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# Primary Productivity, Diet Quality and Voluntary Intake for Estimating Stocking Rate

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**Abstract:** The aim of this study was to estimate stocking rate in open grassland considering its primary productivity, diet quality and voluntary intake of beef cattle. To achieve this, the methodology and systems analysis approach was used. By means of the Stella 8.0 simulation program a model was developed whose predictions show an 11% of difference in the actual primary productivity respect to that estimated of 3 years with different precipitation. In the study period, the stocking rate estimated in 2000 ha in the study period according to dry matter intake, crude protein and metabolizable energy ranged between 248-663, 233-823 and 297-758 animal units, respectively. The monthly stocking rate average estimated by the model base on produced dry matter and protein crude and metabolizable energy was 247.4, 289.5 and 321.54 animal units, respectively. Stocking rate and stocking coefficient predicted by the model indicate that assigning the hectares per animal unit will meet the needs of dry matter intake but there is a deficiency of crude protein and metabolizable energy when the mean annual precipitation is equal or lower to average.

**Key words:** Stella, simulation model, primary production, stocking rate, grassland

## INTRODUCTION

The cattle activity in the extensive system is carried out under the assignment of stocking rate and from this depend the herd efficiency and natural resource preservation.

In Mexico, it was created a guide for assigning the stocking rate that sought to stop the degradation and in special cases to recover the grassland that had been in use without a technical regulation. COTECOCA applied the approach dry matter production per hectare to establish the coefficient of fixed stocking according to the ecological niche in which the area susceptible to exploitation is found. This approach fills the need of dry matter that cattle has and does not offer elements to suggest animal productivity, leading to the need for studies on management of the grassland and herd resource for a more efficient response in terms of production.

The grassland is a complex ecological niche and because of this, studies have been done in irrigated pastures in order to understand processes aimed at conservation and productivity. In them it was established that the stocking rate determines grazing pressure and it is a cause of weight gain (Mott, 1960). On this regard, Owen and Ingleton (1963) mention that a stocking rate allows the animal to consume *ad libitum* but consumption and diet quality may be limited when stocking rate increases.

Weight gain is closely related to forage availability and digestibility. Diaz-Solis *et al.* (2005) when considering the dry matter and digestibility to establish the optimum stocking rate determined that in irrigated pastures at a digestibility of 75% more animals are kept per hectare than at 60 and 70% and thus higher profits per hectare.

Study of stocking rate and diet quality are complicated when trying to include other variables and thus a tool that has proved useful is modeling (Diaz-Solis *et al.*, 2005) because in many situations it is not possible conducting such studies for dangerousness, time or cost (Raczynski, 1993). This has caused that some experiments are performed with reduced or scaled versions of real life situations using models. The use of models in primary production systems is vital because it can estimate variations and test the conditions thrown by the simulations. That is why in this study researchers employed the use of models to evaluate the relationship

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of the stocking rate allocation in open grassland considering primary production, diet quality and voluntary intake.

## MATERIALS AND METHODS

**Description of the study area:** The study area covers an area of 2000 ha and is located in the semi-desert area in the municipality of Durango, Mexico between 24°09' and 24°13'N and between 104°16' and 104°20'W at 1950 masl. The area has a semiarid climate of the type BS1kw (w) and average annual temperature of 16°C. The rainfall is 450-550 mm a year with rainfall in Summer from June to September. The soil is of *in situ* origin, derived from igneous rock, sandy to frank texture, granular structure, internal drainage from medium to rapid, moderately slow surface runoff and pH of 6.5-7.5. The topography is flat with very low undulations and hills with slopes of 0-10%. Vegetation consists of native grasses of the genus *Bouteloua*, together with *Botrhriochloa barbinodis*, *Heteropogon contortus*, *Aristida* sp., *Muhlenbergia* sp., *Trachypogon secundus*, *Enneapogon desvauxi*, *Lycurus phleoides*. The shrub layer is composed of *Opuntia* sp., *Acacia tortuous*, *Prosopis leavigata*, *Celtis pallida* and *Mimosa biuncifera*. Since, 1979 COTECOCA has estimated an index of rangeland 7-8.5 ha per animal unit/year.

