Ciência Rural, Santa Maria, v.53:11, e20210026, 2023
http://doi.org/10.1590/0103-8478cr20210026
Ciência Rural
ISSNe 1678-4596
ANIMAL PRODUCTION

A comprehensive case study on the sustainability of tropical dairy cattle farming in Oaxaca, Mexico

Verónica Rosales Martínez[1] Ángel de Jesús Bautista Valente[2] Urfila Victoria Peláez Estrada[2] José Luis Valenzuela Lagarda[3] Beatriz Herrera González[2] Pedro Cisneros Saguilán[2*]

[1]Cátedras CONACyT, Colegio de Postgraduados Campus Campeche, Carretera Haltunchén-Edzná, Sihochac, Champotón, Campeche, México
[2]Tecnológico Nacional de México, Campus Instituto Tecnológico de Pinotepa, 71602, Santiago Pinotepa Nacional, Oaxaca, México. E-mail: pedro.cs@pinotepa.tecnm.mx. *Corresponding author.
[3]Centro Regional de Educación Superior de la Costa Chica, Universidad Autónoma de Guerrero, Cruz Grande, Guerrero, México.

ABSTRACT: Tropical dairy cattle farming is one the most relevant economic activities for food production; although, currently faces increasing scrutiny from society due to its potential harm to natural resources and the environment. Moreover, some factors are paramount for the evaluation of the sustainability and productive potential of any given tropical dairy farm: soil quality, profitability, and energy efficiency. This study carried out a sustainability analysis in four types of tropical dairy cattle ranches, through three key indicators (economic profitability, energy efficiency and soil quality) and with a comprehensive approach in the *Costa* region of Oaxaca, Mexico. Therefore, four farms of different sizes (*i.e*., small, medium, large, and very large) were selected in *Costa de Oaxaca,* Mexico. The data collection was carried out for daily milk production, the dynamics of farm inputs (introduction or removal) from the production system, alongside with collection of soil samples. The agroecosystems evaluated were economically profitable, and those with greater intensification of their pasture areas display higher profit margins and energy efficiency. In terms of soil quality, there is a regular potential for its rational utilization.
Key words: agro-ecosystems, profitability, energy efficiency, soil quality.

Um estudo de caso abrangente sobre a sustentabilidade da pecuária leiteira tropical em Oaxaca, México

RESUMO: A pecuária leiteira tropical é uma das atividades econômicas mais relevantes para a produção de alimentos, embora atualmente enfrente crescente discussão da sociedade devido ao seu potencial dano aos recursos naturais e ao meio ambiente. Além disso, alguns fatores são primordiais para a avaliação da sustentabilidade e potencial produtivo de qualquer popriedade leiteira tropical: qualidade do solo, rentabilidade e eficiência energética. O objetivo deste estudo foi realizar uma análise de sustentabilidade em quatro tipos de propriedades de gado leiteiro tropical, por meio de três indicadores chave (rentabilidade econômica, eficiência energética e qualidade do solo) e com uma abordagem abrangente na região da Costa de Oaxaca, México. Portanto, quarto propriedades de diferentes tamanhos (isto é, pequenas, médias, grandes e muito grandes) foram selecionadas na Costa de Oaxaca, México. A coleta de dados foi realizada para a produção diária de leite, a dinâmica dos insumos da fazenda (introdução ou retirada) do sistema de produção, juntamente com coleta de amostras de solo. Os agroecossistemas avaliados foram economicamente rentáveis, sendo que aqueles com maior intensificação de suas áreas de pastagens apresentam maiores margens de lucro e eficiência energética. Em termos de qualidade do solo, existe um potencial regular para a sua utilização racional.
Palavras-chave: agroecossistemas, rentabilidade, eficiência energética, qualidade do solo.

INTRODUCTION

Agro-ecosystems (AEs) are conceptualized as any given ecosystem that was modified by human activity, in which there has been action of ecologic, technological, or socioeconomic factors, with the purpose of obtaining a good or service. The current AEs paradigm is to focus on its design, maintenance and evaluation for long-term sustainability (TORO-MÚJICA et al., 2011). In turn, cattle raising may be considered as part of AEs; although, this activity is pointed out as one of the main causes of global environment decline, due to high demand for external farming inputs (CISNEROS-SAGUILÁN et al., 2015).

Cattle-based AEs are accounted for part of the global emissions of greenhouse gases (CO_2, CH_4, and N_2O). For example, enteric fermentation from the digestive system of ruminants and the resulting manure emits CH_4 to the atmosphere. Furthermore, the release of CO_2 comes from the combustion of fossil fuels, burning of biomass, and from microbial decay. Such decay may be due to several contexts, thus including changes in land use or in crop management; while N_2O is released during microbial transformation of nitrogen in the

Received 01.13.21 Approved 01.07.23 Returned by the author 03.09.23
CR-2021-0026.R2
Editors: Rudi Weiblen Pasquale De Palo

soil or in manure (i.e. nitrification of NH_4^+ into NO_3^-, and incomplete denitrification of NO_3^- into N_2 (DE BOER et al., 2011; IPCC, 2019). Other negative effects of raising cattle on the environment are soil desertification and pasture degradation due to overgrazing (IBÁÑEZ et al., 2007). In the process of degradation, pasture productivity and organic matter inputs decrease, non-palatable plant species invade, vegetative cover diminishes (thus increasing susceptibility to erosion), soil becomes compacted and more acidic, and microbial biomass decreases (FONTE et al., 2014).

