Colegio de Postgraduados

Mineral Profile in Soil and Forages of Rangelands of the Huasteca Potosina, Mexico

Martínez-Montoya, Juan F.[1]; **Olmos-Oropeza, Genaro**[1*]; **Ruiz-Vera, Víctor M.**[1]; **Palacio-Núñez, Jorge**[1]; **Rodolfo-Vieyra, Alberto**[2]; **Domínguez-Vara, Ignacio A.**[3]; **Tarango-Arámbula, Luis A.**[1]

[1] Colegio de Postgraduados, Campus San Luis Potosí, Postgrado de Innovación en Manejo de Recursos Naturales. Iturbide 73, Colonia Centro, Salinas de Hidalgo, San Luis Potosí, C. P. 78620.
[2] Instituto de Ciencias Agropecuarias, Universidad Autónoma del Estado de Hidalgo. bAv. Universidad, km 1, Tulancingo de Bravo 43600, México.
[3] Facultad de Medicina Veterinaria y Zootecnia. Universidad Autónoma del Estado de México. Campus Universitario "El Cerrillo,", Toluca, México, C. P. 50090.
* Correspondence: olmosg@colpos.mx

ABSTRACT
Mineral imbalances in soils and forages may cause suboptimal production of forage biomass and livestock.
Objective: To determine the concentrations of minerals in soil and forage during the dry and wet seasons in the Huasteca Potosina.
Materials and Methods: Samples from the soil and the main forage species consumed by livestock were collected in 17 production units (PU). The P content in soil and forage was determined by colorimetry, while the Ca, Mg, Cu, Fe, Zn, Mn, and Co content was established by atomic absorption spectrophotometry, and flame photometry was used to calculate Na and K content. The data were subjected to an analysis of variance; the effect of PU, season, and interactions was considered as fixed effect. Means were compared using Tukey's test.
Results and Discussion: P and Cu content was below the minimum critical level required for adequate plant growth. Furthermore, the P, Mg, K, Na, Cu, Co, and Zn concentration in forage failed to meet the minimum requirements for livestock.
Conclusions: The mineral imbalances in the grazing areas and the forages do not meet the minimum mineral requirements of dual-purpose cattle in the Huasteca Potosina.

Keywords: Ruminant nutrition, forage quality, mineral requirements.

Citation: Martínez-Montoya, J. F., Olmos-Oropeza, G., Ruiz-Vera, V. M., Palacio-Núñez, J., Rodolfo-Vieyra, A., Domínguez-Vara, I. A.,& Tarango-Arámbula, L. A. (2024). Mineral Profile in Soil and Forages of Rangelands of the Huasteca Potosina, Mexico. *Agro Productividad*. https://doi.org/ 10.32854/agrop.v17i8.3001

Academic Editor: Jorge Cadena Iñiguez
Guest Editor: Juan Francisco Aguirre Medina

Received: April 15, 2024.
Accepted: July 29, 2024.
Published on-line: September 09, 2024.

Agro Productividad, 17(8). August. 2024. pp: 203-211.

INTRODUCTION

The Mexican territory covers 1,964,375 km^2, approximately 51% of which are arid and semi-arid, 19% warm sub-humid, 17.9% temperate, 6.9% warm and semi-warm humid, and 2.5% semi-warm sub-humid zones (SEDARH, 2007). Mexico has 33,356,369 heads of cattle, out of which 92.7% are used to produce meat. Fifty percent of these heads are located in the humid and dry tropic (SIAP, 2021). San Luis Potosí has 1,020,109 heads of cattle, 51.4% of which are found in the Huasteca (SIAP, 2021). These herds are managed

Image by Anita Menger at Pixabay

in meadows with cultivated, introduced, and natural pastures whose mineral deficiencies could be reflected in suboptimal production of livestock (McDowell and Arthington, 2005). Poor absorption by the grasses resulting from a low mineral content (N, P, S, Cu, and Na) in the soil limits the growth of grasses and results in nutritional deficiencies in the livestock (McDowell, 1985; Coates *et al.*, 2019). In extensive livestock farming, livestock nutrition depends on the nutrients it obtains from the forage. In turn, nutrient concentration and mineral balance depend on the soils in which the forage plants grow. Therefore, the study of soil fertility —understood as the capacity to supply adequate quantities of nutrients to satisfy the requirements of plants (Kemp *et al.*, 1999)— is an important factor for the development of an adequate management program for livestock herds. The availability of nutrients and their ratios mainly depend on the type of soil, cation exchange capacity (CEC), pH, and organic matter (OM).

