v. 3, n. 11, 2023

Journal of
Agricultural
Sciences
Research

ANNUAL FORAGE PRODUCTION DEPENDING ON MOISTURE AVAILABILITY

Lorenzo Armando Aceves Navarro
ORCID ID: 0000-0002-9301-9223
Postgraduate College - Tabasco Campus.
Environment Knowledge Area.

José Francisco Juárez López
ORCID ID: 0000-0002-7145-1509
Postgraduate College - Tabasco Campus.
Environment Knowledge Area.

Agrícola Arrieta Rivera
ORCID ID: 0000-0002-8107-9379
Tecnológico Nacional de México/IT de la Zona Olmeca.
Academic Body - Natural Resources and Development.

Abstract: Forage production is the basis of cattle feeding, for this it is necessary to have enough forage throughout the year, taking into account that in times of drought there is a deficit. Pastures, like other crops, are sensitive to moisture deficit in their different phenological stages. There is a high correlation between forage production and available moisture. The objective of this study was to present a procedure to estimate the pattern of forage production in the year, based on the availability of moisture and determine its probability for each of the months of the year. To do this, the Tanzania grass (Panicum maximum Jacq.) was used as an example. Likewise, daily climatological information on precipitation, maximum and minimum temperatures, from the weather station 27056 in Balancán, Tabasco, was used. Models were also used to estimate the relative and maximum forage yield, depending on weather variables and pasture characteristics. The results show that in the area of influence of the meteorological station 27056 of Balancán, Tabasco, the highest yields are reached in the rainy season (June to October), while in the period from November to April the relative yield was lower. at 50% of the maximum achievable performance. The maximum achievable yield was obtained in the month of June and was almost 5.0 t ha^{-1} of dry matter; while the minimum yield was obtained in the month of March and was almost 0.50 t ha^{-1}. The probability of obtaining yields equal to or greater than 4.5 t DM ha^{-1} was 12%, while yields of 2.0 and 1.0 t h^{-1} have a probability of exceedance of 52% and 78% respectively.

Keywords: Maximum yield, achievable yield, moisture availability index, biomass production models, probability.

INTRODUCTION

The feeding base of bovines are natural or cultivated pastures, which occupy 52.1% of the state territory. Being a seasonal activity, in the dry months (March to May) there is a forage deficit (Meléndez et al., 2006) which brings weight loss in the animals and even death due to lack of food.

Faced with this problem, it is necessary to adopt techniques that allow an efficient use of resources, including irrigation (Cavero et al., 2000; George et al., 2001), and the storage of forage resources in times of greater production for their use. in times of scarcity.

The leaf appearance rate is a function of temperature, which varies throughout the year, with a visible drop in production in the winter months (Ayala and Basulto, 1992). On the other hand, humidity, radiation and photoperiod also contribute to the seasonal variation of forage production (Monteith, 1977).

Evapotranspiration is a continuous process through which a crop area loses water through soil evaporation and foliage transpiration, while the reference evapotranspiration (ET_0), is the rate of evapotranspiration from a reference surface that occurs without water restrictions (Allen et al., 2006).

The only factors that affect the

ET_0 are the climatic parameters, therefore, ET_0 it is also a climatic parameter that can be calculated from climatological data. ET_0 expresses the evaporative power of the atmosphere at a specific location and time of year.

Various factors influence the yield of crops, being water one of the most important, since if it is not supplied in quantity and opportunity, the growth, development and yield of crops is affected. The magnitude of the affectation varies according to the species and the phenological stage of development (Smith & Staduto, 2012). For most crops, the greatest sensitivity to water deficit occurs during flowering; and to a lesser degree in grain formation and emergence (Smith & Staduto, 2012). The effect of lack of water on forage production can be predicted with a linear function proposed by FAO (Doorenbos and Kassam 1979); which calculates relative performance based on relative water consumption; or a sigmoid function that relates the moisture availability index to the relative performance; as proposed by Hargreaves & Keller, (2005). This relative yield is called 'water-limited achievable yield', which is the yield that is obtained when the deficit in the water supply is a limiting factor. While the maximum yield is one that has no other limitation than crop genetics and global solar irradiation; and it is independent of soil moisture, fertilization, pest and disease control, and other management practices (Monteith, 1977).