Pasture-based livestock systems might contribute to maintaining marginal grasslands, which contributes to carbon sequestration. Further, pasture grasslands may reduce the incidence and severity of wild fires (e.g., savannas or mountain areas), which mitigates GHG emissions (DE BOER et al., 2011). In addition, cattle production is an activity for the basis of human food supply, thus providing basic foods that contribute to human nutrition and health. The cattle-derived products (meat and milk) are responsible for 17% of global human kilocalories consumption (33% of protein consumption) (HERRERO & THORNTON, 2013); therefore, such products are paramount for combating malnutrition and a wide range of nutritional deficiencies.

Several studies have documented the low productivity yields of tropical bovine dairy farming. At the farm level, low milk yields and calving rates, late age at first calving, and long calving intervals prevail and are directly related to nutritional aspects, inappropriate use of breeds, poor farm management, limited disease control, and little technical support (BATEKI et al., 2020; CHIRINDA et al., 2021). These production systems are also characterized by great dependency of external farming inputs and thus remain poorly sustainable and frequently become low-margin endeavors (BAUTISTA et al., 2019). This high demand for farming inputs also leaves producers extremely vulnerable to their availability and price fluctuations (VILABOA et al., 2009; ALBARRÁN-PORTILLO et al., 2015).

This global scenario is not different from cattle raising conditions in *Costa de Oaxaca,* Mexico. Several studies have documented AEs from this region, that display low productivity and profitability associated to inefficient and non-rational use of natural resources (MARTÍNEZ-CASTRO et al., 2015; DURÁN et al., 2018). Therefore, it remains to be described if such scenario is found across ranches of different sizes (small, medium, large, and very large ranches), their economic profitability as dairy farms, their energy efficiency and productivity; Moreover, to know at least as an approximation, the soil quality and the productivity of its pastures, the ultimate indicators that reflect its production potential.

This study carried out a sustainability analysis in four types of tropical dairy cattle ranches, through three key indicators (economic profitability, energy efficiency and soil quality) and with a comprehensive approach in the *Costa* region of Oaxaca, Mexico.

MATERIALS AND METHODS

Location and description of the study units

The study was carried out in four tropical dairy cattle ranches, which are examples of four typical production categories of the Costa de Oaxaca region (small, medium, large, and very large), according to the production typologygenerated by CISNEROS-SAGUILAN et al. (2016)\l "\l". The selected ranches were: *El Chamuscadero* ranch (EC-ranch), *La Aurora* ranch (LA-ranch), *El Bulito* ranch (EB-ranch), and the *San Felipe* ranch (SF-ranch); located in the municipalities of Villa de Tututepec de Melchor O campo and Santiago Pinotepa Nacional (Figure 1). These municipalities have an Aw_1climate (warm sub humid with rain in summer), with average annual rainfall of 1,237.5 mm distributed in the period from June to October. The average annual temperature is 27 °C, with June being the warmest month and February the coldest. The type of vegetation is low deciduous Forest and the dominant soils are Regosol, Gleysol and Phaeozem (INEGI, 2017).

The EB-ranch is focused on milk production for handmade cheese manufacturing (Table 1). Milking was manual (Figure 2C). Around 40% of the area is composed of cultivated pastures (Table 1). The herd is composed of 30 crossbreed cows Brown Swiss x Brahman, which are raised under extensive grazing conditions (Figure 3C). The SF-ranch focused on milk production (whole milk sale and cheese manufacturing) and calves sales (Table 1). Roughly, 15% of the land is formed by cultivated pastures (Figure 3D). Milking is carried out manually, twice a day and throughout the year (Figure 2D). The herd is composed of 80 heads, mostly of Holstein/Simmental/Swiss x Zebu crossbreds. The EC-ranch is a large size ranch that focuses on milk and calves sales (Table 1). Milking occurred once a day, mechanically, and throughout the year (Figure 2A). Further, 20% of the soil are

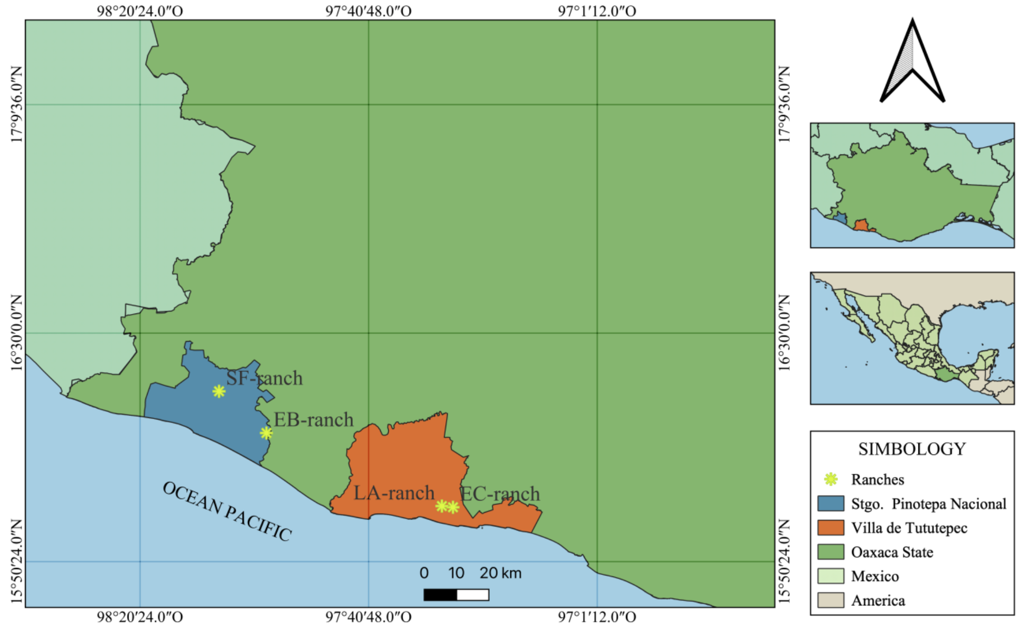

Figure 1 - Geographical location of the study units in the Costa de Oaxaca region, Mexico.

cultivated pastures (Figure 3A). The herd has 100 cattle, mainly from Brown Swiss/Holstein x Zebu crosses. The LA-ranch is also specialized in milk and calves sales (Table 1). Milking was manual in the presence of the calf (Figure 2B). Most of the terrain is plain (Figure 3B). Thus 15% of the soil is cultivated pastures for extensive cattle rising (Table 1). The herd is composed of 312 animals, mostly Brown Swiss x Zebu crosses.

