STRATEGIES TO REDUCING GHG EMISSIONS IN SEMI-ARID RANGELANDS OF MEXICO

Estrategias para Reducir las Emisiones de GEI en Agostaderos Semiáridos de México

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SUMMARY

SESS (Simple Ecological Sustainability Simulator) model was modified to evaluate 3 management strategies that could increase CO_2 sequestration and reduce methane emissions in cow-calf production systems in semi-arid rangelands. The management strategies included (1) maintenance of a high and constant stocking rate (CONTROL), which is the most common current practice, (2) maintenance of a low and constant stocking rate (LOW SR) and (3) adjustment of stocking rate before the beginning of each breeding season based on the amount of precipitation during the previous growing season (REPLA-PPT). The model was parameterized to represent a typical extensive (5 000 ha) cow-calf production system in the northeastern portion of the Mexican state of Coahuila under an historical (1950 to 1994) precipitation regime, and compared carbon sequestration, methane emissions, animal performance and net profit resulting from each strategy. Results of the 45-year simulations indicated the REPLA-PPT stocking rate strategy had the greatest improvement of range condition, captured more CO_2 in vegetation, had the lowest methane emissions, substantially improved mean body condition score and reduced annual mortality of cattle, compared to the constant stocking rate strategies. REPLA-PPT also showed the highest values for calves weaned, and kg weaned per ton of methane produced and highest long-term net profit. This suggests that adaptive management of extensive cow-calf production systems in semi-arid environments could increase carbon sequestration in soils and reduce methane emissions, while improving range production, maintaining animal production and giving the greatest long-term net profit.

Index words: *cattle production; CO_2 sequestration; methane emissions; simulation model.*

RESUMEN

El modelo SESS (Simple Ecological Sustainability Simulator) fue modificado para evaluar tres estrategias de manejo que pudieran incrementar el secuestro de CO_2 en los suelos y reducir las emisiones de metano en sistemas vaca-becerro en agostaderos semiáridos. Las estrategias de manejo incluyeron: (1) mantenimiento de carga animales altas y constantes (CONTROL), las cuales son muy comunes en las prácticas actuales, (2) mantenimiento de capacidades de carga bajas y constantes (LOW SR) y (3) ajuste de la capacidad de carga antes del inicio de cada temporada de empadre en función de la cantidad de precipitación de la temporada previa (REPLA-PPT). El modelo fue parametrizado para representar un sistema de producción extensivo típico (5000 ha) de producción vaca-becerro en la parte noroeste de Coahuila, México usando un régimen de precipitación histórico (1950 a 1994) para comparar el secuestro de carbono, las emisiones de metano, el funcionamiento animal y las ganancias netas de cada estrategia. Los resultados de 45 años de simulaciones mostraron que la estrategia de ajuste de carga animal REPLA-PPT tuvo el mejor desempeño en la condición del agostadero, captura más CO_2 en la vegetación y tuvo las emisiones de metano más bajas, mejorando substancialmente la condición corporal promedio de

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los animales, además de tener una tasa reducida de mortalidad del ganado, comparado con las estrategias de mantener una capacidad de carga constante. REPLA-PPT también mostro los valores más altos de becerros producidos y kilogramos producidos por tonelada de metano generada y, las mayores ganancias de largo plazo. Esto sugiere que el manejo adaptativo de sistemas de producción extensivos vaca-becerro en ambientes semiáridos pudieran incrementar el secuestro de carbono en los suelos y reducir las emisiones de metano y, a la vez, mejorar la producción de los agostaderos y mantener la producción animal, generando las mejores ganancias a largo plazo.