MATERIALS AND METHODS

Weather information: Daily data of maximum temperature, minimum temperature and precipitation for the registration period from 1943 to 2018 were extracted from the weather station 27056 in Balancán, Tabasco, both from the ERIC Software Version 3.2 (Rapid Extraction of Climatological Information), completed with statistical information. reported by the National Meteorological Service on its website (SMN, 2022). The data was entered into a Microsoft ® Excel sheet to facilitate its handling, operation and statistical analysis.

Relative Yield Calculation: The calculation of the relative yield was made using the cubic Equation reported by Hargreaves and Keller (2005), which relates the moisture availability index (IDH) with the relative yield. The equation is:

$$RR = (0.80 * IDH) + [1.3 * (IDH)^2] - [1.1 * (IDH)^3] \quad \text{(Equation 1)}$$

Where, RR is the relative yield and IDH is the moisture availability index.

The Equation that calculates the HDI for the cultivation of pastures is the following:

$$IDH = \frac{P_{0.75}}{ET_0} \quad \text{(Equation 2)}$$

In which, $P_{0.75}$ is the precipitation with a probability of exceedance of 75% in (mm d^{-1}); y ET_o *is the reference evapotranspiration* (mm d^{-1}).

El *IDH* has the following property: 0 ≤ HDI ≤ 1.0; This normalizes Equation (1) such that when the HDI is equal to one, the relative performance is also equal to one. That is to say; if the HDI is greater than 1.0; the final value of the HDI is 1.0

Calculation of reliable and/or effective precipitation ($P_{0.75}$). Reliable or effective precipitation is that precipitation with a 75% probability of exceedance of occurring. The reliable or effective precipitation is the part of the total annual or monthly rainfall that is useful for the production of a crop, either directly or indirectly (George, et al., 2001; Molua & Lambi, 2006). To calculate it, there are two procedures with almost identical results: The first procedure consists of fitting the Incomplete Gamma Probabilistic Function or Gamma of two parameters (alpha and beta) to the data set of each month of the total monthly precipitation of the set of record years. This function is used, because the total monthly precipitation is generally not distributed as a Normal Function; and the Incomplete Gamma function can represent from the Exponential function, the Transforms of the Normal and the Normal itself. The calculation of the alpha and beta parameters (α and β), which are the shape and dispersion parameters, respectively, is carried out with equations 3, 4 and 5, obtained by the Maximum Likelihood method.

$$\alpha = \left(\frac{1}{4A}\right) * \left[1 + \sqrt[2]{1 + \left(\frac{4A}{3}\right)}\right] \quad \text{(Equation 3)}$$

Where, the value of 'A' is calculated with the following Equation (4):

$$A = Ln(X_m) - \left[\frac{\sum_{i=1}^{N} Ln(X_i)}{N}\right] \quad \text{(Equation 4)}$$

In which, *Ln* is the natural logarithm; X_m is the average of the precipitation (mm); X_i is the precipitation value of a particular month; and N is the number of observations.

$$\beta = \frac{X_m}{\alpha} \quad \text{(Equation 5)}$$

Precipitation at 75% probability of exceedance is calculated using the Incomplete Gamma Function that comes as one of the Microsoft ® Excel commands. The command is: **DISTR.GAMMA.INV(probability, alpha, beta).**

As Excel Microsoft ® automatically calculates the probability of Non-exceedance; to obtain the probability of exceedance, we start from the following equality: (Probability of exceedance + probability of non-exceedance) = 1.0; where, Probability of exceedance = 1.0 – probability of non-exceedance = 1.0 – 0.75 = 0.25. Thus, if a probability of exceedance of 0.75 is desired, the value of 0.25 must be entered in the Microsoft ® Excel command; not the 0.75 one.