Regarding the sociodemographic profile of the owners of the ranches, they had an average age of 48.5 years, schooling of 13.0 years, and 17.5 years of experience in cattle production. In three of the four ranches, families were small; however, in all cases, the ranch owner was the only family member involved in ranch activities (Table 2). In addition, in all cases there was a permanent salaried labor (EB-ranch = 1, SF-ranch = 2, EC-ranch = 2, and LA-ranch = 3) and temporal workforce.

Table 1 - Ranch profiles and overall productivity.

Ranch	Area (ha)	Pasture (%)	Pasturegrass	----------------Cow Productivity------------			-----Ranch Productivity----	
				LC (n)	DMP (kg)	MPA (kg ha^{-1})	kg GF ha^{-1}	kg DM ha^{-1}
EB-ranch	10	40	*C. nlemfuensis* *C. dactylon*	14	4.08	5,076.81	6,933.20 3,133.20	1,317.31 595.31
SF-ranch	120	15	*B. brizantha* *C. nlemfuensis*	18	4.35	1,732.75	6,933.20 4,160.00	1,317.31 790.40
EC-ranch	80	20	*B. híbrido* *B. brizantha*	28	6.72	3,915.29	3,066.80 12,800.00	582.69 2,432.00
LA-ranch	150	15	*C. dactylon* *C. nlemfuensis*	56	4.66	3,634.08	2,266.80 4,266.80	430.69 810.69

DMP: Daily milk production; GF: Green forage; DM: Dry matter; LC: lactating cows; MPA: milk production per area.

Figure 2 - Milking conditions in the four ranches. A) El Chamuscadero; B) La Aurora; C) El Bulito; D) San Felipe.

Characterization of the agro-ecosystems and profitability

To characterize the agroecosystems, a questionnaire applied to ranch owners, thus covering topics such as general ranch management, milking practices, and other routine activities of the production system. The general practices of each ranch were also observed on site. To determine the exact area under livestock production within each ranch, measurements were made using a GARMIN Montana 650® GPS device and Google Earth Pro software. To calculate the availability of pasture biomass, the

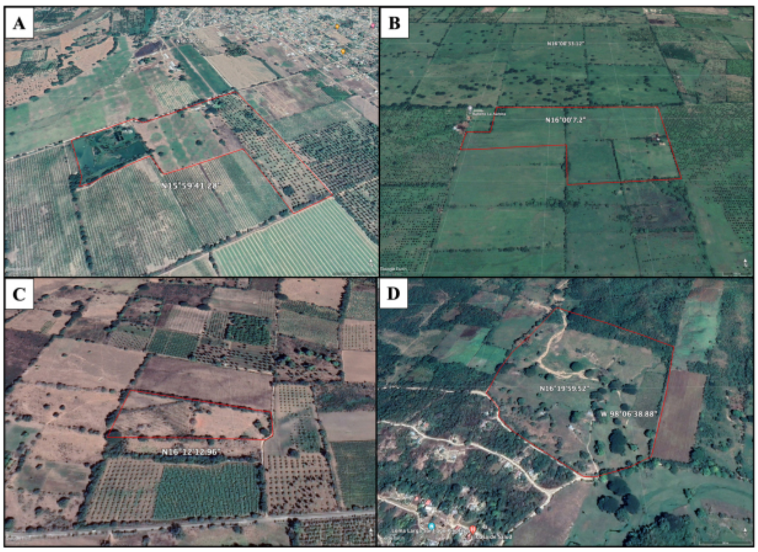

Figure 3 - Pasture mapping in the four ranches. A) El Chamuscadero; B) La Aurora; C) El Bulito; D) San Felipe.

Table 2 - Personal information of ranch owners and their families.

Ranch	---Owner Information---				
	Age (years)	Schooling (years)	Ranching experience (years)	Family members	Family members working in the ranch
El Bulito	59	6	12	2	1
San Felipe	60	17	26	3	1
El Chamuscadero	36	16	20	7	1
La Aurora	39	13	12	2	1

suggested procedure was followed by PEROZO BRAVO & RAZZ (2014). Herd productivity was determined by milk production records (kg cow^{-1} day^{-1}) in each milking and data collection for one month. To determine the economic profitability of each AEs, several indicators were under analysis according to the methodology of budgets by activity (ALBARRÁN-PORTILLO et al., 2015; GARCÍA-MARTÍNEZ et al., 2017): milk cost per unit (MCU), profit or loss (POL), and cost-benefit relationship (CBR). The MCU was determined by identifying the main farm inputs used for milk production: pasture-related costs, human labor, constructions, equipment (with or without engine), food supplements, medicine, combustibles, basic services, land rental, and other costs. The total monthly costs (TMC) from farm inputs, the total monthly production (TMP; kg) and income (total monthly income; TMI) for milk sales, which were also recorded in each farm to determine the profitability indicators, using the following formula: MUC=TMC/TMP. The POL was determined by milk sales subtracted from the costs of the dairy activity (POL= TMI–TMC). The CBR was determined by TMC in the dairy activity and the TMI (CBR=TMI/TMC).