CEC is mainly influenced by OM, texture, and type of clay. It varies horizontally and vertically, with clear variation between horizons (Porta *et al.*, 2003). Ca is the dominant exchangeable cation (60-85%), followed by Mg (5-30%), K (2-6%), and Na (2-6%) (Bohn *et al.*, 1979; Mengel and Kirkby, 1987). With an acidic pH, Al ions $\left(Al_3^+, Al(OH)_2^+\right)$ decrease the availability of phosphate, sulfate, and molybdate and restrict nitrification and decomposition of soil organic matter; the effect is more severe with lower pH (Osorio, 2012). Another limiting factor is the high concentration of Al, Mn, and Fe that interact with P and Se (Whitehead, 2000; McDowell, 1985). As the pH in the soil increases, the availability and absorption of Fe, Mn, Zn, Cu, and Co decreases, while Mo and Se increase in the forage (McDowell, 1985; Suttle, 2022). Vegetable crops maintain an active growth with a 4.0-8.5 pH; however, some are sensitive to extreme values (Whitehead, 2000). Therefore, pH determines the bioavailability of minerals and largely regulates the nutritional value of grasses (Toledo and Schultze-Kraf, 1982).

OM is important for crop sustainability: it improves the soil's physical (texture, structure, bulk density, and water retention capacity), chemical (nutrient availability, cation exchange capacity, reduced aluminum toxicity, and allelopathy), and biological (nitrogen-mineralizing bacteria, nitrogen fixation, mycorrhizal fungi, and microbial biomass) characteristics (Fageria, 2012). A high OM percentage can result in high Mo and S concentrations (Suttle, 2022) and low Cu availability for the plant (Haynes, 2005); conversely, a low OM percentage tends to cause low I concentrations (Suttle, 2022).

Soil productivity tends to fluctuate over time, due to changes in its physical, chemical, and biological fertility (Feng *et al.*, 2021). Both water scarcity and excess cause mineral deficiencies. In the first case, a decrease in the solubility of elements reduces their availability in root systems (Kawas and Houston, 1990). In the second condition, high humidity solubilizes and leaches out the minerals away from the perimeter of root absorption (Velasco, 1992). In the Huasteca Potosina, the intense use of natural resources by agricultural and livestock production systems and the climatic conditions suggests that, from the point of view of the nutritional requirements of the livestock, the soils and forage plants in the area have mineral deficiencies and imbalances. The objective was to determine the concentration of minerals in soil and forages of the Huasteca Potosina, during the dry and wet seasons.

MATERIALS AND METHODS

Characteristics of the Study Area

The study was conducted in the municipalities of Tamuín, Ébano, and San Vicente Tancuayalab, San Luis Potosí. The area is located in the province of Llanura Costera del Golfo Norte, subprovince of Llanuras and Lomeríos (Instituto Nacional de Estadística y Geografía (INEGI, 2002). The dominant landforms are alluvial plains with hills (57.8%), alluvial floodplains (19.3%), valleys with plains (7.3%), alluvial plains (6.5%), and typical hills (4%), among others. The altitude varies from 820 m (Abra-Tanchipa mountain range) to 5 m (alluvial plains) (INEGI, 2002). In the plains, valleys, and hills with gentle slopes the predominant soils are Pellic Vertisol (Vp), Calcaric Phaeozem (Hc), and Eutric Fluvisol (Je). Meanwhile, hills are characterized by Calcaric Regosol (Rc), Calcic Cambisol (Bk), and Haplic Kastanozem (Kh). Lithosol (I), Rendzina (E), and Calcaric Regosol (Rc) are found in rugged areas. The dominant climates are semi-warm humid (A)C(fm) (48.3%), warm sub-humid (A)(C)w_0 (44.6%), and temperate sub-humid Aw_0 (6.2%). The average annual precipitation ranges from 900 to 1,500 mm and the average annual temperature is 25±1 °C (INEGI, 2023). The most abundant vegetation types are secondary, forests, and low, medium, and high jungle. The main land uses are agriculture (32.8%), cultivated grassland (28%), and induced grassland (0.5%) (INEGI, 2021).

