

# Use of Climatic Variables, Ndvi and Stocking Rate in Estimating the Ranch Level Grazing Coefficient

José Contreras Bañuelos<sup>1</sup>, Francisco Guadalupe Echavarría Chairez<sup>2</sup>, Alfonso Serna Pérez<sup>2</sup>, Israel Casas Flores<sup>2</sup>, Eduardo de Jesús Ruiz Fernández<sup>1</sup>, Daniel Rodríguez Tenorio<sup>1\*</sup>

<sup>1\*</sup>Autonomous University of Zacatecas, Academic Unit of Veterinary Medicine and Zootechnics. 31.5 km Pan-American Highway, Zacatecas–Fresnillo, 98500, Zacatecas, México,

<sup>2</sup> INIFAP Experimental Station in Zacatecas. Km 24.5 of the Zacatecas-Fresnillo Highway, 98500, Calera, Zacatecas, México.

---

## ABSTRACT

*The value of grasslands worldwide has been underestimated; however, they sustain more than 800 million people. The state of Zacatecas has 5.4 million hectares dedicated to livestock, of which 2.3 million hectares are highly degraded. To improve grassland conditions, it is necessary to dynamically assess biomass production and have technically and economically feasible measurement tools that allow for informed decisions regarding conservation and production through adjustments to the grazing coefficient. The objective of this study was to evaluate the influence of climatic factors, the Normalized Difference Vegetation Index (NDVI), and stocking rate on the estimation of the grazing coefficient in three ranches, based on the premise that these factors are related to the grazing coefficient. Vegetation status (biomass) was measured using the NDVI index. Precipitation, temperature, and evapotranspiration data were obtained monthly from the climatological stations of the INIFAP (National Institute of Forestry, Agriculture and Livestock Research) network in Zacatecas, from January 2010 to 2024. Area and livestock carrying capacity data for the three ranches were also collected annually. Statistical linear regression analysis shows that climate data, NDVI, and livestock carrying capacity are correlated with the Grazing Coefficient, with  $r^2=0.63$  for NDVI in two ranches and  $r^2=0.72$  for the third ranch. The variables studied were statistically significant ( $P<0.05$ ), revealing that two of the ranches exhibit overgrazing when compared to data from the Technical-Consultative Commission on Rangeland Coefficients (COTECOCA), the government agency responsible for establishing recommended animal units per hectare by region throughout the country. This method represents a simple and easy-to-implement tool for livestock producers, offering lower financial and time costs with an acceptable level of precision. It also allows for in-situ dry matter estimation to provide a more accurate assessment of pasture condition.*

**Keywords:** *Vegetation, indices, precipitation, rangeland coefficient, NDVI.*

## INTRODUCTION

The most important resources for livestock production in extensive systems are water and forage. The condition of the rangelands allows us to make decisions to optimize production and protect natural resources (Fariña et al., 2019). Zacatecas has 5.4 million hectares used for livestock, of which 2.3 million are considered highly degraded due to poor management and climatic events such as drought (Echavarría et al., 2009). Rangelands tends to decrease as a result of overgrazing, excessive stocking rates, and a lack of pasture rotation, leading to soil erosion (Rodríguez, 2022). The combined effects of overgrazing and climate warming accelerate soil water loss in rangelands regions, which has significant implications for pasture management (Xiliang et al., 2017). The consequence is low productivity, reflected in a calving rate of 54% (SINIIGA, 2012), which results in low profitability for livestock farming. The objective of this study is to evaluate the influence of climatic factors (temperature, evapotranspiration, and precipitation), as well as NDVI and stocking rate, on the estimation of the rangeland coefficient in three ranches in the central region of the state of Zacatecas over a 15-year period.

Quantitative information on the ecological condition of pastures is scarce, isolated, and scattered in Zacatecas. However, monitoring pasture condition is key to providing optimal management that allows for the sustainability of natural resources and maximizes the productivity and profitability of livestock farming (Medina et al., 2009). Climate is a determining factor for forage production; therefore, stocking rates must have the necessary flexibility in time and space to ensure animal production without depleting natural resources and consequently compromising sustainability and the rangeland coefficient, which is necessary to adjust stocking rates (Gutiérrez et al., 2018).

The most recent official rangeland coefficient data for the state are those from the Technical-Consultative Commission on Rangeland Coefficients (COTECOCA, 2014) and some others generated by INIFAP (National