Energy efficiency and productivity analyses

Energyefficiency analysis relied on the “process analysis method - PAM”. This PAM method measures the energy input (direct and indirect) based upon physical material flow (LLANOS et al., 2018). The PAM method also considered the limits of the system in space and time to evaluate energy use and further leaves out the energy required for packing, management, warehouses, and transportation when products leave the production system. To obtain energy input (EI), all farm acquisitions used in one hectare (ha) during a month was transformed into an energy scale (multiplied by its energy unit quantity) (PÉREZ NEIRA et al., 2013). The energy output (EO) was measured by the total milk per ha (kg ha^{-1}), also in na energy scale. The energy efficiency (EfE) index came from the relationship between the EI and EO (i.e, EfE: EI - EO). Further, the relationship between product quantity and energy input was also calculated (Energy productivity, EP) and described in monthly MJ ha^{-1}.

Soil analysis

An initial sampling occurred in each ranch, thus obtaining one final sample of 1 kg. Field and laboratory analyses were carried out for several parameters: pH, total nitrogen (%), phosphorus (parts per million - ppm), and potassium (ppm), soil texture, and electric conductivity (mS/cm^{-1}). Soil analysis relied on the Backpack Lab HI3896BP kit (Hanna instruments). Soil texture analysis was carried out using the “Bouyoucos” method, according to the Mexican standard (NOM-021-RECNAT-2000). One additional soil sample collected in each ranch (20 x 20 x 30 cm) allowed identifying the microorganisms reported in the soil of ranch pastures. Microorganisms were classed into: epigean, endogean, and anecic, according to their localization on the soil (organic matter, in-soil, and organic matter/soil**)** as suggested by TESSARO et al. (2016)\l “and FIERER (2019)\l”.

Data systematization and analysis

The raw data obtained for each study variable (productivity, profitability, energy efficiency and productivity, and soil quality) was systematized in Microsoft Excel® spreadsheets for processing and analysis using the formulas respectively described for each variable and its indicators.

RESULTS AND DISCUSSION

Productivity of agro-ecosystems

Productivity differed among the four ranches. The EB-ranch had better productivity indicators, for example with the lower number of lactating cows (n=14), it had higher milk yield per hectare per year; while the SF-ranch had the lowest annual milk productivity per area due to a greater use of pasture land (Table 1). The EB-ranch, LA-ranch and SF-ranch display similar average milk production in their herds, being 4.66, 4.08, and 4.35 kg cow/day, respectively; while EC-ranch held the highest daily milk production of 6.72 kg cow/day. The milk productions reported in this study are higher than those reported in dual-purpose bovine system in dry tropical regions (CUEVAS-REYES & ROSALES-NIETO, 2018), but lower than those reported in humid tropical regions of Mexico (CAMACHO-VERA et al., 2021; VENCES-PÉREZ et al., 2021). The variation regarding milk production values depends on the cow's genetic potential for milk production, the adequacy of the diet, feed and herd management practices, and the environment (SÁNCHEZ-DUARTE et al., 2020).

For pasture productivity, EC-ranch had the highest yield of dry matter for consumption by its grazing cattle: 582.69 and 2,432.00 kg DM ha^{-1} for *B. híbrido* and *B. brizantha*, respectively, what could explain the high milk production. Conversely, the pastures of the LA-ranch presented the minimum average yield of 430.69 and 810.69 kg DM ha^{-1} for *C. dactylon* and *C. nlemfuensis*, respectively, possibly due to a greater pasture degradation. In accordance with ENRÍQUEZ-QUIROZ et al. (2021), the degradation of tropical grasslands in Mexico is the consequence of continuous overexploitation, for decades, animal load has far exceeded pasture capacity and no effort has been made to return nutrients to the soil through fertilization. Therefore, the authors suggested that pastures need to be maintained by implementing grazing strategies that acknowledge seasonal forage production patterns, consider animal load, and return nutrients via chemical or organic fertilizers. In addition, optimal practices in silvopastoral systems should be established, which are promising sustainable systems for animal production in the tropics.

Profitability of agro-ecosystems

The SF-ranch had the highest MCU ($ 6.69), followed by EC-ranch ($ 4.64), EB-ranch ($ 3.94), and LA-ranch ($ 3.24), which are consistent with the cost of production per liter of milk ($ 4.22) found by CAMACHO-VERA et al. (2021) in the dairy system of the Frailesca region, Chiapas. According to the authors, this implies that in the months that producers sell their production below this value, they are incurring losses, a situation that happens at least three months a year during the rainy season. However, the increase in prices during the dry season allows most of the units to operate with a positive profitability and an average benefit-cost ratio close to 3.1. In the present study, items with highest expenditure were feeding (LA-ranch, 44.6%; EC-ranch, 40.8%), human labor (EB-ranch, 52.2%; SF-ranch, 42.6%) and fuel (EC-ranch, 11.5%; LA-ranch, 10.8%). In terms of cattle feeding, the cost grew depending on the number of lactating cows. Further, the cost of human labor increased with growing numbers of permanent and temporary workers. Other less significant items were electricity (mainly in SF-ranch and EC-ranch) and medicine (mainly in LA-ranch and SF-ranch). All ranches relied exclusively on pasture-based feeding, since the study was carried out during the rainy period (august – December, 2017). VENCES-PÉREZ et al. (2021) reported that in dual-purpose cattle ranching in the Mexican dry tropics, 71% of total production costs are due to cattle feed, followed by labor (9%), health (8%), and facilities (7%). Therefore, it suggested planning feeding strategies during the dry period, since, during this period, the production and quality of forage decreases and milk production diminishes. A similar situation was observed in a small-scale dairy production system, in central region of Mexico (SALINAS-MARTÍNEZ et al., 2020), where the cost of the feed represented 75% of total production costs, and this percentage slightly decreased in the largest production systems. Notably, the smaller production systems showed less dependence on purchased feed, which represented only 9% and 7% of production costs. In the study, the remaining variable costs, medicine, reproductive services, fuel, electricity, and fixed costs such as depreciation, represented less than 10% of production costs; therefore, any strategies or attempts to reduce these costs would not achieve a high rate of participation because they would likely not have an immediate impact on costs in the short term.