Location of the Sampled PUs

The number of PUs to be sampled was determined through the stratification of the study area, using cartographic information at a 1:250,000 scale. These maps included pedological, geological, and physiographic information, as well as data about land use, vegetation, climate, and flood-prone areas (SEDARH, 2007). In addition to this cartography and fieldwork, the ArcGIS 9.2 geographic information systems were used, based on the resulting landscape units delimited in ArcView 2.3. Those units were based on the 1:250,000 cartography developed by INEGI (2007), which includes pedological, topographic, geomorphological, hydrological, and geological data, as well as information on land use, vegetation, and flood-prone areas. Seven PUs used to produce dual-purpose cattle were located in Tamuín, six in Ébano, and four in San Vicente Tancuayalab.

Sample Collection and Preparation

Samples of the soil and plant species available to livestock were collected from each PU, in the dry (April and May) and wet (August and September) seasons. Soil samples were collected from the top 20 cm of each site and were divided into 10 subsamples. In total, 35 samples were collected in the dry season and 40 in the wet season. Forage plant species were sampled collecting 500 g of fresh matter, using the simulated grazing technique (hand plucking). The soil samples were air-dried, ground, and sieved with a 2 mm mesh. The forage samples were dried at 60 °C in a forced-air oven until they reached a constant weight; they were subsequently ground and passed through a 1 mm diameter sieve and stored in plastic containers, until they were analyzed in the laboratory.

Laboratory Analysis

The soil was analyzed following the NOM-021-SEMARNAT-2000 official Mexican standard (SEMARNAT, 2002). The exchangeable bases (Ca, Mg, Na, and K) were determined with 1N ammonium acetate at pH 7.0 as a saturating solution, while the diethylenetriaminepentaacetic acid technique (DTPA) and the Olsen method were used to establish microminerals (Cu, Fe, Zn, and Mn) and phosphorus (P), respectively. The technical interpretation was based on NOM-021-SEMARNAT-2000 (SEMARNAT, 2002). Forage minerals were extracted according to Allan (1970). The P content was determined by colorimetry in a Thermo Scientific™ GENESYS™ UV-visible spectrophotometer (Fisher Scientifc Inc.). The Ca, Mg, Cu, Fe, Zn, Mn, and Co content was determined by atomic absorption spectrophotometry (Perking Elmer 3110 spectrometer) and the Na and K content was calculated by flame photometry (Corning 410 flame photometer).

Statistical Analysis

The mineral content of soil and forage was analyzed based on a completely randomized design, considering the effect of PU, season, and interactions as fixed effects, and applying an analysis of variance through the GLM procedure (SAS, 2021). The means were compared with Tukey's test.

RESULTS AND DISCUSSION

The forage plant samples were collected during the dry season (50) and during the wet season (49). The predominant forage species in the area were *Cynodon nlemfuencis* (31.3%), *Brachiaria* spp. (14.1%), *Rhynchelytrum repens* (13.1%), and *Cynodon dactylon* (9.2%); the remaining 32.3% included, in varying rates, *Leucaena leucocephala*, *Panicum maximum*, *Pennisetum purpureum*, *Saccharum officinarum*, *Digitaria eriantha*, *Sorghum vulgare*, *Zea mays*, *Guazuma* sp., *Acacia* sp., and *Prosopis* sp. Additionally, three and five PUs used *Leucaena leucocephala* and *Saccharum* spp. as forage, respectively.