The second procedure consisted of applying an adjustment to the model reported by Hargreaves and Jensen, (2002), which gives very similar results to the first procedure. The proposed Equation is:

$$P_{0.75} = P_m - (0.7328 * \sigma) \quad \text{(Equation 6)}$$

In which, $P_{0.75}$ which has a 75% exceedance probability of occurring (mm d^{-1}) which has a 75% exceedance probability of occurring; P_m is the average monthly precipitation (mm d^{-1}); 0.7328 is a calibrated fit factor to the Incomplete Gamma Function for the probability of exceedance of 0.75; y '**σ**' *is the standard deviation of the precipitation data for the month in question* (mm d^{-1}).

This second procedure is simpler and only requires average monthly precipitation data and its standard deviation, which is reported in the ERIC III program, which is a program for rapid extraction of climatological information for 93 meteorological stations in the state of Tabasco and for more than 5,000 stations in Mexico (IMTA, 2006).

Reference evapotranspiration calculation (*ET_o*). One of the models that best estimates the water consumption of plants is from the Penman-Monteith; which has been used as a reference model worldwide (Allen et. al., 2006). The problem for its use is that it requires climatological data that is hardly available in the vast majority of weather stations in Mexico and the world. The FAO proposes that an alternative model be used (the Hargreaves-Samani model), since a large number of studies are reported in the scientific literature that show a very good correlation with the Penman-Monteith model and that only requires data from temperature (Allen et al., 2006). The Hargreaves-Samani (1985) model that estimates ET_o is the one used in this work and is shown in the following Equation (7):

$$ET_o = 0.0023 * (T_{med} + 17.8) * [(T_{max} - T_{min})^{0.50}] * \left(\frac{R_a}{2.45}\right) \quad \text{(Equation 7)}$$

In which, ET_0 *is the reference evapotranspiration* (mm d^{-1}); 0.0023 is a coefficient of adjustment; T_{med} is the average daily temperature (ºC); T_{max} is the maximum daily temperature (ºC); T_{min} is the minimum daily temperature (ºC) y R_a *is the theoretical extraterrestrial irradiation* (MJ m^{-2} dia^{-1}) that for its calculation it is only required to know the latitude of the locality and the number of the day of the year; and 2.45 is a correction factor that transforms Ra into millimeters per day. The calculation of the monthly values of Ra (in MJ m^{-2} d^{-1}) for the State of Tabasco, it was carried out using equations 8, 9, 10 and 11; reported by Allen et al. (2006, p 45-47) that are described below:

$$R_a = \left(\frac{24*60}{\pi}\right)*[G_{sc}*d_r]*[(\omega_s*sen\delta*sen\varphi)+(\cos\delta*\cos\varphi*sen\omega_s)]$$

(Equation 8)

In which, G_{sc} is the solar constant that has an average value of 0.082 MJ m^{-2} d^{-1}, d_r is the inverse relative distance Earth-Sun, ω_s is the angle of radiation at sunset (in radians), δ is the solar declination (in radians), φ is the latitude of the location (in radians) and J is the number of the day in the year (Julian day) in the middle of each month.

$$d_r = 1 + 0.033*\cos\left(\frac{2\pi}{365}*J\right)$$ (Equation 9)

$$\omega_s = \cos^{-1}[-\tan\delta*\tan\varphi]$$ (Equation 10)

$$\delta = 0.409*sen\left[\frac{2\pi}{365}*J - 1.39\right]$$ (Equation 11)

Obtained the values of $P_{0.75}$ and ET_o, the monthly values of the *IDH*.

Calculation of maximum performance: To calculate the maximum yield of Tanzania grass (Panicum maximum Jacq.), the model reported by both Monteith (1977) and Gosse et al. (1986), and which is shown in Equation (12):

$$B_n = RFA * f * RUE$$ (Equation 12)

In which, B_n is the net biomass or net assimilation rate (g m^{-2}); RFA is photosynthetically active radiation (MJ m^{-2} d^{-1}); *f is the fraction of the RFA intercepted by the plant cover of the crop (adim.) and RUE is the interception efficiency of the crop* (g MJ^{-1}). Babatunde, (2012), reports that $RFA = 0.49*R_g$; in which R_g is the global solar irradiation (MJ m^{-2} d^{-1}).