Regarding monthly net profits, LA-ranch and EB-ranch had the highest ($ 11,699.99 and $ 6,396.29, respectively) due to their lower costs and therefore positive CBR of 1.54 and 1.82, respectively. These results can be explained by EB-ranch production fresh cheese and its amount was considered in TMI. The TMC from the LA-ranch is due to the number of lactating cows (n = 56). VENCES-PÉREZ et al. (2021) carried out a socioeconomic analysis in dual-purpose cattle production units in the central highlands of Mexico, determining that the production of milk and cheese generates average income of $ 3,648.17, with maximum and minimum income of $ 7,585.44 and $ 1,339.34, respectively. In this way, milk production is an attractive economic option and represents a strength for the dual-purpose system due to the tradition of cheese consumption in rural and sub-urban regions of Mexico.

Energy efficiency and productivity in agro-ecosystems

Estimations of monthly energy sequestration of the ranches were as follows: LA-ranch (246,134.38 MJ), EC-ranch (196,688.64 MJ), SF-ranch (112,278.08 MJ) and EB-ranch (67,137.20 MJ). When considering these values according to the surface used (pasture area), a greater intensification of the cattle activity observed in the ranches (Table 3), according to the pasture area and the percentage of lactating cows (Table 1). Items with the highest expenditure were feeding (EB-ranch, 98%; LA-ranch, 95%; EC-ranch, 85% and SF-ranch, 84%), electric power (only SF-ranch, 12% and EC-ranch, 10%) and fuel (LA-ranch, 2.5%; EC-ranch, 2.3%; EB-ranch, 0.1%; SF-ranch, 0.1%).

Based upon the main data collected (EI, EO, EfE, and EP; Table 3), the LA-ranch was considered the most efficient among the four ranches, most probably due to a greater percentage of lactating cows within the herd (Table 1). Furthermore, the EB-ranch showed greater EI (16,784.30 Mj/ha), which represents the highest quantity of farm inputs for human labor, combustibles and medicine and its EO was 1,235.36 Mj/ha for milk produced in a smaller area (4.0 ha). Hence, ranches with a higher degree of intensification of grazing cattle tend to be more energy efficient (LLANOS et al., 2018). Results of the energy efficiency of this study (Table 3) were lower than previously reported by LLANOS et al. (2013). This author stratified energy efficiency in a dairy production system in the south of Uruguay as follows: low (1.40), medium (0.90), and high (0.86) productivities, respectively. In turn, the EP of the SF-ranch was the lowest but higher than reported by DENOIA et al. (2008), who found 0.59 and 0.80 kg milk/100 Mj for two milk production systems in Argentina.

Soil quality of the agro-ecosystems

Ranches displayed contrasting soil quality, based upon nutrient levels (Table 4). Three ranches have lowlands, which have greater concentrations of most evaluated nutrients than the hillslope lands soil found only in the SF-ranch (Table 4). This nutrient deprivation of hillslope soils is most likely due to nitrate losses by lixiviation generated by erosion (ALEWELL et al., 2020). Further, hillslope soils display nutrient deficiencies that may limit pasture growth and forage availability, according to nutrient levels described by SILVEIRA & KOHMANN (2020).

This soil type is found 70 cm in-depth, thus having a rocky condition with moderate water draining. Phosphorus levels can be considered low in most ranches. FONTE et al. (2014) found that low phosphorus levels (<50 ppm) leads to poor pasture development under tropical conditions. Calcium levels may fluctuate from very low (e.g., 0.086 ppm) to very high (e.g., 1.76). This substantial variation in calcium levels is due to soil age, where greater soil development leads to higher nutrient levels (SILVEIRA & KOHMANN, 2020). The botanic composition varied in the four ranches (Table 5). The EB-ranch had more soil occupancy by pastures and less naked soil (Table 5). In contrast, the EC-ranch has more degraded pasture (Table 5).

The edaphic fauna was classified by the ubication and its taxonomic group. Epigean, anecic and endogean organisms were found in all ranches. The various species were spiders (*Tegenaria domestica*), common earthworm (*Lumbricus terrestris*), green conehead katydid (*Neoconocephalus* sp), sweet potato whitefly (*Bemisatabaci*), housefly (*Musca domestica*)

Table 3 - Ranch parameters for energy efficiency analyses.

Indicators	--Ranch--			
	EB-ranch	SF-ranch	EC-ranch	LA-ranch
Energy Input (EI) (MJ/ha/month)	16784.30	6237.67	12293.04	3051.69
Energy Output (EO) (MJ/ha/month)	1235.36	316.23	952.72	884.29
Energy Efficiency (EfE)	0.07	0.05	0.08	0.29
Energy Productivity (EP) (Milk Kg/100 MJ)	2.52	1.74	2.65	2.71

Table 4 - Ranch soil quality parameters.