Soil Mineral Content

Table 1 shows that the concentration of P (14.74 ppm) and Cu (2.87 ppm), in soils where the forage consumed by livestock grows, did not reach the minimum levels required for good plant development (Castellanos *et al.*, 2000) The availability of P in the soil-plant-animal system plays a fundamental role in its productivity, since P deficiency reduces forage growth and quality (Quintero and Boschetti, 2001). Furthermore, an ≈12 ppm P concentration in the soil improves phosphate fertilization (Benavidez *et al.*, 2000), while 25 ppm allow alfalfa crops to reach maximum yields (Vivas *et al.*, 1996; Berardo and Marino, 2000).

PU had an effect ($P<0.01$) on the K in the soil: K concentration ranged from 230 ppm (PU 15) to 836 ppm (PU 14). Likewise, the content of Mg, Fe, Zn, and Mn had $P\leq0.056$, 0.053, 0.070, and 0.080 trends, respectively. Season had an impact on Fe and Mn: concentrations were higher in the wet season ($P<0.05$).

The interaction between PU and the season had an effect ($P<0.05$) on the Ca and Na concentration: higher Ca contents were found in PUs 6 and 14 during the dry season,

Table 1. Mineral concentration in the soils where the forage consumed by the dual-purpose livestock from 17 production units grows, in the Huasteca Potosina, Mexico.

Production units (PU)	**Macrominerals (mg kg^{-1})**					**Microminerals (mg kg^{-1})**			
	Ca	**P**	**Mg**	**K**	**Na**	**Cu**	**Fe**	**Zn**	**Mn**
1	8609[ab]	19.29	458	424[bc]	299[b]	3.51	38.57	4.94	49.69
2	9599[ab]	14.44	378	435[bc]	243[b]	1.43	22.75	3.29	25.72
3	9879[ab]	5.30	313	557[abc]	337[ab]	3.18	30.14	5.49	33.32
4	8520[ab]	34.79	464	383[bc]	188[b]	1.41	7.86	2.66	27.11
5	11096[a]	24.24	398	610[ab]	424[ab]	2.85	15.20	2.26	31.81
6	10472[ab]	8.93	485	528[abc]	418[ab]	3.66	28.98	2.94	31.36
7	11806[a]	19.12	312	477[abc]	317[b]	1.71	17.75	1.80	24.89
8	10119[ab]	12.38	531	679[ab]	515[ab]	3.85	14.00	2.85	29.05
9	10048[ab]	15.95	253	387[bc]	233[b]	2.47	30.70	3.46	25.39
10	9574[ab]	8.63	328	439[bc]	280[b]	2.60	19.34	2.32	17.24
11	10786[ab]	27.70	436	540[abc]	311[b]	2.18	34.30	2.98	31.97
12	12223[a]	12.15	436	553[abc]	388[ab]	2.17	18.58	2.25	26.98
13	10480[ab]	26.64	383	568[abc]	334[ab]	5.28	37.34	4.61	20.42
14	10818[ab]	13.51	782	836[a]	692[a]	2.18	15.35	2.67	29.14
15	6336[b]	7.76	498	230[c]	190[b]	2.79	11.83	2.32	25.34
16	10776[ab]	10.59	644	494[abc]	519[ab]	2.02	8.81	2.34	27.22
17	10743[ab]	9.00	683	418[bc]	262[b]	4.18	25.73	3.10	48.24
SEM[1]	879	7.46	117	72	73	0.92	8.30	0.92	7.39
Season:									
Dry	9450[x]	17.86	401	481	335	2.88	16.85[x]	3.68	26.24[x]
Wet	10860[y]	12.12	471	516	356	2.86	30.54[y]	2.91	33.95[y]
SEM[1]	199	2.18	35	21	19	0.27	2.26	0.28	1.96
production units (PU)	<0.001	0.205	0.056	0.001	<0.001	0.153	0.053	0.070	0.080
Se	<0.001	0.081	0.092	0.517	0.884	0.979	<0.001	0.084	0.046
PU*Se	0.006	0.481	0.511	0.260	0.036	0.440	0.816	0.868	0.114
means	10217	15.91	439	500	347	2.79	24.30	3.26	30.44
critical level [2]	1500	25	200	200	70	3.0	9.0	2.0	12.0

abc, xy=Mean values in the same column with different letters are different ($P \leq 0.05$).
[1] SEM (EEM)=standard error of the mean. [2] Critical level=minimum critical level of minerals in soils required for plant growth (Castellanos *et al.*, 2000).

while the Na content was higher in PUs 1, 5, 6, 7, 8, 13, 14 and 16, during the dry season.