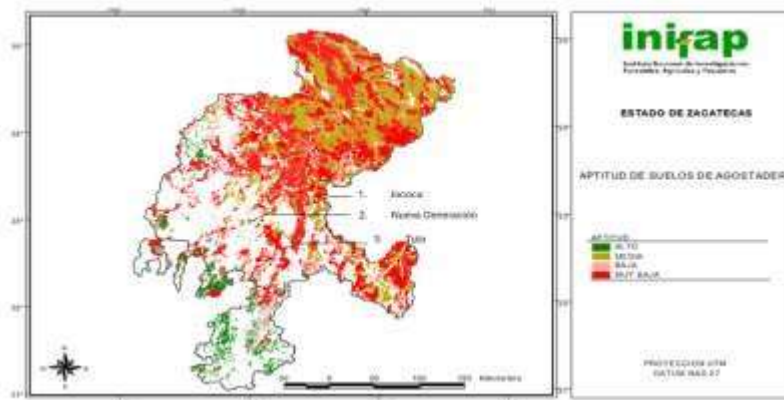
Institute of Forestry, Agricultural and Livestock Research) in Zacatecas, which were used to compare with the data from the ranches under study. The condition of the rangelands is dynamic; it is crucial to have tools that allow for the evaluation of the condition of ecosystems (grasslands). However, the problem of rangelands is complex, involving soils, plant communities, herbivores, erratic rainfall distribution, vulnerability to poor management, and fragility and susceptibility to degradation (Gutiérrez et al., 2007). Rangeland biomass can be estimated in different ways: harvesting (Sala et al., 1981), visual estimates (Waite, 1994), plant height or volume (Thomson, 1998), radiometry (Olson and Cochran, 1998), photographs (Paruelo et al., 2000), and the Normalized Difference Vegetation Index (NDVI) (Wylie, 1995). Regardless of the use of more current methodologies than those employed by COTECOCA (1967) regarding vegetation successional dynamics (NRCS, 1997), the time and cost factors associated with estimating forage biomass are impractical across large areas, especially considering that carrying capacity is dynamic and varies depending on climate, soil, land form, etc. (Holencheck et al., 1989). One way to estimate biomass is using satellite data and simple biophysical models of vegetation growth that can be parameterized with climatic data with a good level of accuracy (Diaz et al., 2003). In this regard, one of the methods used is NDVI, which, combined with climatic data, is a low-cost, short-term tool with broad coverage compared to traditional methods.

**MATERIALS AND METHODS**

The study was conducted in the state of Zacatecas, where the climate is classified as type B (dry) in 80% of the area, temperate in 19%, and warm and humid in 1% (CONAFOR, 2014). The open medium-height grassland is located in a dry climate with warm summers, classified as BS<sub>1</sub>kw (Temperate Semi-dry) according to the Köppen climate classification. The average annual temperature ranges from 15 to 18°C, and the average annual precipitation is 355 mm. Data for this study were obtained from the INIFAP weather stations in Zacatecas. The study was conducted at three contrasting sites (ranches) in terms of soil and climate, located at different levels of productive capacity for livestock farming in the state of Zacatecas (Echavarría et al., 2009). The “Tula” and “Nueva Generación” ranches have high potential, while the “La Jococa” ranch has low productive potential (see Figure 1). Study sites, general information, and their coordinates are shown in Table 1.

**Table 1. Study area and general description of the livestock ranches selected for the research**

Ranch	Municipality	Area ha	Number of paddocks	Head Count	Coordinates
1) Jococa	Panuco	333	4	66	23° 03'08 N 102° 32'44 W
2) Nueva Generación	Fresnillo	640	3	189	22° 58'20.2 N 103° 07'12W
3) Tula	Zacatecas	1 400	7	129	22° 40'57.6 N 102° 37'15 W



**Figure 1. Map of the livestock production potential of the state of Zacatecas and location of the three Branches located at different levels of productive aptitude (Echavarría et al., 2009).**

Climatological Information and NDVI, The Normalized Difference Vegetation Index (NDVI) was estimated monthly from January 1, 2010, to December 31, 2024. NDVI is used to estimate the quantity, quality, and development of vegetation and is based on spectral images, as well as near-infrared satellite imagery (Meera et al., 2015). NDVI is an indicator of existing vegetation and is related to the presence of green biomass, as measured by the amount of photosynthetic radiation absorbed. The value ranges from -1 to 1. It is calculated using the following formula:

$$NDVI = (NIR-Red) / (NIR + Red) \quad (Ec 1)$$

Where:

NDVI = Normalized Difference Vegetation Index, NIR = Near-infrared light, and Red = Red visible light

The LANDSAT satellite (LAND=Earth and SAT=satellite) was used. LANDSAT images are composed of 7 or 8 spectral bands, specifically chosen for vegetation monitoring, geological applications, and the study of natural resources. These bands can be combined to produce a range of color images that significantly expand their applications (INEGI, 2020). This study was conducted using the methodology of (Jiménez-Jiménez et al., 2022) with monthly time series images from 2010 to 2024, as shown in Table 1. Precipitation, evapotranspiration (ETo), and temperature data were obtained from the INIFAP C.E. monitoring network in the state of Zacatecas. In Zacatecas, the network in question uses Adcon brand equipment, which is controlled by the Advantage software. This software calculates evapotranspiration using the standard method proposed by the FAO, based on the Penman-Monteith equation developed by the FAO's Land and Water Division (FAO, 1990). Data were collected monthly from 2010 to 2024, and an annual average was calculated.