Indicators	---Ranch---			
	EB-ranch	SF-ranch	EC-ranch	LA-ranch
pH	6.87	6.9	6.78	6.9
Total Nitrogen (%)	Very Low	Very Low	Very Low	Average
Phosphorum (ppm)	Average	High	Low	Very Low
Potassium (ppm)	Low	Average	Low	Average
Texture	Sandy loam	Sandy clay	Sandy loam	Siltyloam
Electric conductivity (mS/cm^{-1})	278	283	116	106

and red wood ant (*Formica spp*). The presence of endogean organisms is of great importance in the agroecosystems since that they may contribute to soil compactation or decompactation (FIERER, 2019). It is a positive finding to find this diversity in endogean organisms in all ranches. This in turn contributes to the ecological balance and ecological complexes due to ideal conditions of humidity, aeration, temperature, pH and food resources in the upper layer of soil (KITAMURA, 2020).

CONCLUSION

The study provided an approximate estimation of the sustainability of each ranch. Four ranches were profitable, and those with more cows on identically sized pastures generated higher profit margins. The most important factors affecting profitability of the ranches were cattle feed, human labor, and fuels.

These dairy agroecosystems were inefficient in energy use, because they showed a low capacity to convert energy units to the corresponding surface area. Energy productivity improves with a higher number of lactating cows, higher milk production per cow, and lowest pasture surface areas utilized. The energy efficiency of the two ranches El Chamuscadero and La Aurora relied mainly on cattle feed and fuels, while human labor also influenced the other two ranches (El Bulito and San Felipe).

Most of the cattle agroecosystems mentioned here, were evaluated with medium productive potential. The limited potential was due to low soil fertility. Low fertility comes from the limited availability of various macronutrients and macrofaunal diversity, which can be increased with sustainable grazing management.

This analysis revealed a low degree of sustainable intensification of agroecosystems, a phenomenon that does not allow the release of areas dedicated to livestock, to promote their natural regeneration or conservation. Therefore, follow-up studies should focus on determining other agronomic

Table 5 - Ranch botanic composition: pasture profile and soil use.

Ranch	Pasture grass	Pasture (%)	Degraded pasture (%)	Naked soil (%)
El Bulito	*C. nlemfuensis*	96.67	1.67	1.67
	C. dactylon	65.00	31.67	3.33
San Felipe	*B. brizantha*	78.33	6.67	15.00
	C. nlemfuensis	80.00	16.35	3.67
El Chamuscadero	*B. híbrido*	44.17	52.50	3.33
	B. brizantha	93.33	4.67	3.67
La Aurora	*C. dactylon*	71.67	26.67	1.67
	C. nlemfuensis	70.00	25.00	5.00

DMP: Daily milk production; DM: Dry matter; LC: lactating cows; MPA: milk production per area.

parameters such as nutrient balance, in the case of the ecological component; and sensibility analyses or the balance point, for the economic component.

ACKNOWLEDGEMENTS

We thank the Consejo Nacional de Ciencia y Tecnología (Project No. 2181) and the Tecnológico Nacional de México Campus Pinotepa Nacional for the material support to carry out this study. We also thank the owners of the evaluated ranches for the facilities provided.

DECLARATION OF CONFLICT OF INTEREST

The authors declare no conflict of interest. The founding sponsors had no role in the design of the study; in the collection, analyses, or interpretation of data; in the writing of the manuscript, and in the decision to publish the results.

AUTHORS' CONTRIBUTIONS

All authors contributed equally for the conception and writing of the manuscript. All authors critically revised the manuscript and approved of the final version.

REFERENCES

ALBARRÁN-PORTILLO, B., et al. Socioeconomic and productive characterization of dual-purpose farms oriented to milk production in a subtropical region of Mexico. **Tropical animal health and production**, v.47, n.3, p.519-523. 2015. Available from: <https://link.springer.com/article/10.1007/s11250-014-0753-8>. Accessed: Jul. 21, 2021. doi:10.1007/s11250-014-0753-8.

ALEWELL, C., et al. Global phosphorus shortage will be aggravated by soil erosion. **Nature communications**, v.11, n.1, p.1-12. 2020. Available from: <https://www.nature.com/articles/s41467-020-18326-7>. Accessed: May, 29, 2020. doi: 10.1038/s41467-020-18326-7.

BATEKI, C. A., et al. Meta-analysis of the effects of on-farm management strategies on milk yields of dairy cattle on smallholder farms in the Tropics. **Animal**, v.14, n.12, p.2619-2627. 2020. Available from: <https://www.sciencedirect.com/science/article/pii/S1751731120001548>. Accessed: Dec. 14, 2021. doi: 10.1017/S1751731120001548.

BAUTISTA, M. Y., et al. Technical optimum milk and meat production levels in dual-purpose cattle systems in tropical Mexico. **Revista Mexicana de Ciencias Pecuarias**, v.10, n.4, p.933-950. 2019. Available from: <https://cienciaspecuarias.inifap.gob.mx/index.php/Pecuarias/article/view/4927>. Accessed: Dec. 13, 2020. doi:10.22319/rmcp.v10i4.4927.

CAMACHO-VERA, J. H., et al. Characteristics of milk production in La Frailesca, Chiapas, Mexico. **Revista Mexicana de Ciencias Pecuarias**, v.12, n.3, p.845-860. 2021. Available from: <http://www.scielo.org.mx/pdf/rmcp/v12n3/2448-6698-rmcp-12-03-845-en.pdf>. Accessed: Jun. 16, 2022. doi: 10.22319/rmcp.v12i3.5375.