**Vegetation samplings:** During 2008 and 2009 vegetation samplings were conducted in the study area. To perform sampling, the line intercept method (Canfield, 1941) and forage production table were used. Transects used in this study are permanent, 20 m long with a spacing of 50 m between lines. The forage production table method was applied by using an $m^2$ released randomly at the site adjacent to each line canfield. In this sample, the number of species was counted and cut at ground level and dried at 50°C to determine the production of Dry Matter (DM) per ha. As a general rule, the samples were avoided 200 m to the proximity of water sources for livestock.

**Determination of the chemical composition of the diet:** In October 2008 and May 2009 (times of abundance and scarcity of fodder) samples were collected from the diet for five consecutive days for which researchers used three creoles steers with fistula in the esophagus with an average weight of 440 kg, subjected to a conditioning period of 10 days in the pasture. Samplings were conducted from 7:00-8:00 h. Cattle were given diets overnight. The samples were dried at 50°C and ground in a Wiley mill with 1 mm mesh. Once dried and ground were stored in closed containers and placed at room temperature until analysis.

All samples were analyzed for Digestibility *In Vitro* of Dry Matter (DIVDM) (ANKOM Technology, 2008), Crude Protein (CP) from the nitrogen content determination using the method Kjendhal and Metabolizable Energy (ME) by equation (DIVDM×0.038) + 0.18)×0.80.

**Voluntary Intake (VI) estimate of forage:** It was conducted through the technique mentioned by Sanchez, three creoles steers were used with fistula in the esophagus to which were given 20 g/day/animal of chromium oxide impregnated on paper. The chromium oxide was administered at 7:00 and 16:00 h, 10 days prior to sampling of feces and during the sampling period. Fecal collection was carried out at 7:00 and 16:00 h for 5 consecutive days. The determination of chromium in feces was performed by analysis of atomic absorption spectrophotometry (Varian AA-240 FS). To determine the Total Feces Produced (THP) and voluntary intake the following equations were used:

$$\text{THP} = \frac{\text{Daily dose of the indicator}}{\text{Indicator in feces}}$$

$$\text{VI} = \frac{\text{THP}}{1\text{-}\left(\frac{\text{DIVDM}}{100}\right)}$$

**Simulation model:** The model was developed using the methodology proposed by Grant *et al*. (2001). The conceptual model (Fig. 1) was divided into three sub-models: primary productivity of pastureland, animal production and soil productivity which interact to determine the effect of the stocking rate as effect of primary production, diet quality, voluntary intake and the effect that stocking rate has on the soil. For the model development the program Stella Version 8.0 (High Performance Systems, Inc. 2003) was used and a personal computer running Windows XP Home Edition. To develop the quantitative model different equations and values were used whose components are described.

**Primary productivity of grassland:** Grassland primary production was estimated under the sub-model shown in Fig. 2. Production Data of Dm Estimated (PDME) in the samplings taken and records of earlier years were used to estimate the efficiency of rain (Le Houerou, 1984), represented by the rate of dry matter production (TPMS, kg dm/ha/year) based on precipitation (per mm per year):

$$\text{TPDM} = \frac{\text{PDME}}{\text{PA}} \qquad (1)$$

Where:

TPDM = Rate of Dry Matter Production
PDME = Production of Dry Matter Estimated
PA = Annual Precipitation