The results are shown in Table 2. The Penman-Monteith equation for calculating ETo, the method used by the FAO, is as follows:

$$\lambda ET = \frac{\Delta(R_n - G) + \rho_a C_p (e_s - e_a)}{\Delta + \gamma(1 + \frac{r_s}{r_a})} r_a \quad Ec 2$$

Where:

ETo = Reference evapotranspiration [mm day<sup>-1</sup>]; Rn = Net radiation at the crop surface [MJ m<sup>-2</sup> day<sup>-1</sup>], G = Soil heat flux density [MJ m<sup>-2</sup> day<sup>-1</sup>]; T = Air temperature at 2 m height [°C]; u2 = Wind speed at 2 m height [m s<sup>-1</sup>]; es = Saturation vapor pressure [kPa]; ea = Actual vapor pressure kPa; es - ea = Saturation vapor pressure deficit [kPa]; D = Slope of the vapor pressure curve [kPa °C<sup>-1</sup>]; G = Psychrometric constant [kPa °C<sup>-1</sup>].

The FAO Penman-Monteith equation determines evapotranspiration from a hypothetical reference area covered by pasture and provides a standard against which evapotranspiration can be compared at different times of the year or in other regions, and against which the evapotranspiration of other crops can be related. NDVI, precipitation, evapotranspiration, and temperature data were collected monthly and then averaged annually (Table 2). Animal Carrying Capacity and Range Coefficients: The range coefficient data estimated by COTECOCA (2014) for each municipality where the ranches are located are as follows: (Rancho La Jococa, 12.22 ha/AU), (Rancho Nueva Generación, 13.28 ha/AU), and (Rancho Tula, 13.70 ha/AU). This reference value represents the maximum permissible grazing level for each region throughout the country.

A value above the reference point represents overgrazing, while a value below indicates acceptable grazing conditions. The annual stocking rate was obtained from the livestock records of each ranch (Table 2), and the area was provided by the ranch owners (Table 1). Finally, the grazing coefficient was calculated annually according to the following formula: Grazing Coefficient = Total land area (hectares) / stocking rate (AU), which is calculated using the producers' data. Regarding the stocking rate, data from the owners' records (Table 2) were used to convert it to AU/year (Animal Units/year) using the equivalency table for various animal types (Aizpuru, 1979 and NRCS, 2018). The results show the average data for the 15 years. Table 2.

The SAS program version 9.4 (SAS, 2013) was used to perform the linear regression analyses.

Where the dependent variable, independent variable, and significance level are shown.

## RESULTS

Table 2 presents the data for precipitation, temperature, and mean evapotranspiration, the Animal Unit, and the estimated grazing coefficient based on the animal carrying capacity data for those years at the “La Jococa” ranch (1), the “Nueva Generación” ranch (2), and the “Tula” ranch (3). In all cases, the average is for the fifteen years; furthermore, the animal carrying capacity for each year, as well as the grazing coefficient estimate obtained

through regression models, were calculated from the annual averages and their standard deviations for the 15 years of the study for each ranch.

**Table 2. Mean values and standard deviation of Precipitation, Evapotranspiration, Temperature and NDVI, as well as the Animal Unit and Range Coefficient of 15 years of the “La Jococa” Ranch, “Nueva Generación” Ranch and “Tula” Ranch**

Ranch	NDVI	Precipitación mm	Average Temperature	EVO	UA	CA
1 “La Jococa”	0.305	372.569	17.397	1656.3	55.794	6.043
DE	0.044	171.3	0.747	241.662	0.728	0.044
2 “Nueva Generación”	0.284	407.651	16.148	1683.806	92.8	7.452
DE	0.039	151.59	0.539	278.648	2.138	0.039
3 “Tula”	0.283	454.453	15.596	1665.45	108.23	13.184
DE	0.036	172.539	0.6	87.161	1.884	0.036

The observed data corresponding to the standard deviation for the variables under study—NDVI, mean temperature, and grazing coefficient—showed minimum values. Conversely, precipitation, evapotranspiration (EVO), stocking rate (CA), and animal units (AU) showed maximum values. Vegetation had its highest index (NDVI of 0.305), corresponding to growing plants, at the “La Jococa” Ranch. The lowest NDVI values were observed at the “Tula” Ranch (0.283), indicating dormancy. Regarding precipitation, the highest was recorded at the “Tula” Ranch, and the lowest at the “La Jococa” Ranch. Regarding temperature, all three ranches showed a standard value of 0.92. The temperature was similar across the three ranches, as was evapotranspiration (ETo), which also exhibited similar behavior for the ranches studied (Table 2). The data for animal carrying capacity and Animal Units (AU) showed a significant difference between ranches, with Rancho “Tula” having the highest carrying capacity, followed by Rancho “Nueva Generación,” and lastly Rancho “La Jococa.” Finally, the grazing coefficient had a standard deviation of 3.78, but there were differences of 6.5 ha AU between Rancho “La Jococa” and Rancho “Tula” (Table 2), reflecting overgrazing relative to the grazing coefficient recommended by COTECOCA.