The fraction of the AFR intercepted by the crop (f) is calculated with the following equation:

$$f = 0.95 * [1 - \exp(-K_e * IAF)]$$ (Equation 13)

Where, 0.95 is a coefficient of maximum light interception; Ke is the extinction coefficient (which in the case of grass was assigned a value of 0.70) and the LAI is the leaf area index (m2/m). For this case, an average value of the IAF of 1.6 was taken. (m^2/m).

According to Monteith (1977) and Gosse et. to the. (1986), the interception efficiency ratio (RUE) for plants C_3 is 1.9 (g MJ^{-1}) and for plants C_4 is 2.5 (g MJ^{-1}).

Tanzania grass (Panicum maximum Jacq), is a plant C_4, so the RUE value used was 2.5 (g MJ^{-1}).

We proceeded to calculate the monthly values of reliable precipitation ($P_{0.75}$), of ET_o, *IDH,* and relative yield, using the previously described equations (from 1 to 13).

Calculation of stocking rate and cutting intervals: With the value of the monthly forage production, the stocking rate was calculated, taking as average consumption of a cattle herd a value of 12.75 kg of dry matter per animal per day, for bimonthly cutting intervals.

To define the intervals and cutting height in pastures with Tanzania grass (Panicum maximum Jacq.), the recommendation of Barbosa (2004) was taken; Cano et al. (2004); Perozo-Bravo and Contreras-Peña, (2013), who report that the dry matter production of the Tanzania grass (Panicum maximum Jacq.), reaches the maximum light interception at a cutting height between 40 to 70 cm; which according to Pereyra et al. (2012), this high interception (95%) is reached after 45 days in unfertilized pastures. Similar results are reported (Carnevalli, 2003; Rodríguez et al. 2011; and Petit, 2013), which determine at what height of the grass to cut and when. Based on the above, in the present work the selected cutting period was every two months, which is when the grass reaches the appropriate height and intercepts the maximum of solar radiation.

RESULTS

Differences between methods to estimate reliable precipitation (0.75 probability). In Figure 1, the monthly values of reliable precipitation are shown with the two procedures indicated above, to estimate precipitation at 75% probability of exceedance.

In this Figure 1, it can be seen that both procedures give very similar results; with the advantage that the adjusted model of Hargreaves - Jensen, (2002) only requires average values of precipitation and its standard deviation, which are easily available (IMTA, 2006). On the other hand, the application of the Incomplete Gamma Probabilistic Function requires the entire record in years of the precipitation of the meteorological station in question and the corresponding calculation of the alpha and beta parameters.

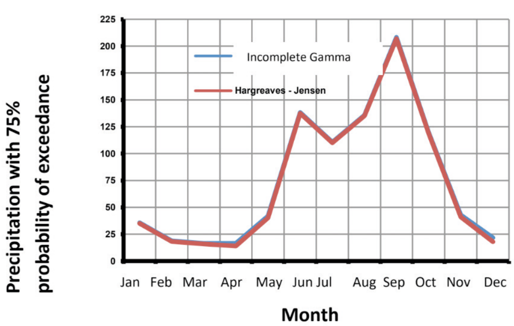

Figure 1. Precipitation values with a 75% probability of exceedance, obtained with the Incomplete Gamma Probabilistic Function and with the adjusted Hargreaves-Jensen Model, (2002).

Relative production: Figure 2 shows the monthly distribution of the relative yield and it is observed that only the month of September obtained the maximum yield (1.0). It is also observed that the period from June to October the relative yield oscillated between 0.94 and 1.0. That is, close to maximum performance. This indicates that in those months forage production approaches its maximum; while the months of December to May the performance decreases, reaching a minimum in the month of March of 0.10. It is in these months where cattle supplementation is necessary because the achievable yields are ten times below the potential yield of the area. A productive alternative that requires a financial analysis would be to introduce relief irrigation in the pasture and eliminate moisture deficiencies that significantly reduce forage production.

Figure 3 shows how the monthly forage production is distributed in (t MS ha^{-1}) corresponding, for the area of influence of the meteorological station 27058 of Balancán, Tabasco, Mexico; where it is observed that the maximum forage yield occurs in the month of June and the minimum in the month of March.