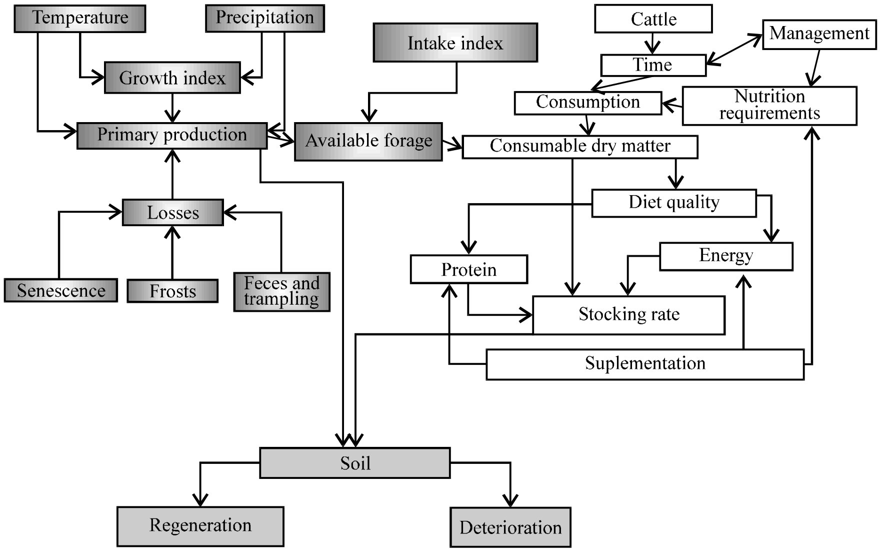

Fig. 1: Conceptual model proposed to estimate the stocking rate

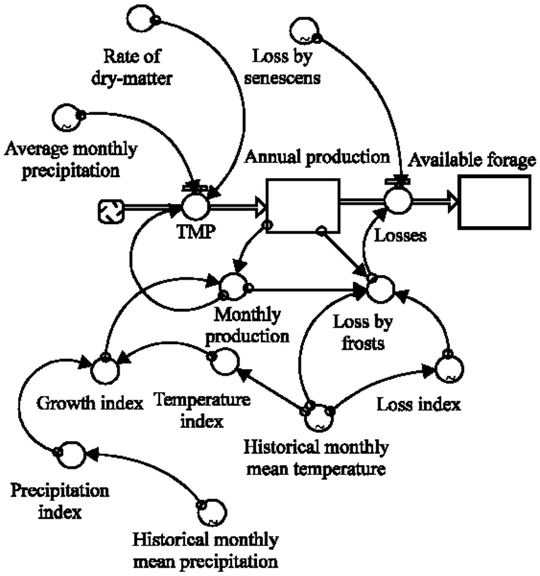

Fig. 2: Sub-model to estimate primary production of grassland

Whereas the production of DM is given for most of the year a growth rate was estimated (Diaz-Solis *et al*., 2005) (Eq. 2) which is closely related to temperature and historical monthly average precipitation for this climate data were used of the period 1979 to 2009. With this growth index it was estimated monthly production (DM/ha/month) when multiplied by the available forage of annual production:

$$GI = (TI \times PI) \times (\sum IT \times PI)^{-1} \tag{2}$$

Where:
GI = Growth Index
TI = Temperature Index
PI = Precipitation Index

The indexes of temperature and precipitation were calculated by Eq. 3 and 4, respectively.

$$TI = (HMAT\text{-}BT \times (\sum HMAT\text{-}TB)^{-1} \tag{3}$$

Where:
TI = Temperature Index
HMAT = Historical Monthly Average Temperature
TB = Base Temperature (10°C)

$$PI = HMAP \times (\Sigma\, HMAP)^{-1} \tag{4}$$

Where:
PI = Precipitation Index
HMAP = Historical Monthly Average Precipitation

Forage production was estimated from the average monthly precipitation (MAP) which multiplied by the production rate gives an estimate of the effect of rainfall throughout the year. To this production monthly production was added which was calculated using the growth rate of vegetation (GI). The basis of this sum is supported in that there are species that have a growth during the Winter months which are often important because they provide green fodder, though scarce. To avoid overestimating the annual production, the monthly production of the rainy months was subtracted. The variable of available forage condition is the product of the subtraction of annual production and losses by senescence and frost.