Palabras clave: *producción de ganado; secuestro de* CO_2*; emisiones de metano; modelo de simulación.*

INTRODUCTION

Concerns over global warming make it important to consider management practices that affect carbon sequestration in soils and emissions of greenhouse gasses. In Mexico, the animal production sector is the main source of methane; in 1990 the national inventory of greenhouse gases reported emissions of 1.89 teragrams (Tg) methane, of which 1.85 Tg were produced by domestic livestock (González and Ruíz-Suárez, 1995). Methane emissions in national inventories of national communications of the last decade show high growth rates: 2006 with 1.83 Tg in the Third Communication (INE-SEMARNAT, 2006), 2009 with 4.89 Tg in the Fourth Communication (INE-SEMARNAT, 2009), 2012 with 45.52 Tg in the Fifth Communication (INE-SEMARNAT, 2012) and 2015 with 64.94 Tg in the Biennial Report (INECC-SEMARNAT, 2015). Differences in emissions are very likely due to the use of different methodologies and sources of data but put into context the problem of methane emissions from the livestock sector and define it as a strategic sector to reduce carbon emissions of the country.

The need for sustaining agricultural production and the livelihoods of producers, restoration of production potential, efficient use of limited resources and reduction in production of harmful by-products, demands the development of management practices that make food production systems more efficient, not only in terms of producing more food per unit of limited resource (*e.g.* water) but also in terms of producing more food per unit of input and harmful by-product produced (*e.g.* methane). O'Mara (2004) has proposed that to reduce methane emissions, among other things, we must (1) increase the productivity per cow, which will reduce methane emissions per unit of animal product and also the total production of emissions per production system, and (2) reduce the rate of replacement of stock cows at the beginning of the breeding season, which will reduce the total production of emissions per production system.

De Ramus *et al*. (2003) indicated that, although emissions of methane from beef cattle that result from meeting maintenance requirements cannot be modified by management practices, methane emission beyond those associated with maintenance can be reduced based on the level of productivity of the animal. These authors evaluated two grazing management systems, one using the extensive, continuous grazing scheme typical of the region, and one using an intensive grazing system with pastures that had been improved by over seeding with additional forage species. However, in areas of low precipitation, it is unwise to make large investments in seeding or infrastructure to improve pastures, thus producers should seek low-investment strategies. Since production in extensive cow-calf systems is tightly linked to the variable and unpredictable precipitation regime, it is not possible to define efficient static management practices, such as is possible in other animal production sectors.

Drought is common in arid and semi-arid regions of the world, and agricultural production systems should be adapted to local weather patterns and variability. Droughts have an enormous impact on agricultural activities, and, especially in developing countries, can be an important cause of poverty and emigration. For example, in the Borana Mesa in southern Ethiopia, the droughts of 1983 - 1985 and 1991 - 1993 caused cattle mortalities of 37 and 42%, respectively. These losses were valued at approximately 15 times the net sales of cattle in the area (Desta and Coppock, 2002). During these same two droughts, Oba (2001) reported cattle mortalities of 70 - 87%, respectively, in northern Kenya. In northern Mexico and the southwestern United States, according to the projections of 19 different climate models, a climate similar to the drought period of the 1950's will return within the next few years or decades (Seager *et al*., 2007).

Due to this climatic variability, the establishment of fixed stocking rates for semi-arid rangelands appears unwise (Behnke and Scoones, 1993; Illius *et al*., 1998). One common option for maintaining a constant stocking rate as climate varies is to provide supplemental feed; however, irreversible vegetation change may occur if animal numbers are held constant when natural resources are scarce (Van de Koppel and Rietkerk, 2000). Díaz-Solís *et al*. (2006), in a simulation modeling study, found that range condition commonly decreases as the level of energy supplementation in the form of hay and concentrates is increased because supplemented cows have a lower mortality rate, thus promoting higher stocking rates which result in even more pronounced over-utilization.

Alternative management strategies for dealing with drought might include increasing or decreasing stocking rate based on the current condition of the pasture, season of the year, and the direction and rate of change in animal body condition. However these reactive strategies have market problems because the producers need to sell when many other producers are liquidating animals and prices are low, and they then have to restock when prices are very high after the drought. Managers also might influence body condition by weaning calves early and shifting the breeding season such that the period in which nutrient requirements of animals are highest coincides with the period of highest forage quantity and quality.

