ANALYSIS OF PRODUCTIVITY, NUTRITIONAL CONSTRAINTS AND MANAGEMENT OPTIONS IN BEEF CATTLE SYSTEMS OF EASTERN YUCATAN, MEXICO: A CASE STUDY OF COW-CALF PRODUCTIVITY IN THE HERDS OF TIZIMIN, YUCATAN

A Thesis

Presented to the Faculty of the Graduate School

of Cornell University

In Partial Fulfillment of the Requirements for the Degree of

Master of Science

by

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January 2007

ABSTRACT

The overall objective of this case study was to systematically evaluate productivity limitations and potentials in beef cattle herds with prolonged calving intervals in tropical Tizimín, Yucatán, México. The Cornell Net Carbohydrate and Protein System model was the primary diagnostic tool applied to specific management groups of cows in a structured set of 48 simulations. Typical herd management was established from a field survey of 63 local Brahman cattle producers. Management groups included different parities in distinct physiological stages of calving intervals initiated in either of four forage seasons of the year. Forage dry matter intake was assumed to be reduced by corralling management to 90% of predicted *ad libitum* consumption.

Findings provided basic understanding about biological and management limitations on performance for dams of all ages and their associations with season of calving. The management practice of corralling without daytime provision of feed certainly prevents *ad libitum* forage energy intake, which reduces (by one-third or more) the milking performance of dams, growth of calves and immature cows, and tissue repletion in dams. Greater feed consumption would reduce the heavy reliance on the tissue turnover subsidy of cow-calf production. Producers should be apprised of tradeoffs between current and alternative practices.

In addition to restricted feed intake, poor quality forage was also a fundamental limitation. Forages with higher feeding value are needed, which involves investment considerations to improve quantity and quality (chemical composition and fermentation rates), grazing management, and hay-making or considering hay-contracting options.

Cows universally rely heavily on tissue catabolism to support milk production. Lactation was initiated by mobilizing from 3 Mcal ME/d to 8 Mcal ME/d for synthesis of 4 kg/d to 8 kg/d of milk. One-fourth to one-third of the total energy required for milk synthesis was obtained from body reserves, which far exceeds adipose tissue contributions in dairy systems.

Least reliance on tissue reserves consistently occurred with calvings in the season of early rains. Greatest reliance occurred with calvings in the season of scarce rain. Dams frequently incurred energy deficits in late gestation, causing them to divert body reserves for fetal growth. Findings indicate it may be wise to synchronize calvings with seasons of forage plenty and to control proportions of the herd calving at other times.

Predicted weaning weights of calves based on the expected milk production of their dams agreed with results reported from a Yucatán herd. Furthermore, these weight predictions indicated that dams in mid-late lactation would have had to devote all dietary energy to milk synthesis with nil energy for tissue repletion.

Findings indicate that body tissue reserves are probably rarely fully replenished during the average calving intervals considered: cows are thin for a long period, which likely results in postpartum delays in returned ovarian cyclicity. Body condition scores ≤2.5 were frequently predicted in mid-late lactation when diets were too deficient to permit repletion or to assure persistent lactation. Immature cows are further disadvantaged by severe restriction on their growth. It appears unlikely that cows can achieve desirable tissue reserve status (i. e., BCS ≥5.0), or needed growth, without incurring longer calving intervals for opportunistic accrual of body tissues when requirements are low and supplies of digestible forage are high.

The typical practice of poultry manure and molasses supplementation when the forage supply is scarce does not address the primary limitation of dietary energy. Cow energy status is aggravated by excess N because its excretion diverts energy from other uses.

Priority research and outreach considerations for the Yucatán (and Mexican) beef industry should be established using a holistic, integrative strategy to generate, and evaluate, management opportunities for, and with, farmers. Considerations include chemical evaluation of forages and other feedstuffs, making this information available to farmers and their advisors, use of high quality hays, better formulation of diets with greater nutrient density for specific management groups, shifting calving patterns to better exploit forage nutrient supplies, quantifying seasonal variation in body weights and monitoring body condition scores of animals, and using nutritional and dietary evaluation tools in herd dietary management.

BIOGRAPHICAL SKETCH

Kotaro Baba was born and grew up in Niigata, northern-central Japan. After he finished his degree in Veterinary Science at Rakuno Gakuen University in Hokkaido, northern Japan, he worked with cattle producers for several years in Tanegashima, a southern island of Kyushu. Later, he joined a Japanese overseas volunteer service, and worked with Aymaran farmers in Bolivia, South America for a few years. He entered an MS program in the Department of Animal Science at Cornell University in August 2004.

ACKNOWLEDGMENTS

This thesis could not have been completed without the help and support of a number of people from all over the world to whom I would like to express my gratitude.

First and foremost, I would like to thank Prof. Robert Wesley Blake. His continuous stimulating advice and support were essential for the completion of the thesis and MS program. It was an honor for me to work on this interesting research topic in México with Prof. Blake, who has 30 years of experience in livestock production in developing countries, especially in Latin America. In addition, I would like to acknowledge the friendship and the support of his wife, Elvira, and their daughter, Victoria, in Yucatán, in the summer of 2005.