CHIRINDA, N., et al. Perspectives on reducing the national milk deficit and accelerating the transition to a sustainable dairy value chain in Zimbabwe. **Frontiers in Sustainable Food Systems**, v.5, p.726482. 2021. Available from: <https://www.frontiersin.org/articles/10.3389/fsufs.2021.726482/full>. Accessed: Jun. 16, 2022. doi: 10.3389/fsufs.2021.726482.

CISNEROS-SAGUILÁN, P., et al. Current Epistemological Perceptions of Sustainability and Its Application in the Study and Practice of Cattle Production: A Review. **Agroecology and Sustainable Food Systems**, v.39, n.8, p.885-906. 2015. Available from: <https://www.tandfonline.com/doi/abs/10.1080/21683565.2015.1050148>. Accessed: Jul. 24, 2020. doi: 10.1080/21683565.2015.1050148.

CISNEROS-SAGUILÁN, P., et. al. Cumplimiento de la norma para ganadería sostenible en diversos ranchos de la costa de Oaxaca. In: Gallardo-López F. (Ed). **Innovando el Agro Veracruzano 2016 - Frente a los retos de la relación Sociedad-Naturaleza**. Veracruz, México. Colegio de Postgraduados, v.1, 2016. Pp: 765-790. Available from: <https://www.researchgate.net/publication/325531621_Cumplimiento_de_la_norma_para_ganaderia_sostenible_en_diversos_ranchos_de_la_costa_de_Oaxaca_Mexico>. Accessed: Jan. 22, 2020.

CUEVAS-REYES, V.; C. ROSALES-NIETO. Characterization of the dual-purpose bovine system in northwest Mexico: Producers, resources and problematic. **Revista MVZ Córdoba**, v.23, n.1, p.6448-6460. 2018. Available from: <https://revistamvz.unicordoba.edu.co/article/view/1240/pdf>. Accessed: Jun. 20, 2022. doi: 10.21897/rmvz.1240.

DE BOER, I. J. M., et al. Greenhouse gas mitigation in animal production: towards an integrated life cycle sustainability assessment. **Current Opinion in Environmental Sustainability**, v.3, n.5, p.423-431. 2011. Available from: <http://www.sciencedirect.com/science/article/pii/S1877343511000856>. Accessed: Feb. 25, 2021. doi: 10.1016/j.cosust.2011.08.007.

DENOIA, J., et al. Análisis de la gestión energética en sistemas de producción ganaderos. **Ciencias Agrarias**, v.7, n.1-2, p.43-56. 2008.

DURÁN, M. E., et al. Competitividad de la ganadería de doble propósito en la costa de Oaxaca, México. **Revista Mexicana de Agronegocios**, v.43, p.77-88. 2018. Available from: <https://ageconsearch.umn.edu/record/281299>. Accessed: Oct. 15, 2020. doi: 10.22004/ag.econ.281299.

ENRÍQUEZ-QUIROZ, J. F., et al. Rehabilitation of degraded pastures in the tropics of Mexico. **Revista Mexicana de Ciencias Pecuarias**, v.12, p.243-260. 2021. Available from: <http://www.scielo.org.mx/pdf/rmcp/v12s3/2448-6698-rmcp-12-s3-243.pdf>. Accessed: Jun. 16, 2022. doi: 10.22319/rmcp.v12s3.5876.

FIERER, N. Earthworms' place on Earth. **Science**, v.366, n.6464, p.425-426. 2019. Available from: <https://science.sciencemag.org/content/366/6464/425.summary>. Accessed: Sept. 11, 2020. doi: 10.1126/science.aaz5670.

FONTE, S. J., et al. Pasture degradation impacts soil phosphorus storage via changes to aggregate-associated soil organic matter in highly weathered tropical soils. **Soil Biology and Biochemistry**, v.68, p.150-157. 2014. Available from: <https://www.sciencedirect.com/science/article/abs/pii/S003807171300326X?via%3Dihub>. Accessed: May, 15, 2020. doi: 10.1016/j.soilbio.2013.09.025.

GARCÍA-MARTÍNEZ, A., et al. Análisis productivo y económico de unidades de producción de ganado bovino para carne en

Tlatlaya, Estado de México. **Agroproductividad**, v.10, n.10, p.22-28. 2017. Available from: <http://www.revista-agroproductividad.org/index.php/agroproductividad/article/view/93/86>. Accessed: Apr. 30, 2020.

HERRERO, M.; P. K. THORNTON. Livestock and global change: Emerging issues for sustainable food systems. **Proceedings of the National Academy of Sciences**, v.110, n.52, p.20878-20881. 2013. Available from: <http://www.pnas.org/content/110/52/20878.short>. Accessed: Jun. 23, 2020. doi: 10.1073/pnas.1321844111.

IBÁÑEZ, J., et al. Desertification due to overgrazing in a dynamic commercial livestock-grass-soil system. **Ecological Modelling**, v.205, p.277-288. 2007. Available from: <https://www.sciencedirect.com/science/article/abs/pii/S0304380007000993>. Accessed: Apr. 19, 2020. doi: 10.1016/j.ecolmodel.2007.02.024.

INEGI, (INSTITUTO NACIONAL DE ESTADÍSTICA Y GEOGRAFÍA). **Anuario estadistico y geografico de Oaxaca 2016**. Aguascalientes, México: Instituto Nacional de Estadística y Geografía**:** 1751 p. 2017.Available from: <https://www.inegi.org.mx/contenidos/productos/prod_serv/contenidos/espanol/bvinegi/productos/nueva_estruc/anuarios_2016/702825084295.pdf>. Accessed: May, 18, 2021.