Mineral Content in Forage

The diversity and predominance of the forages found in the study area did not enable the evaluation of the independent effect of the PUs. The P and K content was higher ($P<0.01$) in the wet season. Underwood (1999) reported higher P concentrations in the same season in northern Australia and southern Africa. Meanwhile, the higher K content in forages in the wet season differs from the findings of Almaráz *et al.* (2007). High Fe contents ($P<0.05$)

in the dry season were also recorded by Domínguez-Vara and Huerta-Bravo (2008). The P, Mg, K, and Na content in forages does not meet the minimum requirements for livestock (Puls, 1994; NRC, 2001). Mn and Fe at soil level possibly reduced the absorption by the forages, hindering the quantification of Cu and Co (Ungerfeld, 1998) (Table 2).

Table 2 shows that only Ca and Mn had an adequate range, Fe level was in excess, and the rest of the minerals were below the appropriate concentration for dual-purpose cattle (Puls, 1994; NRC, 2001). The effect ($P<0.01$) of the interaction between PU and season on the Mn content in the forage was caused by its higher concentration in PUs 3, 5, 7, 8, and 16, during the dry season. The main forage species and their mineral profiles in the dry and wet seasons, were: *Cynodon nlemfluencis* (31.3%), *Brachiaria* spp. (14.1%), *Rhynchelytrum*

Table 2. Mineral concentration in the forage consumed by dual-purpose livestock from 17 production units in the Huasteca Potosina, Mexico.

Production units	Macrominerals (%)					Microminerals (ppm)		
	Ca	P	Mg	K	Na	Fe	Zn	Mn
1	0.65	0.08	0.06	0.17	0.10	142	28	35
2	0.14	0.06	0.03	0.13	0.07	201	20	25
3	0.13	0.07	0.04	0.10	0.06	151	17	33
4	0.35	0.07	0.05	0.13	0.06	125	26	21
5	0.20	0.06	0.06	0.14	0.07	89	31	36
6	0.30	0.07	0.05	0.12	0.09	163	29	20
7	0.24	0.61	0.03	0.07	0.05	82	17	30
8	0.42	0.04	0.04	0.07	0.08	138	16	27
9	0.27	0.06	0.03	0.15	0.08	196	25	28
10	0.23	0.05	0.03	0.16	0.09	115	22	33
11	0.29	0.07	0.04	0.18	0.10	91	29	40
12	0.24	0.06	0.03	0.15	0.10	177	22	32
13	0.26	0.11	0.03	0.15	0.12	163	27	62
14	0.39	0.11	0.06	0.17	0.15	177	20	44
15	0.44	0.15	0.08	0.28	0.17	61	34	77
16	0.38	0.07	0.05	0.14	0.07	92	19	35
17	0.26	0.04	0.03	0.14	0.07	119	18	22
SEM[1]	0.11	0.01	0.01	0.03	0.02	35	5	9
Season:								
Dry	0.33	0.06^{y}	0.05	0.13^{y}	0.08	149^{x}	26	30
Wet	0.27	0.07^{x}	0.04	0.17^{x}	0.09	114^{y}	20	36
SEM[1]	0.024	0.002	0.003	0.009	0.006	9	5	2
production units	0.090	0.058	0.256	0.210	0.064	0.160	0.679	0.072
Se	0.397	0.003	0.172	0.003	0.875	0.035	0.127	0.071
PU*Se	0.714	0.544	0.705	0.334	0.765	0.237	0.507	0.009
Average	0.30	0.07	0.04	0.14	0.08	131	23	33
Adecuate concentration[2]	0.30-0.50	0.25-0.30	0.10-0.20	0.90-1.40	0.10-0.16	15-100	30-75	15-40

xy=Mean values in the same column with different letters are different ($P\leq0.05$).
[1]SEM (EEM)=standard error of the mean. [2] Adequate concentration in forage for livestock (Puls, 1994).

repens (13.1%), and *Cynodon dactylon* (9.1%). Other species were found in smaller quantities (32.3%), including *Leucaena leucocephala*, *Panicum maximum*, *Pennisetum purpureum*, *Saccharum officinarum*, *Digitaria eriantha*, *Sorghum vulgare*, *Zea mays*, *Guazuma* sp., *Acacia* sp., and *Prosopis* sp. Some of these forages are used to feed livestock in both seasons of the year (Table 3).