I would like to express special thanks to Prof. Danny Gene Fox for his valuable comments and advice on this research, based on his profound experience, not only in the US cattle industry, but also in developing countries. I do not forget that he helped me a great deal in my preparations for a presentation in Veracruz, México, in January 2006, even during the holiday season around Christmas and New Year's Day, 2005 to 2006.

I would also like to thank Dr. Luis Tedeschi, who is currently a professor at Texas A & M University, Dr. Charles Nicholson at Department of Applied Economics and Management for his help and feedbacks for the thesis, and Dr. Michael Van Amburgh, who is an animal nutrition professor at Cornell University, for his generous help on the CNCPS and animal nutrition, and Terry Kinsman and Judy Sherwood for their help to me. I would like to acknowledge the help for this research and friendship of other people in Cornell: Cristina Lanzas, Seong (Terry) Seo, Mamadou Chetima, David Parsons, Cristina Giosué, Luis Nabté, Victor Absalón, Omar Cristobal, Keenan

McRoberts. Yes, I got a lot of help from the librarians at Mann and Olin to find references for this thesis, and from Japanese students who studied international (or agricultural) development at Cornell from 2004 to 2006. I also want to thank all of my friends in Ithaca.

I appreciate Drs. Juan Magaña, Guillermo Ríos and Armín Ayala, who are professors at the Universidad Autónoma de Yucatán, for providing valuable information for the CNCPS simulations and for their devoted support and I would like to acknowledge the friendship of UADY students (especially Andres Calderón, Miguel Huchín, and Gabriela González).

I would like to express sincere appreciation to the producers and local panel of professionals in Tizimín, Yucatán, México, especially Fernando Duarte, a researcher of the INIFAP (Instituto Nacional de Investigaciones Forestales y Agropecuarias), his wife, Tere, and their daughter, María José, and also Antonio Díaz, a local veterinarian. They gave me great support in 2005. Without their continuous help, I could not have completed the research in 2005 or this thesis.

I would like to thank Dr. Francisco Juárez Lagunes (Universidad Veracruzana) and Dr. Bertha Rueda (INIFAP) in Veracruz for their suggestions for the CNCPS simulations. I am also grateful to HED (Higher Education for Development) and USAID-México, which permitted me to participate in the TIES project [Decision Support of Ruminant Livestock Systems in the Gulf Region of Mexico].

Finally, I would like to thank to my friends and family in Japan. I am grateful to Ono-San, Watanabe-San of JICA Tokyo, who were in charge of me, for their help.

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1. Introduction

The global revolution in animal agriculture, especially in tropical regions, impacts human health, human livelihoods, and the environment. Consequently, growth in human population, household incomes and greater urbanization in developing countries all contribute to the increasing demand for foods of animal origin (Delgado et al., 1999; Blake and Nicholson 2004). Delgado and colleagues (1999) urged that industry leaders and policy makers respond to this rapid change with long-term policies and investments to satisfy the expected increase in consumer demand for these products.

Mexico's human population, currently more than 100 million citizens, is expected to continue to grow at an annual rate of 1.6% (Unisef, 2004). About 76% of Mexicans live in urban areas, where the annual population growth rate is about 1.9%. These trends indicate greater market demands for foods of animal origin, including beef. Consequently, greater production of beef from Mexico's cattle systems will be needed, especially if there is to be less reliance on imported beef.

Mexican agriculture has been described as under-capitalized, inefficient and uncompetitive (Jacques et al., 1996). Evidence also indicates that Mexican farmers have been displaced from agriculture since the North American Free Trade Agreement (NAFTA) was implemented in 1994 (Jacques et al., 1996; Peel, 1996). For foods of animal origin, México has a comparative advantage in cow-calf production and, consequently, in the export of feeder beef cattle to the US. The US possesses comparative advantages in feedlot inputs and technology, packing, and processing technologies for beef product exports. This scenario results in US-finished and processed beef from Mexican-born animals among the US exports to Mexican consumers (Peel, 1996). Therefore, México has short-term opportunities to become more competitive in producing beef from pasture-based systems, especially those in the Gulf region.

Yucatán State in the Gulf region of México contains possesses about 36,000 hectares of land devoted to about 643,000 cattle, especially for beef production (Yucatán Today, 2006; SAGARPA, 2002). Eastern Yucatán is especially known for its beef herds, especially near the rural city of Tizimín which is about 160 km east of Mérida at 21° 09′ N and 88° 10′ W. The annual rainfall from 1999 to 2003 in this tropical region averaged about 1300 mm with large seasonal variation and a mean annual temperature of 25 °C (Comisión Nacional de Agua, 2003). The rainy season typically occurs from June through September. A pronounced dry season begins in October and continues through May (Figure 1(a)).