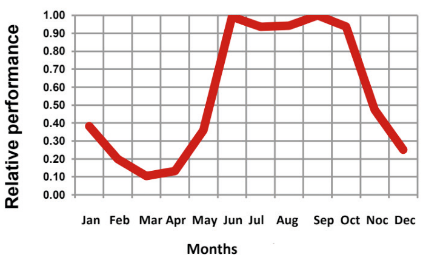

Figure 2. Monthly distribution of the relative yield of the Panicum maximum Jacq grass. cv. 'Tanzania', under storm conditions in the area of influence of the meteorological station 27056 of Balancán, Tabasco, Mexico.

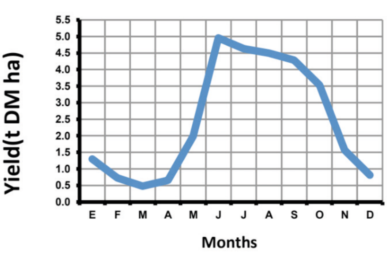

Figure 3. Monthly distribution of forage production (t DM ha-1) of the Panicum maximum Jacq grass. cv. 'Tanzania', under storm conditions in the area of influence of the meteorological station 27056 of Balancán, Tabasco, Mexico.

Forage production and stocking rate: Forage production is variable over time and mainly depends on soil moisture; that is why the highest yields occur during the rainy season and the lowest during the dry season (Barbosa, 2004). Showing a cyclical pattern in the production of dry matter, highly correlated with the deficit of soil moisture, which has been reported by Rodríguez et al. (2011); and whose pattern is repeated in the case of Balancán, as shown in Figures 2 and 3.

The cutting height determines the time spent in the paddock. The time required for Tanzania grass (Panicum maximum Jacq.) to reach a cutting height between 40 to 70 cm. The height will depend on the time of year; and a rest period of every two months tends to stabilize production in the long term (Cano et al. 2004; Rodríguez et al. 2011 and Petit, 2013).

The achievable performance for the area of influence of the meteorological station 27056 of Balancán, Tabasco, varied from 0.48 to 5.0 t MS ha^{-1}. The minimum performance is recorded in the cutting cycle (March-April), and the maximum of 5.0t MS ha^{-1} for the cutting cycle (July-August). The maximum potential yield calculated was in the month of May with 5.3 t DM ha-1 and the minimum in December with 3.23t MS ha^{-1} (Figure 4). Values that fall within the range reported for this grass by Carnevalli, (2003); Barbosa, (2004); Rodríguez et al., (2011); and Petit, (2013).

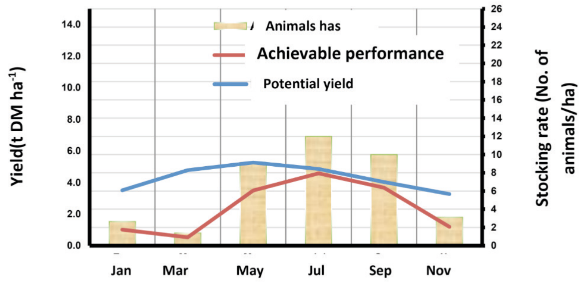

Figure 4. Potential and achievable performance (t MS ha^{-1}) of bimonthly forage with Tanzania grass (Panicum maximum Jacq.) and its corresponding stocking rate, in the area of influence of the meteorological station 27056 of Balancán, Tabasco, México.

In this Figure 4, it is shown how the achievable yield (limited by water) becomes almost equal to the maximum yield in the July-August cutting cycle. The rest of the year, the achievable yield is below the maximum yield due to moisture deficits. It becomes evident in this Figure 4, that, in the 3 cutting cycles, which includes the period from May to October, which is the rainy period;

In the area of influence of the weather station 27058 in Balancán, Tabasco, Mexico. That is, during the rainy season the Tanzania grass (Panicum maximum Jacq.) reaches its maximum yield.

Fodder Production Probabilities: To the achievable yields limited by water, the Incomplete Gamma Probabilistic Function was fitted to obtain the probability that, in a month or cutting cycle, at least one certain harvest could be obtained (exceedance probability). The resulting model was the one shown in equation (13) and whose graphic representation is shown in Figure 5.

$$P_E = 1.1142 - (0.361 * RA) + [0.0313 * (RA^2)] \quad \text{(Equation 13)}$$

Where, P_E is the probability of exceedance; and RA is the achievable performance (t ha^{-1}).