**Losses:** To estimate loss by frost the HMAT of 30 years is taken into account. Considering that grasses of temperate Climate (C3) have a reduced growth when temperature is close to 10°C a linear relationship was established of temperature of 20-10°C with loss index from 0-1. This index was applied to annual production and forage loss by frost was establishedand when the temperature was higher than or equal to 10°C only the monthly production was considered. To estimate senescence losses it was taken into account empirical data that Diaz-Solis *et al.* (2005) reported and estimated for the semi-desert area of Coahuila and Table 1 was elaborated where the month and the rate of loss are related.

**Animal production:** In this sub-model (Fig. 3), the stocking rate was estimated and for it, total dry matter production was taken into account which was obtained from the surface of the plot and was divided by three and multiplied by 0.65 as use factor to define the actual amount of dry matter available for use in the number of animal units that it can support without causing any change. The factor three was used because references state that grazing livestock wastes of 2-3 kg $\text{kg}^{-1}$ of DM consumed by effect of trampling and contamination by feces (Diaz-Solis *et al.*, 2005).

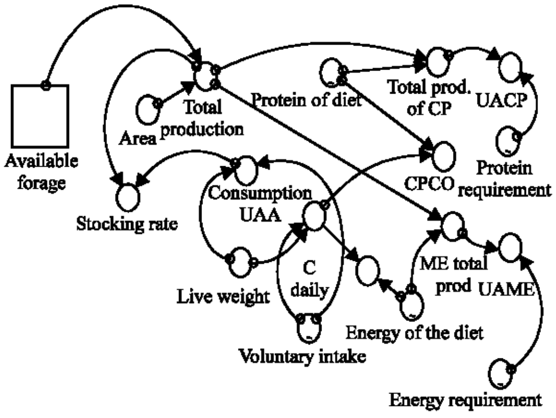

Fig. 3: Sub-model animal production

Table 1: Forage losses relationship throughout the year

| Months | Loss index |
|---|---|
| January | 0.01 |
| February | 0.01 |
| March | 0.02 |
| April | 0.08 |
| May | 0.12 |
| June | 0.14 |
| July | 0.15 |
| August | 0.15 |
| September | 0.14 |
| October | 0.14 |
| November | 0.08 |
| December | 0.02 |

**Stocking Rate (SR):** It was estimated according to the bases established by COTECOCA in 1979 and for this it was considered one animal unit to a belly of 450 kg of weight bodily with a forage intake per day of 2.51 and 2.16% of live weight, quantified through voluntary intake by fistulated animals during the rainy and dry season, respectively. CP and ME data of the diet (Table 2) were considered for the estimation of SR and contrasted with SR estimated based on forage production. PC and ME data of the diet obtained in this study were supplemented with data from Chihuahuan semi-desert grassland by Chavez (Table 2).

For the calculation of animal units (UA) based on CP (UACP) and ME (UAME) it was necessary to determine the daily needs. They were taken from the numerical information of tables of nutrient requirements, courtesy of National Academy Press, Washington, DC (Shimada, 2005). Requirements of CP and ME were established for pregnant cows of 450 kg empty last third (703 g $\text{day}^{-1}$ and 17.2 Mcal), lactating calves (911 g $\text{day}^{-1}$ and 19.1 Mcal) and pregnant cows empty middle third (570 g $\text{day}^{-1}$ and 14.3 Mcal) and it was considered the calendar of the ranch management under study where breeding takes place in May to June, births in March to April and weaning in October to November.

In order to estimate the deficiencies on consumption of DM, CP and ME variables of VI (C daily) were estimated and with it, CP Consumption per Day (CPDC) and ME per Day (CMED) were quantified.