The low productive efficiency of extensive cow-calf production systems is due to the fact that we use static management rules, that is, we do not adapt pasture and animal management to the variable precipitation. For example, during a drought we employ the same stocking rate that is estimated based on periods of "normal" precipitation, which results in a larger proportion of cows that do not produce a calf, but continue producing methane (De Ramus *et al*., 2003).

Although the arrival of a drought is unpredictable, in this study we examine whether it is possible to increase CO_2 sequestration in soils and reduce methane emissions, as well as reduce the negative effects of drought on cow-calf production systems, by using different management decision strategies in drought-prone regions. In a previous study, in which we simulated dynamics of extensive cow-calf production systems (Díaz-Solís *et al*., 2003), we observed predictable time lags between precipitation events, production of phytomass, and changes in body condition of cattle. Specifically, loss of body condition was greater the year after a dry year, even when that dry year was followed by a year with higher than average precipitation. Kgosikoma (2006)[1] searched for correlations between time-lagged precipitation and variables affecting agricultural production to relate climatic variability and animal population dynamics in Botswana. Illius *et al*. (1998) conducted a similar simulation study with some different results, however, their study focused on an essentially grass-dominated system and a single species of small ruminant (sheep or goats).

This study evaluates the potential of three management strategies to increase CO_2 sequestration, reduce methane emissions, and reduce the financial and environmental negative effects of drought on cow-calf production systems in semi-arid rangelands: (1) The traditional strategy (CONTROL) uses a relatively high stocking rate that is not adjusted and open cows are not sold after breeding season; (2) the first alternative strategy (LOW SR) is similar to CONTROL but uses low stocking rate; and (3) the second alternative strategy (REPLA-PPT) uses the decision of replacement of breeding stock cows based on the amount of precipitation during the last growing season with a relatively low stocking rate. In this strategy, open cows are sold after breeding season, and replacement of breeding cows is based on the amount of precipitation during the previous growing season.

MATERIALS AND METHODS

First it is described the study area selected as the test case, and the alternative management strategies, and the modeling procedures. Model SESS (Simple Ecological Sustainability Simulator) (Díaz-Solís *et al*., 2003) was modified to represent each of three different management strategies (sets of decision rules). In the sections that follow, it is described the basic structure of the model SESS and the modifications done to SESS for this paper. Then use of the model to evaluate CO_2 sequestration by vegetation, methane emissions, and animal performance and net long-term profits under these management strategies.

Description of the Study Area

To evaluate the performance of the management strategies, the SESS model was parameterized to represent a region of extensive cow-calf production systems in the northeastern portion of the Mexican

[1] Kgosikoma, O. E. 2006. Effects of climate variability on livestock population dynamics and community drought management in Kgalagadi, Botswana. Thesis for the degree of Master's of science in Management of Natural Resources and Sustainable Agriculture Universitetet for Miljø–Og Biovitenskap (Norwegian University of Life Sciences). Department of International Environment and Development Studies (NORAGRIC).

state of Coahuila, specifically within the municipalities of Allende, Zaragoza, Muzquiz, Monclova, Sabinas, and San Juan de Sabinas. The area has a mean annual precipitation near 400 mm, with a coefficient of variation of more than 30% (Figure 1). The carrying capacity of these lands for cattle varies significantly both seasonally and from year to year in a manner that is typical of drought-prone rangelands throughout the world. Cattle production systems in the area also are typical of semi-arid rangelands throughout the world in that producers seldom adjust stocking rates based on environmental conditions. In the study area, a governmental agency establishes permissible stocking rates (statics) based on vegetation surveys conducted almost 30 years ago (COTECOCA, 1979) that do not consider precipitation variability or if the precipitation in the year of the study was higher, lower or average.