When applying this equation, it is enough to enter the value of the desired minimum performance to obtain its corresponding probability of exceedance. Thus, the probability of having a return equal to or greater than 4.5 t ha^{-1} of dry matter per harvest, is 12%. That is, it will happen once every 8 years. While the probability of having a return equal to or greater than 2 t ha^{-1} dry matter is 52%. That is, once every 2 years.

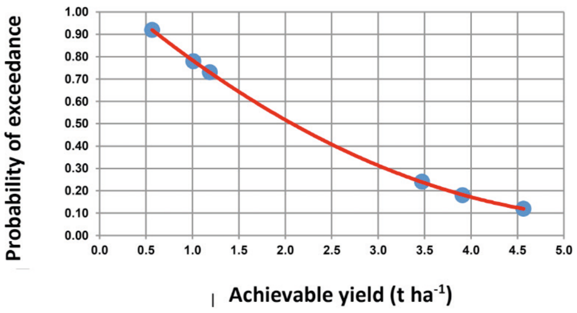

Figure 5. Probability of achievable yield per forage harvest of Tanzania grass (Panicum maximum Jacq.) in the area of influence of weather station 27056 in Balancán, Tabasco, México.

CONCLUSIONS

The applied procedure allows estimating the monthly forage production of Tanzania grass (Panicum maximum Jacq.) and its probability of occurrence. Likewise, it allows knowing the intensity of the effect of moisture deficiencies on yields. The results applied to Balancán show that in the dry season the yield can be reduced up to 10 times less compared to the rainy season. This way, the proposed procedure has great application for different localities and cattle-raising regions, in relation to the management of pastures and the cattle herd, since it allows predicting the productive behavior of pastures, defining the animal load that they can support and quantifying the scarcity or abundance of fodder. With which it is possible to design and establish the technologies for the use of surpluses, either as packed forage or through the construction of silos, for its use in critical times and thereby increase the daily weight gains of the animals without resorting to external supply. of fodder, which translates into decreased profits or losses.

REFERENCES

Allen, G. R., L. Santos P. L., Raes, D., y Smith, M. (2006). *Evapotranspiración del cultivo. Guías para la determinación de los requerimientos de agua de los cultivos*. FAO. Riego y Drenaje 56. Roma, Italia. 298 p.

Ayala, A., y Basulto, J. (1992). Evaluación de gramíneas y leguminosas forrajeras en la región oriental de Yucatán, México. *Pasturas Tropicales*, 4(1):36-40.

Barbosa, R. A. (2004). Características morfofisiológicas e acúmulo de forragem em capim-tanzânia (*Panicum maximum* Jacq. cv. Tanzânia) submetido a freqüências e intensidades de pastejo. Tese Doutorado em Zootecnia. Universidade Federal de Viçosa, Brasil. 122 pp.

Babatunde, E. B. (2012). Solar radiation, a friendly renewable energy source. In: Babatunde, E. B. (Ed.). (2012). *Solar radiation*, 0-18.

Cano, C. C. P., Cecato, U., Canto, M. W. D., Rodrigues, A. B., Jobim, C. C., Rodrigues, A. M., ... & Nascimento, W. G. D. (2004). Produção de forragem do capim-tanzânia (Panicum maximum Jacq. cv. Tanzânia-1) pastejado em diferentes alturas. *Revista Brasileira de Zootecnia*, *33*, 1949-1958.

Carnevalli, R. A. (2003). Dinâmica da rebrotação de pastos de capim-mombaça submetidos a regimes de desfolhação intermitente. Tese Doutorado. Escola Superior de Agricultura Luiz de Queiroz. Universidade de São Paulo. São Paulo, Brasil. 136 pp.

Cavero, J., I. Farre, P. Debaeke, and J. Faci. (2000). Simulation of maize yield under water stress with the EPICphase and CROPWAT Models. *Agron. J.* 92:679-690.

Doorenbos, J., y A. Kassam. (1979). *Efectos del Agua sobre el Rendimiento de los Cultivos*. FAO. Riego y Drenaje 33. Roma, Italia. 212 p.