**Soil productivity:** The productivity of the soil is represented by the forage production which in turn

Table 2: Crude protein and metabolizable energy content of the diet obtained by grazing cattle (Chavez)

| Months | Crude protein (%) | Metabolizable energy (Mcal $\text{kg}^{-1}$) |
|---|---|---|
| January | 7.2 | 1.83 |
| February | 7.2 | 1.83 |
| March | 7.2 | 1.83 |
| April | 6.7 | 1.83 |
| May | 6.7 | 1.83 |
| June | 6.3 | 1.83 |
| July | 8.9 | 2.27* |
| August | 13.5 | 2.27* |
| September | 12.6 | 2.27* |
| October | 7.9 | 2.38 |
| November | 7.2 | 1.91* |
| December | 7.2 | 1.91* |

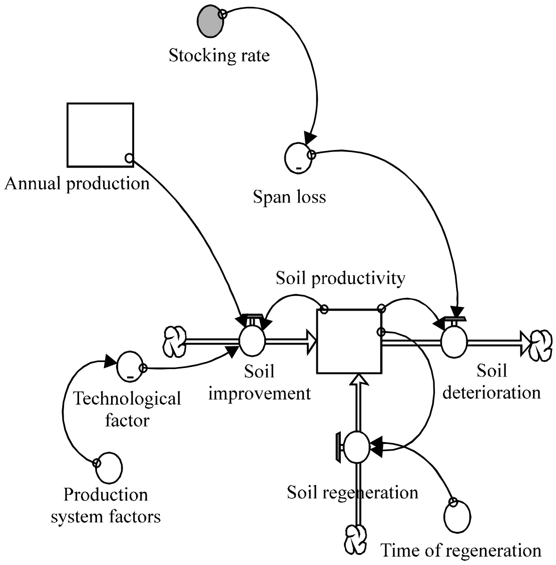

Fig. 4: Sub-model of soil productivity

influences the improvement and deterioration of soil due to the SR effect (Fig. 4). Both the deterioration and soil improvement are represented by an index of one as the balance in conservation. Thus, it was established as optimal stocking rate 300 UA for the study area as a balancing factor.

The variable soil improvement was estimated taking into account the total production less soil productivity multiplied by the technological factor. The regeneration time was established under criteria of FAO which states that the regeneration of the vegetation cover in areas under grazing can be retrieved in a span of 10 years minimum.

## RESULTS AND DISCUSSION

The dry matter production (Fig. 5) in the study area during the years 1979, 1999 and 2008 were 1067, 2780 and 3875 kg ha$^{-1}$, respectively effect of an average annual precipitation of 293, 507.86 and 803.5 mm to which corresponded an average production rate of 4.8. The higher production rate (5.47) was obtained when precipitation was equal or close to the annual average (450-550 mm). Annual production obtained by the model considering precipitation above mentioned was 1994, 2317.82 and 4128.88 kg ha$^{-1}$ which represents as forage available 1263, 2006.16 and 3433.41 kg ha$^{-1}$, making an average difference of 13% between the real and the calculated by the model.

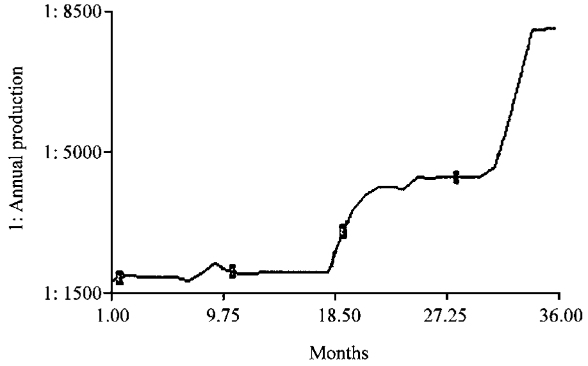

Fig. 5: Accumulative production of forage in the study area during the years 1979 (from month 1-12), 1999 (from month 13)