Table 3. Mineral concentration in the forages used to feed dual purpose cattle in the Huasteca Potosina, Mexico, in both seasons of the year.

Forage	Wet season								Dry season							
	%					$mg\ kg^{-1}$			%					$mg\ kg^{-1}$		
	Ca	P	Mg	K	Na	Fe	Zn	Mn	Ca	P	Mg	K	Na	Fe	Zn	Mn
Star grass (*Cynodon nlemfluencis*)	n=17								n=14							
Average	0.22	0.08	0.03	0.18	0.09	152	20	43	0.23	0.06	0.04	0.13	0.09	155	22	27
Road grass (*Rhynchelytrum repens*)	n=7								n=6							
Average	0.25	0.07	0.03	0.17	0.10	89	20	34	0.35	0.03	0.03	0.10	0.06	125	31	39
Brizantha (*Brachiaria brizantha*)	n=6								n=8							
Average	0.08	0.07	0.03	0.14	0.08	152	31	24	0.32	0.06	0.06	0.14	0.08	129	32	29
Bermuda grass (*Cynodon dactylon*)	n=6								n=3							
Average	0.27	0.09	0.04	0.22	0.12	102	21	61	0.19	0.02	0.02	0.12	0.06	212	21	22
Guinea grass (*Panicum maximum*)	n=3								n=2							
Average	0.17	0.07	0.03	0.13	0.07	108	19	30	0.33	0.07	0.07	0.14	0.13	109	22	37
Sugar cane (*Saccharum officinarum*)	n=1								n=4							
Average	0	0.03	0.05	0	0.02	33	8	15	0.38	0.06	0.05	0.14	0.11	117	26	23
Leucaena (*Leucaena leucocephala*)	n=3								n=4							
Average	1.17	0.10	0.07	0.17	0.12	143	27	51	0.62	0.10	0.07	0.16	0.08	182	35	54
Mulatto grass (*Brachiaria hibrido*)	n=1								n=2							
Average	0	0.04	0	0	0	73	10	18	0.32	0.06	0.06	0.11	0.07	145	40	45
Pangola grass (*Digitaria eriantha*)	n=1								n=1							
Average	0	0.02	0.02	0.12	0.06	58	8	11	0.19	0.02	0	0.12	0.06	189	18	16
Sorghum (*Sorghum vulgare*)	n=1								n=1							
Average	0.29	0.07	0.05	0.36	0.20	40	22	49	0	0.05	0.04	0.17	0.08	228	16	14

n=number of samples analyzed.

CONCLUSIONS

The concentration of P and Cu in the soil was below the minimum critical level for adequate plant growth. The mineral concentrations in the forage were below the recommended requirements for livestock in both seasons of the year, except for Fe and Mn. Along with these mineral imbalances, the failure to meet the minimum requirements that grazing areas must have for dual purpose cattle in the Huasteca Potosina may affect livestock health and result in suboptimal production.

REFERENCES

Allan, J. E. (1970). The preparation of agricultural samples for analysis by atomic absorption spectroscopy. Ruakura Soil Research Station Varian Techtron.

Almaráz, E. M., Vara, I. D., González-Ronquillo, M., Escutia, G. J., Ortega, O. C., Sálas, N. P., & Bravo, M. H. (2007). Diagnóstico mineral en forraje y suero sanguíneo de bovinos lecheros en dos épocas en el valle central de México. *Técnica Pecuaria en México, 45*(3), 329-344.

Benavidez, R. A., Boschetti, N. G., Quintero, C. E., Barrera, R., & González, A. (2000). Evaluación de la fertilidad fosfatada de los suelos para los principales cultivos extensivos de Entre Ríos. *Ciencia Docencia y Tecnología*, 21, 221-266.

