a$ | 16.80 $^a$ | 2.58 | 0.137 | <59 |
| pH | 6.35 $^a$ | 8.33 $^b$ | 6.13 $^a$ | 0.30 | <0.001 | 5.8-7.5 |
| OM, % | 3.15 $^a$ | 3.00 $^a$ | 2.83 $^a$ | 0.22 | 0.863 | 1.8-3.5 |

[w] P, Ca and K(21), and Mg and Na(22) contents suggesting deficiencies; ideal pH interval for most of the plants and organic matter content range (%) for non-volcanic soils(11).

[u] For soil samples from the sites 1 and 3, P was determined by means of the Bray y Kurtz(14) approach; and for soil samples from the site 2, the Olsen *et al*(13) procedure was used.

ab Means with different letters within each row indicate difference among sites ($P<0.05$).

of the three sites are within the range linked to plant nutrient deficiencies. Soil OM contents were not different among the three sites. Thus, these three sites have soils with medium OM content as pointed out by others[11]. The OM values of the mentioned range are higher than that reported by Echavarría *et al*[24] for the case of a natural grassland composed by thorny bushes and cacti in the Zacatecas state, Mexico. This difference could be due to yearly produced forage in the three sites is not entirely used by livestock, then, surplus forage should be incorporated into the soil, whereas the grassland of the cited case was under overgrazing condition.

Values of pH corresponding to soils of the sites 1 and 3 are within the range linked to plant nutrient deficiencies but that to soil of the site 2 is higher than the upper limit of such a range. Soil pH of site 2 was higher ($P≤0.05$) than those of sites 1 and 3. Remarkably, values of soil pH <6.5 were estimated for the sites 1 and 3; then, this soil condition could diminish P, Ca and Mg absorption by plants[11]. On the other hand, soil pH=8.33 could be too alkaline for most plants in the site 2 case. This situation explains, in part, why soil of the site 2 soil had higher available P than soils of the sites 1 and 3.

Concentrations of P, Ca and Mg from soil of the site 2 were higher than the soil reference content. On the other hand, those from soils of the sites 1 and 3 were lower than the target. In addition, soil P, Ca and Mg mean contents were strongly different ($P≤0.001$) among sites. Therefore, soil P, Ca and Mg could be limitative factors of plant growth in the sites 1 and 3, which reinforce the result on soil pH.

Contents of Na and K in soils from all three sites are lower than those reported as soil reference levels suggesting deficiencies. Moreover, soil Na and K concentrations were not statistically different among all sites under study. Therefore, soil Na and K concentrations suggest both macro-minerals could be limitative nutrients of plant growth in all three sites.

Notably, P, Ca, Mg and Na concentrations in forage from all three sites were strongly lower ($P≤0.05$) than those considered as requirements for growing cattle and lactating cows, except Mg content in forage from the site 2 for growing cattle case (Table 2). These results suggest P, Ca, Mg and Na deficiencies in foraging plants from all three sites. In addition, K/Ca+Mg index in forage from all three sites was lower than the references for growing cattle and lactating cows. On the other hand, forage from sites 1 and 2 shown higher K concentrations than requirements for growing cattle and lactating cows. In addition, Ca:P ratio in forage from the site 2 did not surpass the reference value for both growing cattle and lactating cow. Ca:P ratio in forage from the site 1 was higher than the reference value for growing cattle, and Ca:P ratio in forage from the site 3 was higher than both growing cattle and lactating cow reference values.

The evidenced P deficiency in all three sites agrees with a marginal P deficiency for range

Table 2. Forage mineral concentrations at native rangelands (Sites) used for beef cattle in Zacatecas state, Mexico

| Mineral | Site | | | Mean Standard Error | *p* | Reference value (Requirement)[w] | |
|---|---|---|---|---|---|---|---|
| | 1 | 2 | 3 | | | Growing cattle | Lactating cow |
| P, % | 0.17[ab] | 0.23[b] | 0.10[a] | 0.0177 | 0.002 | 0.25 | 0.25 |
| Ca, % | 0.21[a] | 0.18[a] | 0.23[a] | 0.0103 | 0.075 | 0.30 | 0.30 |
| Mg, % | 0.07[a] | 0.10b | 0.08[a] | 0.0063 | 0.022 | 0.10 | 0.20 |
| Na, % | 0.05[a] | 0.04[a] | 0.04[a] | 0.0055 | 0.664 | 0.06–0.08 | 0.10 |
| K, % | 0.72[a] | 0.72[a] | 0.57[a] | 0.0394 | 0.236 | 0.60 | 0.70 |
| Ca:P | 1.34[ab] | 0.80[b] | 2.47[a] | 0.2590 | 0.008 | 1.1 | 2 |
| K/Ca+Mg, mEq[v] | 1.20[a] | 1.04[a] | 0.81[a] | 0.0848 | 0.176 | <2.2 | <2.2 |