Overview of Basic Model Structure

SESS (Simple Ecological Sustainability Simulator) (Díaz-Solís *et al*., 2003) was formulated as a compartment model based on difference equations (Δt = 1 month) programmed in STELLA_ 6.0 (High Performance Systems, Inc., Hanover, New Hampshire) to simulate the dynamics of standing crop forage, range condition, diet selection, and cattle production. To relate annual aboveground net primary production (ANPP, kg dry matter ha^{-1} year^{-1}) to annual precipitation (PPT, mm year^{-1}), the concept of rain use efficiency (RUE, kg aboveground dry matter (DM) produced ha^{-1} mm^{-1} of precipitation-year^{-1}) proposed by Le Houreou (1984) was used. Soil characteristics (SC, unit-less index) were used to modify ANPP based on soil depth, slope, and topographic position of site. The forage submodel represents the dynamics of green and dry standing crop. Green standing crop is converted into dry standing crop via frosts and senescence. A fraction of senescent forage, representing senescence, respiration, and translocation, is lost, with the remainder transferred to dead standing crop (Blackburn and Kothmann, 1989). Green standing crop also is lost due to consumption, trampling, and dung deposition by cows. Dry standing crop is lost due to consumption, trampling, and dung deposition by cows, and via decomposition. The range condition submodel represents long-term changes in range condition based on the proportion of ANPP consumed by cattle. Range condition (RC) is quantified on a relative scale to represent ranges in Excellent (RC $\geq$ 1.25), Good (0.875 $\leq$ RC< 1.25), Fair (0.5< RC < 0.875), and Poor (RC $\leq$ 0.50) classes. ANPP is proportional to range condition.

The diet selection submodel estimates the proportions of green and dry forage in cattle diets based on preference and harvestability, as described by Blackburn and Kothmann (1991). The cattle production submodel simulates dry matter intake, body condition scores of cows (unit-less index with values between 1 = extremely thin and 9 = very obese) NRC (2000), and herd pregnancy rates. The model also simulates the growth of calves as live weight at weaning. Grazing efficiency is calculated as the proportion of ANPP consumed by cattle. For details see Díaz-Solís *et al*. (2003).

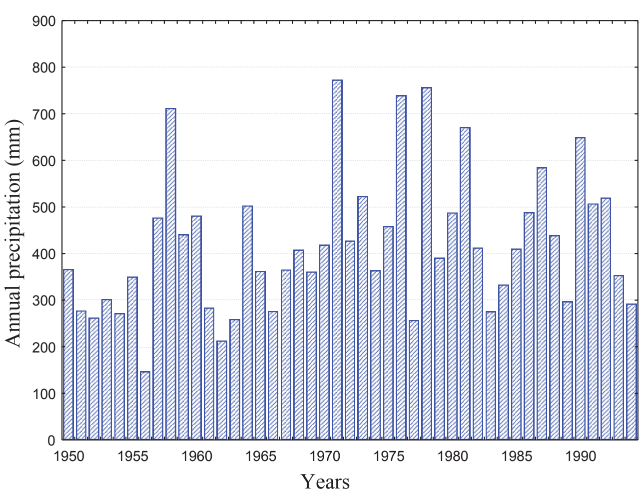

Figure 1. Mean annual precipitation (mm) in the northeast of Coahuila, Mexico, during the period from 1950 to 1994.