The information in Table 2 was used to develop a regression model that relates the grazing coefficient to the variables NDVI, ETo, precipitation, and temperature. The resulting model, although showing an r2 of 0.63 for two of the ranches and an r2 of 0.72 for Nueva Generación (Table 3), also serves as a comparison against the value obtained for the Range Coefficient estimated by COTECOCA (2014). This coefficient acts as a reference for the area allocated to each animal unit and represents the sustainable use of the rangeland resource. This, in turn, represents a condition of overgrazing or adequate management for each of the ranches and corroborates the association between climatic variables and the NDVI values estimated from satellite images.

Figures 2, 3, and 4 show the behavior of the Range Coefficient estimate for the “La Jococa,” “Nueva Generación,” and “Tula” ranches, with r2 values ranging from 0.63, 0.72, and 0.63, respectively. The regression models obtained were the following:

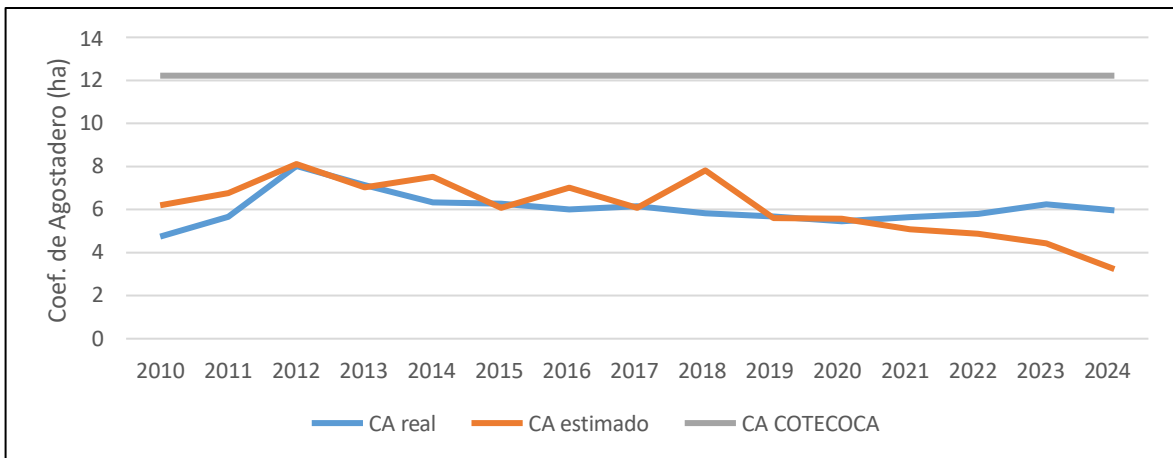
**Table 3. Regression models and their statistical variables for the three ranches.**

Rancho	Ecuación	R <sup>2</sup>
1) La Jococa	CA=61.16932 + 0.00748 (PP) – 1.74389 (TEMP) – 0.00683 (EVTP) – 51.86503 (NDVI)	0.6363
2) Nueva Generación	CA= 31.88061+ 0.01077 (PP) – 0.00672 (EVTP) – 59.77894 (NDVI)	0.7203
3) Tula	CA=61.16932 + 0.00748 (PP) – 1.74389 (TEMP) – 0.00683 (EVTP) – 51.86503 (NDVI)	0.6363

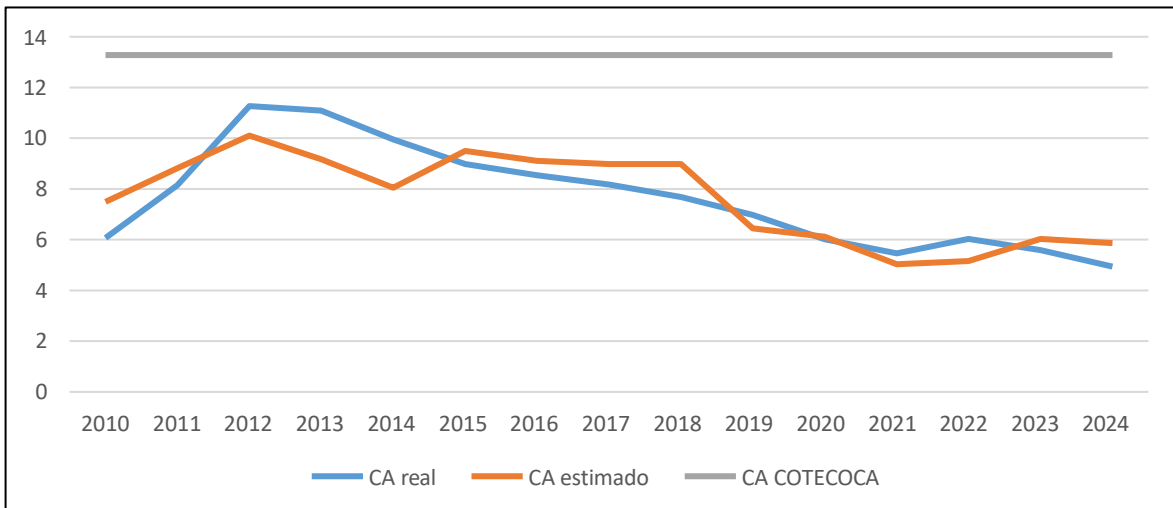
Figure 2 shows the difference between the estimated grazing coefficient value from COTECOCA, which was 12.22 ha/AU for the "La Jococa" Ranch, and the value calculated by the regression model, which was 6.06 ha/AU. This indicates overgrazing on this ranch, representing a 49.59% overload compared to the COTECOCA (2014) reference grazing coefficient values.