Berardo, A., & Marino, M. A. (2000). Efecto de la fertilización fosfatada sobre la disponibilidad de P y su relación con la producción de forraje en molisoles del sudeste bonaerense. In *Actas XVII Congreso Argentino de la Ciencia del Suelo, Mar del Plata*.

Bohn, H. L., McNeal B. L., & O'Connor, G. A. (1979). Soil Chemistry. John Wiley and Sons, New York, p 151.

Castellanos, J. Z., Uvalle, B. J. X., & Aguilar, S. A. (2000). Manual de interpretación de suelos y aguas. Colección INCAPA. México, DF.

Coates, D. B., Dixon, R. M., & Mayer, R. J. (2019). Between-year variation in the effects of phosphorus deficiency in breeder cows grazing tropical pastures in northern Australia. *Tropical Grasslands-Forrajes Tropicales, 7*(3), 223-233. https://doi.org/10.17138/tgft(7)223-233.

Domínguez Vara, I. A., & Huerta Bravo, M. (2008). Concentración e interrelación mineral en suelo, forraje y suero de ovinos durante dos épocas en el Valle de Toluca, México. *Agrociencia, 42*(2) 173-183.

Fageria, N. K. (2012). Role of Soil Organic Matter in Maintaining Sustainability of Cropping Systems. *Communications in Soil Science and Plant Analysis, 43*(16), 2063-2113. DOI: 10.1080/00103624.2012.697234.

Feng, G., Tewolde, H., Zhang, B., Buehring, N., & Adeli, A. (2021). Soil physical and hydrological properties as affected by a five‐year history of poultry litter applied to a cotton–corn–soybean rotation system. *Soil Science Society of America Journal, 85*(3), 800-813.

Haynes, R. J. (2005). Labile organic matter fractions as centralcomponents of the quality of agricultural soils: anoverview. *Advances in Agronomy*, 5, 221-268.

INEGI, (Instituto Nacional de Estadística y Geografía). (2023). Climatología. Recuperado de https://www.inegi.org.mx/temas/climatologia/.

INEGI, (Instituto Nacional de Estadística y Geografía). (1970). Carta edafológica, Hojas F14-5 Ciudad Mante y F14-8 Ciudad Valles, escala 1:250 000. Aguascalientes, Ags. Instituto Nacional de Geografía e Informática.

INEGI, (Instituto Nacional de Estadística y Geografía). (2002). Síntesis de información geográfica del Estado de San Luis Potosí. Aguascalientes, Ags: Instituto Nacional de Geografía e Informática.

INEGI, (Instituto Nacional de Estadística y Geografía) (2015). Uso del suelo y vegetación serie v escala 1:250 000. Recuperado de http://www.inegi.org.mx/geo/contenidos/recnat/usosuelo/.

INEGI (Instituto Nacional de Estadística y Geografía). (2007). Censo agropecuario. Recuperado de www.inegi.org.mx.

INEGI (Instituto Nacional de Estadística y Geografía). (2010). Territorio nacional. Recuperado de www.inegi.org.mx.

INEGI (Instituto Nacional de Estadística y Geografía). (2021). Conjunto de datos vectoriales de uso del suelo y vegetación. Escala 1:250 000. Serie VII. Conjunto Nacional. https://www.inegi.org.mx/app/biblioteca/ficha.html?upc=889463842781.

Kabata-Pendias, A. (2001). Trace elements in soils and plants (3rd ed). Boca Raton, Fla: CRC Press.

Kawas, J.R., & J.E. Houston. (1990). Nutrient Requeriment of hair sheep in tropical and subtropical environments. In: Small Ruminant: Hair sheep production in Tropical and Subtropical environments. Chapter 4. Collaborative Research Program, University of California-Davis/US-AID.

Kemp, P. D., Condron, L. M., & Matthew, C. (1999). Pastures and soil fertility. *New Zealand Pasture and Crop Science*, 67-82.