Changes to SESS

Monthly biomass production (MNPP) depends on precipitation, RUE, RC and a temperature growth index (TGI) presented by Sikhalazo (2005):

$$MNPP= (PPT*RUE*RC)*TGI \qquad (1)$$

where PPT is precipitation (mm month^{-1}), RUE and RC are rain use efficiency and range condition respectively as described by Díaz-Solís *et al*. (2003)

To simulate the new alternative management strategy (REPLA-PPT), we added the following decision rule to SESS:

IF PDIF > 0 THEN REPLA ELSE 0 (2)

where PDIF represents the difference between the total precipitation observed during the last growing season (PPT_c); (March through November) and the historical mean precipitation observed during the growing season (PPT_m):

$$PDIF = PPT_c - PPT_m \quad (3)$$

Thus, under this rule, breeding cows are replaced (REPLA) when growing season precipitation of current year has been higher than average. To avoid the number of cows reaching 0, for those years in which PDIF ≤ 0 and the number of cows ≤ 20% of the base-level stocking rate (BSR), a sufficient number of stock cows are replaced to achieve a stocking rate = 20% of BSR.

To estimate carbon sequestration by vegetation we used simulated aboveground and belowground biomass production. Belowground biomass production was considered as 2.8 time's aboveground herbaceous biomass. C captured by biomass, on a basis of dry matter weight = (aboveground biomass production + belowground biomass production)*0.5 (Westlake, 1966; Penman *et al*., 2003). Carbon sequestration by vegetation (aerial vegetation is a flux) is an indirect measure of soil organic carbon (SOC) sequestration (Paz *et al*., 2015) that must be used to represent carbon sequestration. Nevertheless, in this study, total vegetation (above and belowground) was used as an indirect proxy for SOC estimation. Data from Paz (2010)[2] show that the transition from primary to secondary condition of vegetation in northern Mexico (scrub and grassland), which implies a loss of at least one category in the range condition; generate a loss of around 9.3 Mg C ha^{-1}. However, considering that the loss of soil organic carbon in the first five years account for 80% of total long-term losses (West *et al*., 2004), in this period a loss of 1.5 Mg C ha^{-1} is present, which it represents values comparable to deforestation processes.

To estimate methane production we used the total livestock biomass (kg) simulated by SESS and information from the Livestock Analysis Model (LAM 1.01) (http://www.epa.gov/rlep/library/lam/intro.html, consulted May 2009). The total livestock biomass simulated by SESS consisted of the mass of each class of animal (stock cows, calves, heifers, bulls) multiplied by the mean body weight in kg (SBW) of that class. LAM estimates methane production by beef cattle on rangelands in which both quality and availability of forage is low as 20 kg $head^{-1}$ $year^{-1}$ for heifers (200 kg) and 71 kg $head^{-1}$ $year^{-1}$for adult females (450 kg), respectively. Based on this information, we estimated:

$$\text{Methane (kg head}^{-1}\text{ year}^{-1}) = 16.18 + 0.084 * SBW \quad (4)$$

Since methane global warming potential is 21 times that of carbon dioxide, we multiplied by 21 to convert kg of methane $head^{-1}$ $year^{-1}$ to kg CO_2 eq. $head^{-1}$ $year^{-1}$ (Penman *et al*., 2003).

A simple net present value economic sub model was added to SESS (Teague *et al*., 2008) to generate the state variable PROFIT. The profit values shown in Table 1 are United States Dollars (US$) for the whole ranch (5000 ha) over the 45 years simulated. Revenue consists of: -weaned kilograms * $ per kg (US$2.10), -sale of cows (#) * price per cow (US$500), and -hunting income (US$12 ha^{-1} $year^{-1}$). The costs of the system considered were: -replacement of stock cows (US$ 750 $head^{-1}$) and -annual cow cost (US$350 $head^{-1}$). The costs and product prices used in this paper were taken from neighboring Texas (Teague *et al*., 2009) because we were unable to get this information for ranches in northern México. Notwithstanding the previous statement, the financial data are representative of operations in Coahuila, Mexico.

Description of Management Strategies

The first strategy (CONTROL) represented the traditional type of management with high base stocking rate (BSR=250 AUY), no animal sales due to drought, open cows are not eliminated from the herd two months after the end of the breeding season, and, each year, three months prior to the breeding season (April, May, and June) a number of stock cows sufficient to replace losses is added to the herd (re-establishment of the base-level stocking rate, BSR). We define the base-level stocking rate as the number of stock cows present at the beginning of the breeding season.