Figure 3 contrasts the grazing coefficient data (COTECOCA, 2014), which was 13.28 ha/AU, with the actual coefficient for the "Nueva Generación" Ranch, which is 7.66 ha/AU. This shows a 57% overload, indicating overgrazing.

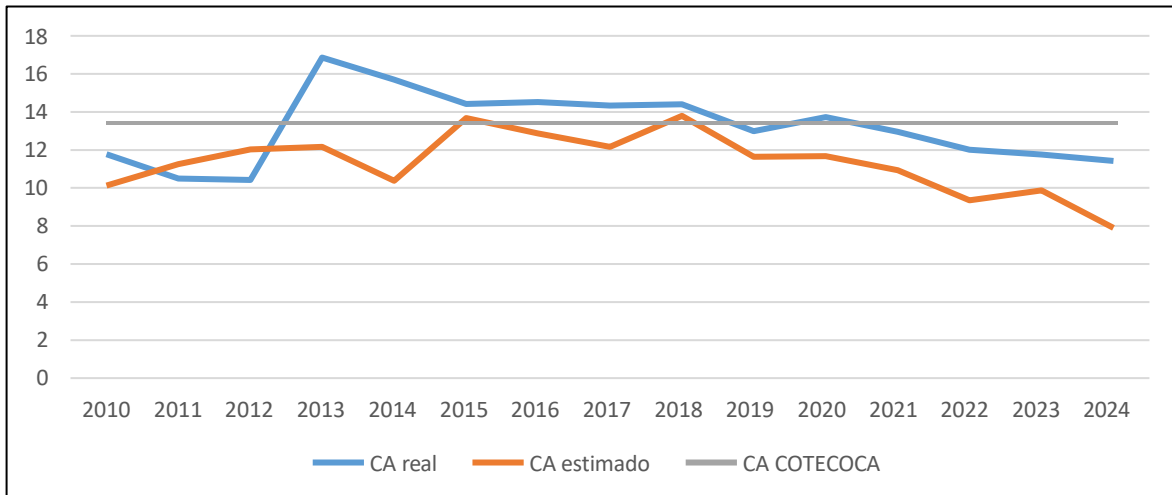
Finally, Figure 4 presents the data for the "Tula" Ranch. It can be seen that the Grazing Coefficient value reported by COTECOCA (2014) is 13.70 ha/AU, a figure very close to the coefficient estimated by the regression model for this ranch, which is 13.06 ha/AU. Although slightly lower, this similarity indicates that COTECOCA's reference values remain valid in this case, allowing for adequate animal production without causing deterioration of natural resources and, consequently, without compromising the sustainability of the livestock operation.



**Figure 2. Animal carrying capacity and the actual, estimated, and COTECOCA grazing coefficient of the "La Jococa" ranch are inversely proportional over a timeline from 2010 to 2024, with an  $r^2= 0.6363$ .**



**Figure 3. Stocking rate and the actual, estimated and COTECOCA rangeland coefficient of the "Nueva Generación" ranch are inversely proportional along a time line from 2010 to 2024, with an  $r^2= 0.7203$  with a probability of ( $P<0.01$ )**



**Figure 4. Animal carrying capacity and the actual, estimated, and COTECOCA grazing coefficient of the “Tula” ranch are inversely proportional over a timeline from 2010 to 2024, with an  $r^2=0.6363$ .**

Not only with current and previous year precipitation, but also with the vegetation from previous years (Taosuo et al., 2019), a recurrent neural network (RNN) was used to correct for this lag, capturing both the temporal lags of the NDVI with respect to itself and the NDVI with respect to precipitation. This was significantly improved by using multiple linear regression (MLR) in the back propagation neural network (BPNN). However, due to the effects of the temporal lag, there are delays in the NDVI's response to precipitation.