[w] Mineral minimum requirements for growing and lactation beef cattle[1,2].

[v] Tetany potential, mEq[20].

[ab] Means within a row with different superscript differ ($P<0.05$).

forages (foliage from trees and cacti) from seven locations within the territory of Durango State, Mexico[25]. It is noteworthy the results on P may be considered as similar to findings of other research[26], who reported P contents of 0.13 % for a grassland in Durango state, Mexico. Those agreements can be explained because the sites of our study and that grassland are within the Chihuahua Desert.

Concentrations of Ca in forage from all three sites and those corresponding to requirements are lower than that (0.57 %) found by Murillo *et al*[26]. This disagreement is unexplained because in that work did not report soil Ca content and botanical composition. In addition, the case of the resulting Mg deficiency in forage from all three sites is similar to other report[27] in the case of oats and ryegrass in Northwestern Florida, United States of America.

Concentrations of Na and K in forage from all three sites and those considered as requirements are lower than those reported elsewhere (i.e. Na =0.15 %[26] and K=1.1 %[28] in forage) for grasslands at Durango state, Mexico. It is not easy explaining those disagreements because they did not report soil K and Na contents and botanical composition.

Concentrations of P and Mg as well as the Ca:P ratio showed strong differences ($P \leq 0.05$) among sites. On the other hand, differences of Ca, Na, K, and the K/Ca+Mg index among sites were not significant ($P > 0.05$). Nonetheless, due that K/Ca+Mg values did not surpass both mentioned reference values, there persist a risk of grass tetany or hypomagnesaemia occurrence in lactating cows grazing, especially at the sites 1 and 3 because of the forage having Ca and Mg at insufficiency levels.

Soil pH was positively correlated with P and Mg concentrations in forage and negatively correlated with Ca content and Ca:P ratio in forage (Table 3). These results suggest as pH increase, P and Mg contents in forage tend to be higher, and Ca content and Ca:P ratio in forage tend to be lower. The alkaline soil pH could explain P, Ca and Mg high availability in the site 2 case.

Soil available P content showed significant ($P \leq 0.05$) positive linear correlations with P and Mg concentrations in forage as well as negative linear correlations with Ca concentration and Ca:P ratio in forage. These correlations suggest positive effects of soil P content on P and Mg concentrations in forage, and indicate negative effects of soil P content on Ca concentration and Ca:P ratio in forage. These results could be explained because of the restricted quantity of available P in the soil from the sites 1 and 3 (Table 1) and to the fact that Ca fixes P at the interchange sites in alkaline soils.

Available Ca in the soil was positively correlated ($P \leq 0.05$) with P and Mg concentrations in forage and negatively with Ca concentration and Ca:P ratio in forage. Those correlations indicate positive effects of soil Ca on P and Mg concentrations in forage, and suggest soil Ca negative effects on Ca concentration and Ca:P ratio in forage. These results suggest plants prefer to take up calcium phosphates and

Table 3. Pearson correlation coefficients (r) between soil and forage variables

| Plant (%) | | Soil (mg kg$^{-1}$) | | | | |
|---|---|---|---|---|---|---|
| | | P | Ca | Mg | Na | pH |
| P | r | 0.758 | 0.845 | 0.752 | | 0.804 |
| | *p* | 0.004 | 0.001 | 0.005 | NS | 0.002 |
| Ca | r | -0.590 | -0.706 | -0.750 | -0.719 | -0.601 |
| | *p* | 0.043 | 0.010 | 0.005 | 0.008 | 0.039 |
| Mg | r | 0.740 | 0.609 | | | 0.751 |
| | *p* | 0.006 | 0.036 | NS | NS | 0.005 |
| Ca:P | r | -0.608 | -0.772 | -0.700 | -0.601 | -0.654 |
| | *p* | 0.036 | 0.003 | 0.011 | 0.039 | 0.021 |

NS= Not significant.

many Ca ions were fixed as its availability increased, whereas soils could had have a low potential to fix natural P. This late idea is supported by Gagnon *et al*[29] finding in the case of alkaline soils.