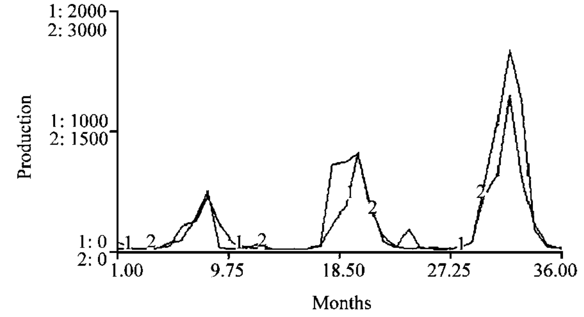

Fig. 6: Monthly forage production by rainfall effects and growth index; 1 = monthly production; 2 = total monthly production

Monthly production shows that the pasture has a dynamic behavior during the year (Fig. 6) at occurring the growth of *Elionurus* sp., *Trachypogon* sp., *Bothriochloa barbinodis* and *Melinis repens* species that are present in the diet of cattle in the dry season.

Figure 6 shows the monthly production which never exceeds the total monthly production because the model avoids overestimating by effect of rain. Regarding losses obtained in the simulation in the January to May period are greater than the monthly production. Senescence and frost losses calculated by the model on average amounted to 91.1 kg ha$^{-1}$ for the dry season. In June, production begins to recover and fell again in November (Fig. 7). The annual forage production exceeds losses due to the effect of precipitation (Fig. 7).

The historical precipitation curve indicates that the rainy season begins in late May or early June with an average of 40.68 mm and concludes in late September and early October with an average of 428.12 mm. The distribution of precipitation recorded for 1979 and 2008 is similar but not for the year 1999 where there were no rains in the January to May period but the precipitation reached the historical average annual and forage production was higher than that obtained in 1979 (Table 3 and Fig. 7). The

Table 3: Annual and historical precipitation (1979, 1999 and 2008) in different periods

| Years | January to May | May | June to October | November to December | Total (mm) |
|---|---|---|---|---|---|
| 1979 | 25.30 | 10.0 | 256.00 | 12.1 | 293.4 |
| 1999 | 0.00 | 0.0 | 458.00 | 50.0 | 508.0 |
| 2008 | 11.00 | 6.4 | 792.50 | 0.0 | 803.5 |
| Historical prepipitation | 40.68 | 13.0 | 428.12 | 22.3 | 491.1 |

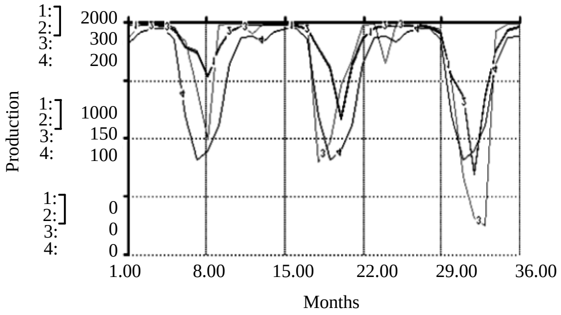

Fig. 7: Behavior of total loss, monthly production of dry matter, historical and annual precipitation in open grassland. 1 = loses; 2 = monthly production; 3 = precipitation; 4 = historical precipitation

different behavior in the distribution of rainfall in 1999 and 2008 and the amount of rainfall influenced forage production (Fig. 6 and 7).

**Animal sub-model:** Once obtained the annual forage production losses by frost and senescence were subtracted to obtain available forage for animal consumption. The resulting amount was multiplied by the area of grassland with which an average production estimated of 5,408,000 vs. 5,606,000 kg real during the years reported, representing a 3.5% of difference.

With the estimated total production the stocking rate is calculated based on DM intake, CP and ME requirements (Table 4). For the year 1979, COTECOCA estimated animal coefficient of 7.6 ha $au^{-1}$ and for the same year the model predicts a stocking coefficient of 8 ha $au^{-1}$. The stocking rate and the stocking coefficient predicted by the model indicate that when assigning the hectares per animal unit will meet the needs of dry matter intake during the year as it adjusts the number of animal units per month, a fact that supports the allocation principle of stocking variable. Under normal rainfall conditions, the average stocking rate estimated by the model is 332 animal units exceeding 69 animal units to that established by COTECOCA-SARH.