## DISCUSSION

The theoretical development of NDVI allows for the analysis of spectral patterns using existing vegetation (grassland, scrubland, shrubs, cacti). However, a problem with the methodology was the lack of data such as soil type, water availability, livestock management, and production expressed in kilograms of meat, which would have allowed for a better fit to the statistical model using linear regression. Nevertheless, climatic data (temperature, precipitation, and evapotranspiration), as well as NDVI and the grazing coefficient, reflect an  $r^2=0.63$  for the “La Jococa” and “Tula” ranches ( $P<0.01$ ). Other authors, such as Marie et al., (2021), investigated the potential of vegetation indices and precipitation-related variables derived from remote sensing to assess pasture productivity in the arid environment of eastern Morocco and identify challenges related to this specific biome. They concluded that, primarily due to the presence of a large proportion of non-photosynthetic vegetation, it is not possible to accurately estimate pasture productivity in this region using a global model. They recommend focusing on methods designed to study dry, non-photosynthetic vegetation, as it alters the signal emitted by vegetation, especially in the red and infrared regions. Finally, the vegetation index results during the driest years could have been misinterpreted as a reduction in pasture productivity without comparison with on-the-ground measurements, with  $r^2$  values of 0.30 and 0.52.

Linear regression analyses in this study show an  $r^2=0.063$  for the “La Jococa” and “Tula” ranches and an  $r^2=0.072$  for the “Nueva Generación” ranch, relating years to NDVI, similar to the findings of Medina et al., (2009) and Fariña et al., (2019), with an  $r^2$  value of 0.66 ( $P < 0.01$ ). However, other authors, such as Villa et al., (2014), developed a vegetation index for normalized slopes with a linear relationship to the leaf area index and biomass. The methodology developed here was based on estimating animal carrying capacity in the grasslands and shrublands of the state of Coahuila, Mexico, at 24 sites measuring  $1.5 \text{ km} \times 1.5 \text{ km}$ . with  $r^2=0.77$  for shrublands and  $r^2 = 0.95$  for grasslands, although the difference is that only one type of grassland was evaluated, which explains the high correlation, in addition to the study area being only one year. (Gillan et al., 2019) developed a method to estimate biomass production using NDVI, by observing the reduction in the height of herbaceous plants represented by three-dimensional point clouds. The method was evaluated in a semi-arid savanna in southern Arizona, comparing utilization estimates with terrestrial methods after one month of grazing. In six plots, we found a strong correlation between the images and the soil-based estimates ( $r^2=0.78$ ) and a similar mean estimate of utilization across all plots ( $r^2=0.78$ ). The concept was found to provide reliable estimates of forage utilization patterns in large pastures and landscapes, with levels of spatial accuracy consistent with terrestrial methods (Villa et al., 2014).

Regarding the difference in NDVI at the “La Jococa” ranch, which was higher than the other two despite having the lowest precipitation, this is attributable to the type of vegetation. It is predominantly shrubby and remains green for most of the year, resulting in higher NDVI readings. Therefore, it is advisable to conduct separate studies in areas with this type of vegetation (Villa et al., 2014) (Chang et al., 2018 and Martiny et al., 2005). A ranch-by-ranch analysis revealed that the “La Jococa” and “Tula” ranches both had  $r^2$  values of 0.63 ( $p < 0.01$ ), explaining 63% of the observed value. The “Nueva Generación” ranch had an  $r^2$  of 0.72 ( $p < 0.01$ ). In other words, NDVI is an integrative index, meaning it reflects all the variation present in each pasture site. Therefore, there is a strong relationship between NDVI values and the biomass production of native grasslands (Diallo et al., 1991; Hobbs et al., 1995; Echavarría et al., 2006; Medina et al., 2009). In arid and semi-arid regions, annual NDVI is highly sensitive to interannual precipitation variability (Chang et al., 2018). Recently, it has been shown that annual NDVI is highly dependent on current and previous year precipitation (Chang et al., 2018 and Martiny et al., 2005). The dependence of vegetation variation on precipitation is called “time lag effects.” It is common knowledge that vegetation variation is correlated with precipitation.

The grazing coefficient data obtained for the three ranches range from 6 to 13.8 ha per AU, averaging 8.96 ha/animal unit. In comparison, COTECOCA (2014) reported an average grazing coefficient of 13.06 ha for the municipalities of Fresnillo, Panuco, and Zacatecas. Furthermore, Gutiérrez et al., (2007), in their studies of the grazing coefficient in the aforementioned municipalities, reported average grazing coefficients of 10.77 ha/AU. Initially, a difference of 2.3 to 5.1 ha is observed compared to COTECOCA (2014), indicating overgrazing on the “La Jococa” and “Nueva Generación” ranches, which average 7.2 ha/AU. This difference is likely attributable to the fact that COTECOCA's data are averages. municipal (Ejido, small property) therefore the data are very similar, even though they are coefficients reported in 2014 and 2007, they are still valid for the ranches evaluated

## CONCLUSIONS

The range of grazing coefficients obtained, with a range of 6 to 13.8 ha, is evidence of overstocking on the “La Jococa” and “Nueva Generación” ranches, although the “Tula” ranch showed values below those recommended by COTECOCA. Continuous monitoring of grazing areas, using tools such as remote sensors (satellites) and climatological data such as precipitation, temperature, and evapotranspiration, all available online, can contribute to monitoring the current condition with a level of precision at the production unit (ranch) level. This allows for comparison against the grazing coefficients generated by COTECOCA at the municipal level, guiding ranchers to adjust stocking rates and prevent grazing degradation. This method has the advantage of being less time-consuming and costly, and it also provides greater coverage per unit area compared to traditional methods. However, it is advisable to link them to in situ dry matter studies to have a more accurate approximation of the condition of the pasture, as well as the use of common sense and acumen in the field will continue to be fundamental for the logical interpretation of the results.