The second strategy (LOW SR) represents the same management of the CONTROL strategy but with low base stocking rate (BSR=125 AUY).

The third strategy (REPLA-PPT) adapts to variable weather conditions with a low base stocking rate (BSR=125 AUY), elimination of open cows after the

[2] Paz, F. 2010. Evaluación, importancia y perspectivas de la captura de carbono y la reducción de emisiones de gases efecto invernadero en pastizales y matorrales: Hacia la implementación de REDD+. pp. 7-22. *In:* M. E. Velasco, M. Salvador, M. L. Adriano, R. A. Perezgrovas y B. Sánchez (eds.). Memorias del I Congreso Internacional de Pastizales Chiapas 2010. SOMMAP. Tuxtla Gutiérrez, Chiapas, México.

breeding season and variable replacement based on past precipitation, of cows lost to death or through culling. The decision is based on a comparison of amount of precipitation accumulated from March to November (the growing season for plants) of the last year with the historical average amount accumulated during this period.

Total stocking rate (TSR) for all strategies was calculated as a weighted average of the following AUY(animal unit year) equivalents: 1.25, 1.0, 0.8, 0.6, and 0.2 AUY for bulls, stock cows, and heifers older than 18 months of age, heifers 7 to 18 months of age, and calves before weaning, respectively. An AUY is defined as the forage demand of a 450 kg per cow for one year. Demands of other animal classes were converted to AUY using the equivalents listed above.

Description of Modeling Procedures

The model was parameterized with a series of 540 monthly historical precipitation values from 1950 to 1994. The simulated system considered a herd composed of breeds such as Angus, Charolais, Hereford, or Limousin, with a 3-month breeding season (April to June). We calculated net energy for maintenance based on weight, breed, lactation and previous plane of nutrition (NRC, 2000). Initial body condition score was 5 and the weight of cows for that body condition was 450 kg. The initial range condition value was 0.75 (fair).

Note that "base-level stocking rate" (BSR) is a constant that defines the number of stock cows at the beginning of the simulation and at the beginning of each breeding season; whereas, "total stocking rate" (TSR) is a variable that represents the numbers of stock cows, bulls, heifers and calves, which changes during the simulation as a result of natality, mortality, sales and management strategies.

RESULTS AND DISCUSSION

REPLA-PPT was the best strategy in terms of C sequestered, methane emissions, range condition, animal performance and economic profit. The CONTROL was the worst strategy. The total carbon sequestered by vegetation (on 5000 ha during a 45-year period) under the adjustable stocking rate strategy (REPLA-PPT) was over 0.55 million tons, and only 0.39 million tons under the constant stocking rate strategy (CONTROL) (Table 1). The difference of sequestration between strategies increased over time (Figure 2), due to an improvement in range condition (Table 1) and higher biomass production, which resulted from a lower overall stocking rate and, hence, a lower level of utilization of the available biomass with adjustable stocking.

According to Table 1, the range condition is regular for CONTROL and it is excellent for REPLA-PPT, involving a change between a "primary" and well preserved rangeland and a "secondary" and no preserved, which would imply losses of around 1.5 Mg C ha^{-1} organic carbon in the soil (30 cm), according to what is previously discussed.

Since methane emissions are intrinsically correlated with animal numbers, emissions always were lower with REPLA-PPT and LOW SR strategies than with CONTROL (Figure 3). Emissions were lowest with REPLA-PPT during the drought from 1951 to 1959, and the two or three years after a dry year (64-65, 67-71, 80-81, 85-86) when stocking rate was lowered by not replacing culled, non-pregnant cows. Mean annual precipitation from 1950 to 1956 was 282 mm, and annual precipitation during 1956 was 147 mm, which is only 35% of the long-term historical mean annual amount (Figure 1). The main seasonal differences in emissions with CONTROL were due to large seasonal changes in the number of animals on the ranch, which resulted from high mortality (Table 1) and subsequent high annual restocking to maintain the base-level stocking rate (250 AUY).