IPCC -The Intergovernmental Panel on Climate Change. **Refinement to the 2006 IPCC Guidelines for National Greenhouse Gas Inventories**. Switzerland, 110 p. 2019. Available from: <https://www.ipcc.ch/report/2019-refinement-to-the-2006-ipcc-guidelines-for-national-greenhouse-gas-inventories/>. Accessed: Jul, 19, 2022.

KITAMURA, A. E. Soil macrofauna as bioindicator of the recovery of degraded Cerrado soil. **Ciencia Rural**, v.50, n.8, p.1-8. 2020. Available from: <http://www.scielo.br/scielo.php?script=sci_arttext&pid=S0103-84782020000800251&nrm=iso>. Accessed: Nov. 21, 2020. doi: 10.1590/0103-8478cr20190606.

LLANOS, E., et al. Eficiencia energética en sistemas lecheros del Uruguay. **Agrociencia Uruguay**, v.17, p.99-109. 2013. Available from: <http://www.scielo.edu.uy/scielo.php?script=sci_arttext&pid=S2301-15482013000200011&nrm=iso>. Accessed: Apr. 22, 2020.

LLANOS, E., et al. Energy and economic efficiency in grazing dairy systems under alternative intensification strategies. **European Journal of Agronomy**, v.92, p.133-140. 2018. Available from: <http://www.sciencedirect.com/science/article/pii/S1161030117301648>. Accessed: Dec. 10, 2021. doi: 10.1016/j.eja.2017.10.010.

MARTÍNEZ-CASTRO, C. J., et al. Sustentabilidad de agroecosistemas en regiones tropicales de México. **Tropical and Subtropical Agroecosystems**, v.18, n.1, p.113-120. 2015. Available from: <https://www.revista.ccba.uady.mx/ojs/index.php/TSA/article/view/2106>. Accessed: Jul. 24, 2020.

PÉREZ NEIRA, D., et al. Energy Indicators for Organic Livestock Production: A Case Study from Andalusia, Southern Spain. **Agroecology and Sustainable Food Systems**, v.38, n.3, p.317-335. 2013. Available from: <http://dx.doi.org/10.1080/21683565.2013.833154>. Accessed: Apr. 27, 2020. doi: 10.1080/21683565.2013.833154.

PEROZO BRAVO, A.; G. R. C. RAZZ. Buenas prácticas para el manejo de pasturas en sistemas de ganadería de doble propósito. In: Y. Villasmil-Ontiveros (Ed.). **Buenas prácticas en ganadería doble propósito**. Maracaibo, Venezuela: GIRARZ, v.1, 2014. p.213-222. Available from: <https://www.researchgate.net/profile/Yenen-Villasmil/publication/342927055_Buenas_Practicas_en_Ganaderia_de_Doble_Proposito/links/5f506ad4458515e96d25c5b2/Buenas-Practicas-en-Ganaderia-de-Doble-Proposito.pdf#page=231>. Accessed: Dec. 27, 2021.

SALINAS-MARTÍNEZ, J. A., et al. Cost analysis and economic optimization of small-scale dairy production systems in Mexico. **Livestock Science**, v.237, p.104028. 2020. Available from: <https://www.sciencedirect.com/science/article/abs/pii/S1871141319314660>. Accessed: Jun. 19, 2022. doi: 10.1016/j.livsci.2020.104028.

SÁNCHEZ-DUARTE, J. I., et al. Production response in dairy cows milked two or three times a day: A meta-analysis. **Veterinaria México OA**, v.7, n.2, p.1-17. 2020. Available from: <http://www.scielo.org.mx/pdf/vetmexoa/v7n2/2448-6760-vetmexoa-7-02-e00003.pdf>. Accessed: Jun. 16, 2022. doi: 10.22201/fmvz.24486760e.2020.2.562.

SILVEIRA, M. L.; M. M. KOHMANN. Maintaining soil fertility and health for sustainable pastures. In: M. A. Rouquette, Glen E. (Ed.). **Management Strategies for Sustainable Cattle Production in Southern Pastures**: Elsevier, 2020. Maintaining soil fertility and health for sustainable pastures, p.35-58. Available from: <https://www.sciencedirect.com/science/article/pii/B9780128144749000037?via%3Dihub>. Accessed: Jul. 24, 2021. doi: 10.1016/B978-0-12-814474-9.00003-7.

TESSARO, D., et al. Wastewater use in agriculture and potential effects on meso and macrofauna soil. **Ciência Rural**, v.46, p.976-983. 2016. Available from: <http://www.scielo.br/scielo.php?script=sci_arttext&pid=S0103-84782016000600976&nrm=iso>. Accessed: Dec. 14, 2019. doi: 10.1590/0103-8478cr20141648.

TORO-MÚJICA, P., et al. Sustentabilidad de agroecosistemas. **Archivos de Zootecnia**, v.60, n.R, p.15-39. 2011. Available from: <https://www.uco.es/az/index.php/az/article/view/4914>. Accessed: Jan. 15, 2020. doi: 10.21071/az.v60i232.4914.

VENCES-PÉREZ, J., et al. Análisis socioeconómico y tendencias de desarrollo de la ganadería doble propósito en Trópico seco. **Tropical and Subtropical Agroecosystems**, v.24, n.57. 2021. Available from: <https://www.revista.ccba.uady.mx/ojs/index.php/TSA/article/view/2785>. Accessed: Jun. 16, 2022.

VILABOA, J., et al. Estructura de comercialización de bovinos destinados al abasto de carne en la región del Papaloapan, Veracruz, México. **Economía, Sociedad y Territorio**, v.9, n.31, p.831-854. 2009. Available from: <https://www.scielo.org.mx/scielo.php?pid=S1405-84212009000300009&script=sci_arttext>. Accessed: Jun. 16, 2020.