## LITERATURE CITED

1. Aizpuru, G.E. 1979. Grassland Management I (Grassland Ecology) Parts 1 and 2. National Teacher Training Program. SEP. UACH. ES.Z. pag 289. (2 – 10).
2. CONAFOR 2014. State forest and soil inventory -Zacatecas. First edition. ISBN. 978-607-8383-29-0. Pag. 158.
3. COTECOCA 2014. Department of Agriculture, Livestock, and Rural Development. Fisheries and Food, Technical Advisory Committee on Grazing Coefficients. (Grazing coefficients for the state of Zacatecas) [www. SAGARPA.gob.mx](http://www.SAGARPA.gob.mx). Consultation 2024.
4. COTECOCA 1967. Technical commission for determining grazing coefficients. Methodology for determining vegetation types, sites, and site productivity. Publication No. 8, México, D.F. 84 p.
5. Chang, J.; Tian, J.; Zhang, Z.; Chen, X.; Chen, Y.; Chen, S.; Duan, Z. 2018. Changes of grassland rain use efficiency and NDVI in Northwestern China from 1982 to 2013 and its response to climate change. *Water*, 10:11. 689. <https://doi.org/10.3390/w10111689>.
6. Diallo O., Diouf A., Hanan N. P., Nidiaye A. Prevost Y. 1991. AVHRR monitoring of savanna primary production in Senegal, West Africa: 1987 1988. *International journal of remote sensing*. 12:16. 1259-1279. [doi.org/10.1080/01431169108929725](https://doi.org/10.1080/01431169108929725).
7. Diaz-Solis, H., M. M. Kothmann, W. T. Hamilton, and W. E. Grant. 2003. A simple ecological sustainability simulator (SESS) for stocking rate management on semi-arid grazing lands, *Agric. System* 76: 655-680. [Doi.org/10.1016/S0308-521X\(01\)00115-9](https://doi.org/10.1016/S0308-521X(01)00115-9).
8. Echavarría C. F. G., Gutiérrez L. R., Ledesma R. R. I., Bañuelos V. R., Aguilera S. J. I., Serna P. A. 2006. Influence of the grazing system with small ruminants on a semi-arid pasture in Zacatecas: Native vegetation. *Mexican Journal of Livestock Sciences*. 44(2) 203-217.
9. Echavarría C. F. G., Medina G. G., Rumayor R. A. F., Serna P. A., Salinas G. H., Bustamante W. J. G. 2009. Diagnosis of natural resources for planning technological intervention and ecological management. INIFAP. CIRNOC. Technical book No 10. pag 174.
10. Fariña C., Easdale M., Bruzzone O., Umaña F. 2019. Grassland assessment: Looking at the photo and the film. INTA EEA Bariloche, IFAB (INTA- CONICET) Presence No 71. Pag. 9-12.
11. Gillan K. J., McClaran M. P., Swetnam. L. and Heilman P. 2019. Estimating Forage Utilization with Drone-Based Photogrammetric Point Clouds. *Rangeland Ecology and Management*. 1-11. [doi.org/10.1016/j.rama.2019.02.009](https://doi.org/10.1016/j.rama.2019.02.009).