George, B., Shende, S., and Raghuwanshi. N. (2001). Development and testing of an irrigation scheduling model. *Agric. Water Manage*. 46:121-136.

Gosse, G., Varlet-Grancher, C., Bonhomme, R., Chartier, M., Allirand, J. M., & Lemaire, G. (1986). Maximum dry matter production and solar radiation intercepted by a canopy. *Agronomie (Paris)*, *6*(1), 47-56.

Hargreaves, G. H., & Keller, A. A. (2005). Global Mapping of the Moisture Availability Index: Using the World Water and Climate Atlas. In *Impacts of Global Climate Change* (pp. 1-9).Ismail, S., and H. Depeweg. 2005. Water productivity and crop production simulation under surge flow irrigation in short furrows in Egypt. Irrigation and Drainage 54:103-113.

Hargreaves, G. H., & Jensen, D. T. (2002). Simplification of planning to meet future demands for food and water. *Energy. Climate, Environment and Water-Issues and Opportunities for Irrigation and Drainage*, 513.

Hargreaves, G.H. and Samani, Z.A. (1985) Reference Crop Evapotranspiration from Temperature. *Applied Engineering in Agriculture*, 1, 96-99. http://dx.doi.org/10.13031/2013.26773

IMTA, (Instituto Mexicano de Tecnología del Agua). (2006). *Extractor Rápido de Información Climatológica III, v. 1.0*. Información climatológica disponible en formato electrónico. Jiutepec, Morelos, México.

Meléndez N, F., J. A. González M., y J. Pérez P. (2006). Manejo Tecnológico del Pasto Estrella Africana en el Trópico. Instituto para el Desarrollo de Sistemas de Producción del Trópico Húmedo de Tabasco (ISPROTAB). Segunda edición. Villa- hermosa, Tabasco, México. 79 p

Molua, E. and Lambi, C. (2006). Assessing the impact of climate on crop wáter use and crop wáter productivity: The CROPWAT analysis of three districts in Cameroon. CEEPA discussion paper no. 33, CEEPA, University of Pretoria. 44 p.

Monteith, J. L. (1977). Climate and the efficiency of crop production in Britain. *Philosophical Transactions of the Royal Society of London. B, Biological Sciences*, *281*(980), 277-294.

Pereyra, R. R. O. & Homen, A. M. A. (2012). Solar radiation utilization by tropical forage grasses: light interception and use efficiency. In: Babatunde, E. B. (Ed.). (2012). *Solar radiation*, 221-244.

Perozo-Bravo, A., y Contreras-Peña, D. (2013). Empleo de la altura del pasto para determinar el ingreso y salida de animales en sistemas intensivos de pastoreo rotativo. En: *Manejo de pastos y forrajes tropicales*. *Cuadernos Científicos* Girarz 13. Perozo Bravo A (ed). Fundación Girarz. Ediciones Astro Data S.A. Maracaibo, Venezuela. 280 pp.

Petit, A. R. (2013). Prácticas de manejo de pastizales y productividad de leche en la cuenca del lago de Maracaibo. *Manejo de pastos y forrajes tropicales*, 105.

Rodríguez, L., Torres, V., Martínez, R. O., Jay, O., Noda, A. C., & Herrera, M. (2011). Modelos para estimar la dinámica de crecimiento de Pennisetum purpureum vc. Cuba CT-169. *Revista cubana de ciencia agrícola*, *45*(4), 349-354.

Smith, M., & Steduto, P. (2012). Yield response to water: the original FAO water production function. *FAO Irrigation and Drainage paper*, (66), 6-13.

Zaikin, A., and W. Butcher. (2008). Economic evaluation of farmers´ alternatives during irrigation water deficit; *In:* Qi J., and K. T. Evered (eds). Enviromental Problems of Central Asia and their Economic, Social and Security Impacts. Tashkent, Uzbekistan. *Springer Science*. pp: 251-266.

SMN, (Servicio Meteorológico Nacional), (2022). Climatología/Información climatológica. https://smn.conagua.gob.mx/es/climatologia/informacion-climatologica/informacion-estadistica-climatologica. (Consultado el 11 de abril de 2022).