Soil available Mg content showed a significant ($P$≤0.05) positive linear correlation with P concentration in forage and negative correlations with Ca concentration and Ca:P ratio in forage. These results mean P concentration in forage increased as soil available Mg content did, whereas Ca concentration and Ca:P ratio in forage decreased as soil available Mg increased. However, due to the lack of correlation between soils available Mg content and Mg concentration in forage, there appear soil available Mg content could be a limitative factor as pointed out *ut supra*, that is, it is at insufficiency levels in the soil, especially in the sites 1 and 3.

Available Na in the soil was negatively correlated with Ca concentration and Ca:P ratio in forage. These relationships suggest that whereas available Na increased in the soil, Ca concentration and Ca:P ratio in forage diminished. However, due to available Na in soil is at insufficiency level, there remains the idea on improving this situation throughout inclusion of such a mineral in food intake.

In general, results suggest current situation of P and Ca insufficiencies in forage could affect growth of cattle and food use efficiency[1]. Consequently, these problems should be solved through increasing P and Ca concentrations by means of soil or foliar fertilization or including these minerals in food intake.

In general, soil of the site 2 showed better conditions for plant growth than those of the sites 1 and 3. Nonetheless, Na and K in soil could be limitative nutrients of plant growth in all three sites. Macro-minerals P, Ca and Na in forage from all three sites were at insufficient levels for growing cattle and lactating cows. Concentration of Mg in forage from sites 1 and 3 were at insufficient levels, and K in forage was at insufficient level in the site 3, mainly for growing cattle. Significant correlations suggest a positive effect of soil P content on forage P and Mg concentrations, and indicate soil P content may affect forage Ca concentration and Ca:P ratio. Other important correlations indicate positive effects of soil Ca on forage P and Mg concentrations, and suggest soil Ca negative effects on Ca concentration and Ca:P ratio in forage. The lack of correlation between soil available Mg content and Mg concentration in forage suggest soil available Mg content could be a limitative factor as pointed out *ut supra*, that is, it is at insufficiency levels in the soil, especially in the sites 1 and 3. Moreover, available Na in soil of the three sites was at insufficiency level. Then, the evidenced nutrient insufficiencies can be improved through increasing nutrient forage concentrations by means of soil or foliar fertilization, or including these minerals in food intake.

## ACKNOWLEDGEMENTS

Thanks to "Centro de Investigaciones en Recursos Naturales y Medio Ambiente" of the "Universidad Autónoma Chapingo", which partially supported the research project through the grant number 147302001.

## CITED LITERATURE

1. McDowell LR, Arthington JD. Minerales para rumiantes en pastoreo en regiones tropicales. 4ª ed. Universidad de Florida, Gainesville, Florida, USA; 2005.
2. National Research Council (NRC). Nutrient requirements of beef cattle. Seventh rev ed. Washington, DC, USA: National Academy Press; 2000.
3. Wacker WEC. Magnesium and man. Cambridge, Mass., USA: Harvard University Press; 1980.
4. Jones GB, Tracy BF. Evaluating seasonal variation in mineral concentration of cool-season pasture herbage. Grass Forage Sci 2013;70:94-101.
5. Suttle NF. Mineral nutrition of livestock. Cabi. 2010.
6. Grings EE, Haferkamp MR, Heitschmidt RK, Karl MG. Mineral dynamics in forages of the Northern Great Plains. J Range Manage 1996;49:234-240.
7. Spears JW. Minerals in forages. In: Fahey GC editor. Forage quality, evaluation, and utilization. Madison, WI, USA: ASA, CSSA; 1994:281-317.
8. Instituto Nacional de Estadística y Geografía. Anuario estadístico y geográfico de Zacatecas. Instituto Nacional de Estadística y Geografía. Aguascalientes, Ags. México. 2014.
9. Trejo HR. Respuesta de dos zacates de un pastizal semiárido a diferentes intensidades y épocas de utilización [tesis licenciatura]. Saltillo, Coahuila, México. Universidad Autónoma Agraria Antonio Narro; 2005.