12. Gutiérrez L. R., Medina G. G., Amador R. M. 2007. Animal stocking rates on medium-open grassland in Zacatecas. North Central National Research Center, Zacatecas Experimental Field. Information brochure. No.46, 42 pag.
13. Gutiérrez L. R., Velásquez V. M. A., Sánchez C. I., Gutiérrez L. S., Martínez T. G. 2018. Sustainable use of grasslands through adjustment of stocking rates in dry areas. North Central National Research Center. Zacatecas Experimental Field. Technical Brochure No. 94. 59p. ISBN: 978-607-37-1069-5.
14. Hobbs, T. J. (1995). The use of NOAA-AVHRR NDVI data to assess herbage production in the arid rangelands of Central Australia. *International Journal of Remote Sensing*, 16(7): 1289-1302. doi.org/10.1080/01431169508954477
15. Holechek, J.L., Pieper, R.D. and C.H. Herbel. 2004. Range management: Principles and practices. 5th Ed. Pearson / Prentice Hall. Upper Saddle River, NJ. pp 607.
16. INEGI 2020. Geospatial Data Cube of Mexico (CDGM). [https://www.inegi.org.mx/contenidos/investigacion/geomediana/doc/cubo\\_de\\_datos.pdf](https://www.inegi.org.mx/contenidos/investigacion/geomediana/doc/cubo_de_datos.pdf).
17. Jiménez-Jiménez S. I., Marcial-Pablo M. D. J., Ojeda-Bustamante W., Sifuentes-Ibarra E., Inzunza-Ibarra M. A. and Sánchez-Cohen I. 2022. VICAL: global calculator to estimate vegetation indices for agricultural areas with landsat and sentinel-2 data. *Agronomy*, 12(7): <https://doi.org/10.3390/agronomy12071518>.
18. Lang M., Mahyou H. and Tychon B. 2021. Estimation of rangeland production in the arid oriental region (Morocco) combining remote sensing vegetation and rainfall indices: challenges and lessons learned. *Remote Sensing*, 13(11), 2093. doi.org/10.3390/rs13112093.
19. Martiny N., Richard Y. and Camberlin P. 2005. Interannual persistence effects in vegetation dynamics of semi-arid Africa. *Geophysical research letters*, 32(24). doi.org/10.1029/2005GL024634.
20. Medina G.M., Gutiérrez L.R., Echavarría F.C., Amador R.M.D., Ruiz C.J.A., 2009. Use of satellite images to assess forage production in the rangelands of Zacatecas Mexican Journal of Livestock Sciences;47(2): ISSN: 0040-1889.
21. Meera G.G., Parthiban B.S., Nagaraj T. and Christy A. 2015. Ndvi: Vegetation change detection using remote sensing and gis- A case study of Vellore District. CC BY-NC-ND Procedia Computer Science 57 license (<http://creativecommons.org/licenses/by-nc-nd/4.0/>). Peer-review under responsibility of organizing committee of the 3rd International Conference on Recent Trends in Computing 2015 (ICRTC-2015)
22. Monteith, J.L., 1965. Evaporation and environment. 19th Symposium, vol. 19. University Press. Society for Experimental Biology. Cambridge, 205-234.
23. NRCS. 2018. Determining carrying capacity and stocking rates. <https://nrcs.usda.gov/sites/default/files/2022-10/determining%20carry%20capacity%20and%20stocking%20rates%20ND.pdf>.
24. SAS System V 9.4 for Windows, Copyright 2013 Institute Inc. Cary Nc 26513 USA all Rights Reserved.
25. NRCS. 1997. National Range and Pasture Handbook, Natural Resources Conservation Service, United States Department of Agriculture, Washington, D.C. 472 p.
26. Olson KC, Cochran RC. 1998. Radiometry for predicting tallgrass prairie biomass using regression and neural models. *J Range Manage* ;(51):186-192.
27. Paruelo J. M., Lauenroth, W. K., and Roset, P. A. 2000. Estimating aboveground plant biomass using a photographic technique. *Rangeland Ecology and Management/Journal of Range Management Archives*, 53(2):190-193.
28. Rodríguez T.D.2022. XI Congreso Internacional de Manejo de Pastizales, Memorias. pag 502, ISSN: 1870-8192.
29. Sala O.E., Deregibus V.A., Schlichter T., Alippe H.1981. Productivity dynamics of a native temperate grassland in Argentina. *J Range Manage*; 34:48-51. DOI 10.2307/3898453
30. SINIIGA.2012. National individual livestock identification system. Livestock statistics information desk Zacatecas.
31. Thomson E.F., Mirza S.N., Afzal J. 1998. Technical Predicting saltbush Predicting the components of aerial biomass of fourwing saltbush form shrub height and volume. *J Range Manage* ;(51):323-325.
32. Villa H.A., Paz P.F., Pérez H.M., Rojas M.C., Rodríguez A.M., Ortiz A.S., Casiano D.M., Díaz S.H. Grenaser. 2014. Animal carrying capacity estimation in rangelands using a normalized slopes vegetation index. Graduate School, Campus Montecillo, km 36.5 highway México Texcoco, Montecillo. 56230. México. (ferpazpel@gmail.com). Department of Natural Resources, Antonio Narro Autonomous Agrarian University, Saltillo, Coahuila, CP 25315, México, ISSN: 1405- 3195.
33. Waite R.B.1994. The application of visual estimation procedures for monitoring pasture yield and consumption in exclosures and small plots. *Trop Grassl* 1994;(28):38-42.
34. Wylie B. K, Denda I, Piepper R.D., Harrington J.A., Reed B.C., Southwood G.M. 1995. Satellite-Based herbaceous biomass estimates in the pastoral zone of Niger. *J Range Manage* 1995;(48):159-164. This article is available at Digital Commons @ University of Nebraska - Lincoln: <https://digitalcommons.unl.edu/usdaarsfacpub/1132>.
35. Xiliang Li X., X. Houz., Z. Liu, F. Guo., and Y. Ding .2017 Long- term Overgrazing Induced Changes in topsoil Water- Retaining Capacity in atypical Steppe. *Rangeland Ecology & Management*. Volume 70(3): 324 -330.
36. Wu Taosuo, Feng Feng, Qian Lin, and Hongmei Bai. 2019. "Advanced Method to Capture the Time-Lag Effects between Annual NDVI and Precipitation Variation Using RNN in the Arid and Semi-Arid Grasslands" *Water* 11, no. 9: 1789. <https://doi.org/10.3390/w11091789>