McDowell, L. R. (1985). Contribution of tropical forages and soil toward meeting mineral requirements of grazing ruminants. *Nutrition of Grazing Ruminants in Warm Climates*, 165-188.

McDowell L. R., & Arthington J. D. (2005). Minerales para rumiantes en pastoreo en regiones tropicales (4.a ed.). Universidad de Florida.: IFAS.

Mengel, K., & Kirkby, E. A. (1987). Principles ofplant nutrition. Bern: International Potash Institute.

NRC (National Research Council). (2001). Nutrient requirements of dairy cattle: 2001. National Academies Press.

Osorio, N.W. (2012). pH del suelo y disponibilidad de nutrientes. *Manejo Integral del Suelo y Nutrición Vegetal, 1*(4): 1-4.

Porta, Casanellas, J., López-Acevedo Reguerín, M., & Roquero de Laburu, C. (2003). Edafología para la agricultura y el medio ambiente. 3ra. ed. Mundi-Prensa. Madrid, España. 929 p.

Puls, R. (1994). Mineral levels in animal health. Diagnostic data. Sherpa International.

Quintero, C. E., & Boschetti, N. (2005). Manejo del fósforo en pasturas. *Misterio de Producción, Instituto Nacional de Tecnología Agropecuaria: Buenos Aires, Argentina*.

SAS, Institute Inc. (2021). Statistica ver. 3.8. Recuperado de https://www.sas.com/es_mx/home.html.

SEDARH (Secretaría de Agricultura y Desarrollo Rural). (2007). Cartografía 1:250 000 en formato vectorial proporcionada por la SEDARH. Gobierno del estado de San Luis Potosí, México.

SEMARNAT (Secretaria del Medio Ambiente y Recursos Naturales). (2002). Norma Oficial Mexicana NOM-021-SEMARNAT-2000 Fertilidad, Salinidad y Clasificación de suelos, Estudio, Muestreo y análisis. Diario Oficial de la Federación, 85-85. Recuperado de https://www.dof.gob.mx/nota_detalle.php?codigo=717582&fecha=31/12/2002#gsc.tab=0.

SIAP (Servicio de Información Agroalimentaria y Pesquera). (2021). Población Ganadera, avícola y apícola. Resumen Nacional 2012-2021. Servicio de Información Agroalimentaria y Pesquera. Recuperado de https://www.gob.mx/siap/documentos/poblacion-ganadera-136762?idiom=es.

Suttle, N. F. (2022). Mineral nutrition of livestock. Cabi.

Toledo J. M., & Schultze-Kraf R. (1982). Metodología para la evaluación de pastos tropicales. En: Toledo, J. M., ed. Manual para la evaluación agronómica. Red Internacional de Evaluación de Pastos Tropicales RIEPT. (pp. 91-110). Centro Internacional de Agricultura Tropical (CIAT).

Underwood, E. J. (1999). The mineral nutrition of livestock (3rd ed.). Wallingford, Oxon, UK ; New York: CABI Pub.

Ungerfeld, A. E. (1998). Factores que afectan el contenido de minerales en pasturas naturales y el estado nutricional de vacunos y ovinos en Uruguay. INIA. Tacuarembó, Uruguay.

Velasco, H. A. (1991). Las zonas áridas y semiáridas: sus características y manejo. LIMUSA. Mexico, D.F. 725 p.

Vieyra-Alberto R., Domínguez-Vara I. A., Olmos-Oropeza G., Martínez-Montoya J.F., Borquez-Gastelum J.L., Palacio-Nuñez J., Lugo de la Fuente J.A., & Morales-Almaráz E. (2013). Perfil e interrelación mineral en agua, forraje y suero sanguíneo de bovinos durante dos épocas en la Huasteca Potosina, México. *Agrociencia*, 47: 121-133.

Vivas, H., Guaita, S., Hein, W., & Empinotti, V. (1996). Fertilización de alfalfa en un suelo representativo del centro este de Santa Fe: Producción de primavera, 1995. *Información Técnica N° 200, INTA Rafaela, 510*(1006.25), 754-75.

Whitehead, D. C. (2000). Nutrient elements in grassland soil-plant-animal relationships. New York: CABI Pub.