10. García E. Modificaciones al sistema de clasificación climática de Kôppen. Instituto de Geografía, Universidad Nacional Autónoma de México. México, DF. 1988.

11. Rodríguez H, Rodríguez J. Métodos de análisis de suelo y plantas. Criterios de Interpretación. 2da ed. México: Trillas; 2011.

12. Wayne CC. Collection forages samples representative of ingested material of grazing animals for nutritional studies. J Anim Sci 1964;23:265-270.

13. Olsen SR, Cole CV, Watanabe FS, Dean LA. Estimation of available phosphorus in soils by extraction with sodium bicarbonate. USA Department of Agriculture, Circular No. 939. 1954.

14. Bray RH, Kurtz LT. Determination of total, organic, and available forms of phosphorus in soils. Soil Sci 1945;59:39-46.

15. Thomas GW. Exchange cations. In*:* Page AL, *et al*. editors. Methods of soil analysis. Part 2. Chemical and microbiological properties*.* 2nd ed. Madison, WI, USA: ASA, SSSA; 1982:159-165.

16. Fassel VA, Kniseley RN. Inductively coupled plasma optical emission spectroscopy. Anal Chem 1974;46(13):1110A-1120A.

17. Dahlquist RL, Knoll JW. Inductively coupled plasma-atomic emission spectrometry: Analysis of biological materials and soils for major trace, and ultra-trace elements. Appl Spectroscopy 1978;32(1):1-30.

18. Walkley A, Black I. An examination of the degtjareff method and a proposed modification of the chromic matter and a proposed modification of the chromic acid titration method*.* Soil Sci 1934;34:29-38.

19. Fick KR, McDowell LR, Miles P, Wilkinson NS, Funk DJ, Conrad JH. Métodos de análisis de minerales para tejidos de plantas y animales. 2da ed. Florida, USA: Universidad de Florida; 1979.

20. Grunes DL, Welch RM. Plant contents of magnesium, calcium and potassium in relation to ruminant nutrition. J Anim Sci 1989;67:3485-3494.

21. McDowell LR. Detection of mineral status of grazing ruminants. In: McDowell LR editor. Nutrition of grazing ruminants in warm climates. Florida. USA: Academic Press, Inc; 1985:339-357.

22. Rhue RD, Kidder D. Analytical procedures used by the IFAS extension soil laboratory and the interpretation of results. Soil Sci Dept. Univ of Florida, Gainesville. USA. 1983.

23. Statistical Analysis System (SAS) Institute Incorporation. SAS/STAT User's Guide. SAS Publishing, Cary, NC, USA. 2001.

24. Echavarría FG, Serna A, Bañuelos R. Influencia del sistema de pastoreo con pequeños rumiantes en un agostadero del semiárido zacatecano: II. Cambios en el suelo. Rev Mex Cienc Pecu 2007;45:177-194.

25. Guerrero-Cervantes M, Ramírez RG, González-Rodríguez H, Cerrillo-Soto A, Juárez-Reyes A. Mineral content in range forages from north Mexico. J Applied Anim Res 2012;40(2):102-107.

26. Murillo OM, Herrera E, Carrete FO, Ruiz O, Serrato JS. Chemical composition, *in vitro* gas production, ruminal fermentation and degradation patterns of diets by grazing steers in native range of North Mexico. Asian-Aust J Anim Sci 2012;25:1395-1403.

27. Spann AJ, Carter JN, McDowell LR, Wilkinson NS, Myer RO, Maddox MK, Brennan M. Forage mineral concentrations and mineral status of beef cattle grazing cool season pastures in Northwestern Florida, emphasizing magnesium. Communications in soil science and plant analysis, 2010;41(4):472-481.

28. Murillo OM, Herrera E, Reyes O, Gurrola JN, Ríos FG. Spatio-temporal variations in nutritive quality and mineral contents of diets by grazing steers in native range. J Anim Vet Adv 2011;10:674-678.

29. Gagnon B, Demers I, Ziadi N, Chantigny MH, Parent L-E, Forge TA, Buckley KE. Forms of phosphorus in composts and in compost-amended soils following incubation*.* Canadian J Soil Sci 2012;92:711-721.