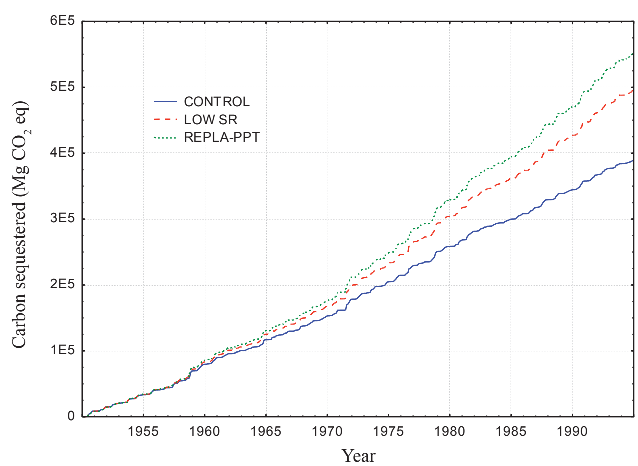

Figure 2. Cumulative carbon sequestered by vegetation under three management strategies in a cow-calf operation in the northeast of Coahuila, Mexico during the period from 1950 to 1994 (Ranch area = 5000 ha).

Table 1. Simulated carbon sequestration, methane emissions and animal performance under three management strategies in a cow-calf operation in the northeast of Coahuila, Mexico during the period from 1950 to 1994 (Ranch area = 5000 ha).

Variables	Units	Strategies		
		Control	Low sr	Repla-ppt
Base-level SR	AUY (Animal Unit Year)	250	125	125
Total SR	AUY	199	117	91
Range condition	Unit less	0.66	1.07	1.26
CO_2 captured	Mg CO_2 eq	389 248	496 052	551 580
CH_4 emission	Mg CO_2 eq	9945	6671	5887
Mean body condition	(scale 1-9)	2.85	3.79	4.78
Mortality	% $year^{-1}$	45.87	28.88	9.42
Weaned mass	kg ha^{-1} $year^{-1}$	1.3	1.94	2.68
Efficiency[†]	kg weaned (Mg CO_2 eq)$^{-1}$	29.3	65.45	102.47
Profitability	US \$ $\times 10^6$	-4.79	-0.39	1.97

[†] SR = stocking rate.

The relation between methane emissions by animals and CO_2 sequestration by vegetation in extensive, adjustable stocking, cow-calf production systems results in a simulated net decline in these substances which it is assumed would result in a decline in human contributions to global warming. Quite likely, the current contribution of cattle production systems as high sources of greenhouse gases is due to feedlot operations and intensive dairy cattle operations in which high animal densities are maintained.

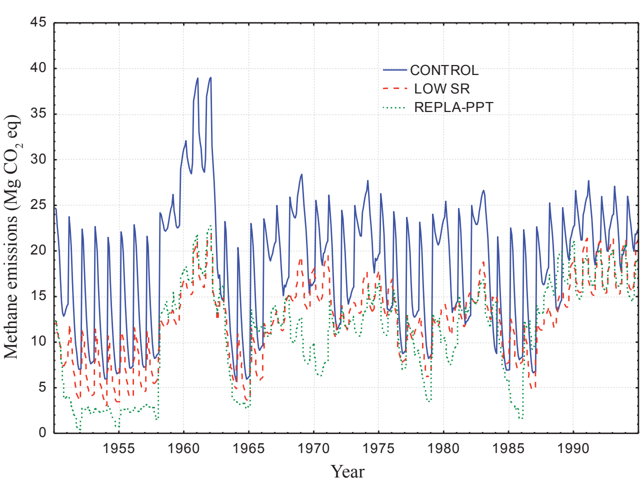

Figure 3. Monthly dynamics of methane emission by animals under three management strategies in a cow-calf operation in the northeast of Coahuila, Mexico during the period from 1950 to 1994 (Ranch area = 5000 ha).