Considering CP content in the diet and the nutrient requirements to estimate the stocking rate it was observed that the model establishes a greater stocking during the period from June to January than the stocking estimated by the needs of dry matter. A lower stocking was estimated for the period from February to May and only from April to June a CP deficiency is shown which should be supplemented with 0.261 kg/animal/day (Table 5). This deficiency is due to the decrease in the diet quality (CP = 6.3%) and low consumption that cattle showed (2.16%) during this period.

Table 4: Stocking rate and grassland coefficient estimated by the model base on produced dry matter, crude protein and metabolizable energy of the diet

| Years | Forage production (kg/dm/ha) | Stocking rate MS (uaa) | Stocking rate PC | Stocking rate EM | Grassland coefficient MS (ha/uaa) | Grassland coefficient PC | Grassland coefficient EM |
|---|---|---|---|---|---|---|---|
| 1979 | 1067 | 248.1 | 233.9 | 297.0 | 8.06 | 8.5 | 6.7 |
| 1999 | 2780 | 417.3 | 361.0 | 497.8 | 4.79 | 5.5 | 4.1 |
| 2008 | 3875 | 663.1 | 823.8 | 758.3 | 3.05 | 2.4 | 2.6 |

Table 5: Monthly stocking rate estimated by the model base on produced dry matter and protein crude of dieta

| Months | Stocking rate (DM) | Stocking rate (CP) | Requirements of CP/day (kg) | Consumption of CP/day (kg) |
|---|---|---|---|---|
| January | 185.48 | 214.56 | 0.730 | 0.81 |
| Februry | 216.19 | 215.22 | 0.730 | 0.70 |
| March | 216.78 | 215.80 | 0.730 | 0.70 |
| April | 217.44 | 201.43 | 0.730 | 0.65 |
| May | 219.13 | 203.00 | 0.911 | 0.65 |
| June | 224.07 | 240.72 | 0.911 | 0.61 |
| July | 214.14 | 377.65 | 0.911 | 1.01 |
| August | 240.02 | 401.75 | 0.911 | 1.52 |
| September | 287.70 | 449.45 | 0.570 | 1.42 |
| October | 309.86 | 303.51 | 0.570 | 0.89 |
| November | 316.88 | 282.88 | 0.570 | 0.81 |
| December | 318.80 | 368.79 | 0.730 | 0.81 |

With respect to the estimation of stocking rate by means of the diet ME there was an increase of 73, 84 and 95 animal units per year compared to the estimated by allocation of dry matter and of 45 units more than in which was assigned by CP during 3 years.

Considering the monthly stocking allocation, the model allows us to adjust the stocking rate as the quality of the diet changes (Table 4-6) which shows that during the period from May to June there is a decrease in the stocking rate due to the fact that energy consumption does not meet the needs and must be supplemented with 1.31 Mcal of ME per animal/day. The behavior of the stocking rate estimated by the model with respect to the CP and ME differs every year due to consumption and quality of the selected diet by the animal.

Considering the production of ME as an indicator of rangeland coefficient allows us to assign a greater stocking on the pasture than when the need for DM is considered (Table 6).

The dry matter condition for stocking allocation is based on the production of fodder which in turn is dependent on the amount of rain. The stocking rate determination in rainy conditions lower or equal to average is larger when the DM is used rather than CP.