Calf production efficiency, measured as kg ha^{-1} $year^{-1}$ of calf production per Mg CO_2 eq of methane emission, was more than three times higher with REPLA-PPT as compared to CONTROL (102.47 *versus* 29.30, respectively). Average body condition score was 4.78, 3.79 and 2.85 for REPLA-PPT, LOW SR and CONTROL respectively. Results for profit had the same trend and only REPLA-PPT showed a positive economic balance with the CONTROL showing the largest economic loss (Table 1).

The advantages of adjustable stocking based on replacement are due to its flexibility to adapt ranch management to current conditions, specifically, those resulting from the variable precipitation regime. The REPLA-PPT strategy reduces stocking rate during unfavorable precipitation conditions by selling more livestock and by not replacing livestock that have died. When favorable precipitation conditions return, this strategy replaces only enough stock cows to reach the low base-level stocking rate (125 AUY).

High and constant stocking rates have both short- and long-term negative effects on coupled social-ecological systems. In the short term, high stocking levels increases competition for forage resources. This results in less selective grazing and lower total consumption per cow. In the long term, the resulting overgrazing lowers range condition and, hence, forage productivity, which, in turn, reduces vegetation cover and increases soil erosion. In the long-term this reduces the ecosystem services that rangelands provide and ability of the population to feed itself.

Livestock Insurance Program in Mexico

Due to variability and unpredictability of forage resources in rangelands, is necessary to develop strategies for adaptation and mitigation under extreme climatic conditions (*e.g.* droughts). In this perspective, Mexican government has implemented a national livestock satellital parametric insurance program (AGROASEMEX, 2006; Paz *et al*., 2006). This mechanism provides financial compensations when droughts are present. This parametric insurance is based on a spectral vegetation index (VI) that has a linear relationship with aboveground biomass and the leaf area index of vegetation (Paz *et al*., 2007). Using the VI, a reference for range condition of the previous year, is established as done in the REPLA-PPT strategy and the program makes payments in the areas where body condition score was reduced from 5 to 1, evaluated through VI reductions, due to drought conditions in the year of operation (AGROSEMEX, 2006). This program has been operational since 2005 over almost 60 million hectares of rangelands in Mexico and represents financial support to apply strategies to reduce drought effects. Traditionally in Mexico, the preferred government strategy against drought is to provide producers with hay to keep livestock alive. However, this practice produces a higher utilization and deterioration of the rangeland as reported by Díaz-Solís *et al*. (2006).

Governments could assist producers involved in production systems subject to a high degree of uncertainty. If precipitation conditions in a given region dictate that livestock need to be reduced, an appropriate agency could facilitate moving excess livestock to regions experiencing more favorable precipitation using the payments of the insurance program. This would reduce negative ecological and climatic impacts of animal production systems in areas of high environmental uncertainty, but would require improved ranch-level and regional-level management, as well as adequate cooperation between these levels of management.

CONCLUSIONS

- Management of semi-arid environments that adjusts stocking rates to adapt to changing environmental conditions can increase carbon sequestration and reduce methane emissions while improving range condition, maintaining or increasing animal production, and improving producer incomes. Such adaptation can be accomplished using management strategies that do not require additional technological, financial or human resources. In particular, management strategies that adjust stocking rate based on the recent precipitation regime provide a practical and economical alternative to improve and sustain the extensive cow-calf production systems of the semi-arid rangelands of north Mexico.
- The simulation results clearly show that simple management schemes, which can be coupled to livestock insurance programs, produce significant reductions in the emission of greenhouse gases, allowing the implementation of public policies for sustainable rural development and low emissions economy. In the perspective of the producers, the use of simple adaptation rules results in better financial returns of their activities.

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