Table 6: Stockin rate estimated by model base on dry matter and metabolizable energy

| Months | Stocking rate (DM) | Stocking rate (ME) | Requirements of ME/day (Mcal) | Consumption of ME/day (Mcal) |
|---|---|---|---|---|
| January | 185.48 | 222.90 | 17.2 | 20.67 |
| Februry | 216.19 | 223.58 | 17.2 | 17.79 |
| March | 216.78 | 201.88 | 19.1 | 17.79 |
| April | 217.44 | 202.50 | 19.1 | 17.79 |
| May | 219.13 | 204.08 | 19.1 | 17.79 |
| June | 224.07 | 208.67 | 19.1 | 17.79 |
| July | 214.14 | 287.45 | 19.1 | 25.64 |
| August | 240.02 | 322.20 | 19.1 | 25.64 |
| September | 287.70 | 515.84 | 14.3 | 25.64 |
| October | 309.86 | 582.50 | 14.3 | 26.88 |
| November | 316.88 | 478.06 | 14.3 | 21.57 |
| December | 318.80 | 399.86 | 17.2 | 21.57 |

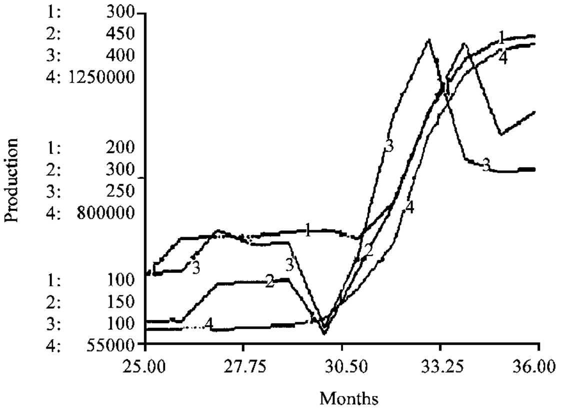

Fig. 8: Stocking rates simulated using Dry Matter (UADM), Crude Protein (UACP) and Metabolizable Energy (UAME) adjusting the calendar of management; 1 = UADM; 2 = UAME; 3 = UACP; 4 = total production

However, when the amount of rainfall exceeds average, the stocking rate is greater if CP is used rather than DM (Table 4). In this regard Diaz-Solis conducted a stocking allocation model in Chihuahuan semi-desert areas with different precipitations (270, 351 and 467 mm) and concluded that the recommended stockings by COTECOCA are high to achieve sustainability in the pasturelands with 270 and 351 mm, so it is necessary a supplemental feeding. Model results suggest that in the absence of supplementary feed, ecological sustainability and an acceptable level of animal production with light stocking can be simultaneously achieved. As established by Diaz-Solis it was considered a fixed stocking and that could be the difference with what was found in this model.

Model results were obtained under the management scheme established by the landowner. Being adjusted the calendar where births occur in May to June one can see the same behavior of the stocking rate as earlier but clearly is displayed that only in May to June requires protein supplementation (Fig. 8). The adjustment made is an example of the versatility to handle data to simulate conditions different from those established and that in turn establishes new paradigms that lead to new ideas to be developed in the appropriate field.

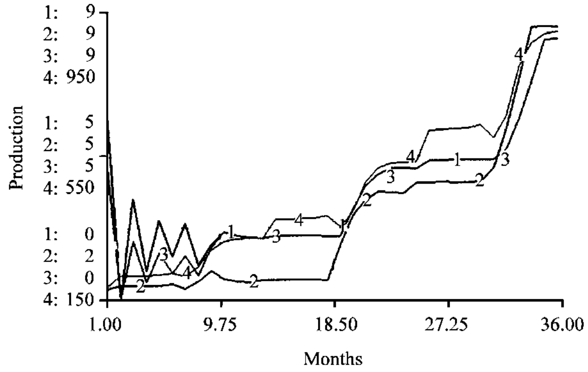

Fig. 9: Soil variables and annual production; 1 = soil deterioration; 2 = soil improvement; 3 = soil productivity; 4 = stocking rate

**Soil sub-model:** The variables indicators of deterioration and soil improvement not differ in their values since stocking rate in any of the predicted modes is adequate to the production so that ecosystem degradation is minimal when forage production declines due to rains (Fig. 9).

## CONCLUSION

Under conditions of higher precipitation production of crude protein and metabolizable energy as indicators of coefficient of rangeland allow us to assign a higher stocking to the pasture than when considering the need of dry matter.

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