Seasonal variation in rainfall results in large differences in the supply and quality of forage. Figure 1(b) summarizes the range in forage availability throughout the year. Assuming trampling losses of 15% of the total dry matter (DM) produced, the maximum available DM for animal consumption in the rainy season ranges from about 680 kg/ha from pastures that typically are neither fertilized nor irrigated (e.g., Guinea grass, *Panicum maximum*) to about 1300 kg/ha from irrigated pastures receiving commercial fertilizer (e.g., African star grass, *Cynodon plectostachyus*). The gross supply of available forage is about half as much in the dry season. If fully exploited these supplies could support two to four animal units (one animal unit = 450 kg of live weight) per hectare during the rainiest months and one to two animal units per hectare in the dry season assuming *ad libitum* daily forage consumption per animal equal to 2% of its live body weight (Allison, 1985). Although irrigation and fertilization benefit forage growth, these costly practices are rarely utilized by Tizimín producers. Consequently, beef cattle systems in Tizimín are especially constrained by

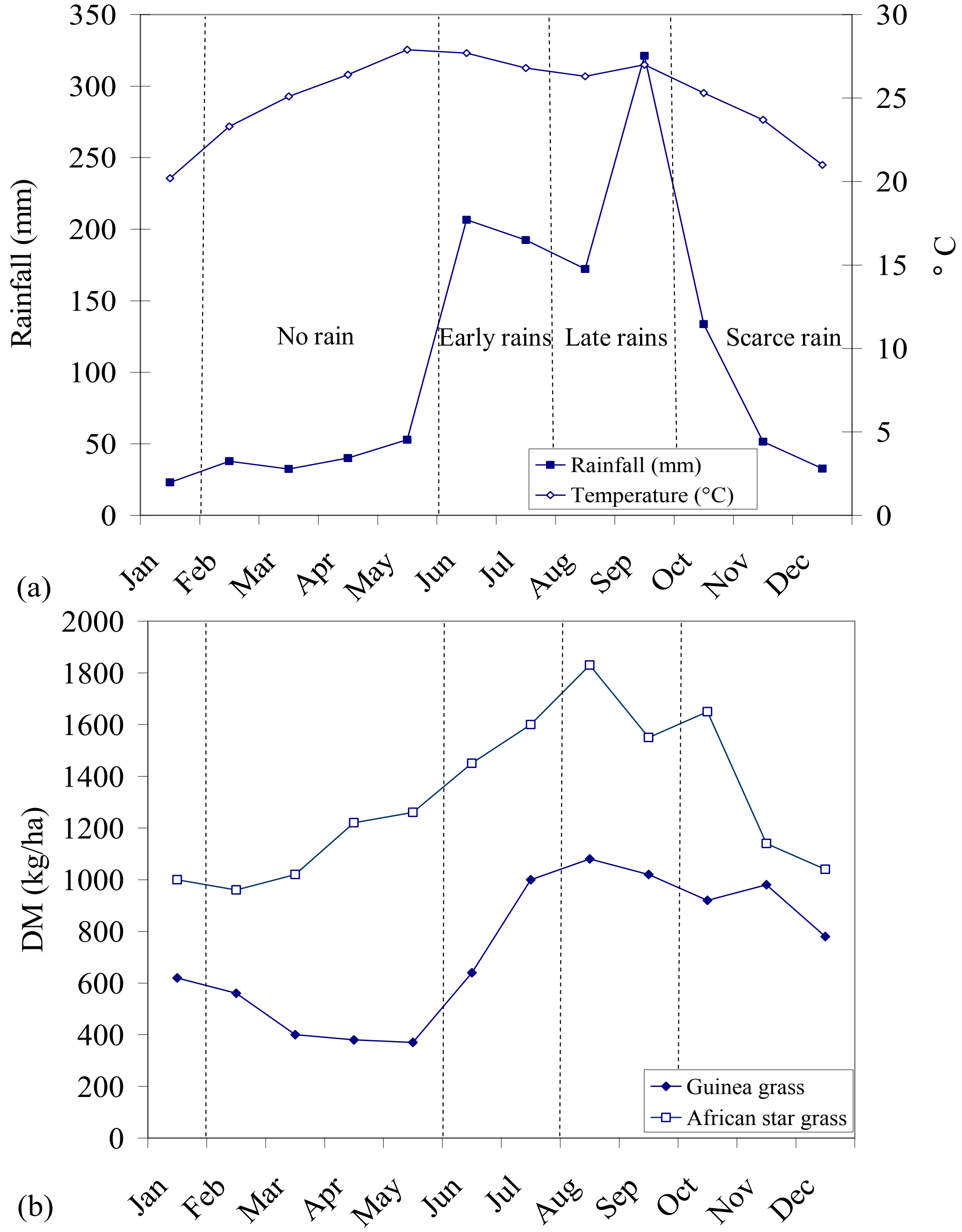

Figure 1(a) Mean monthly temperature (°C) and rainfall (mm) in Tizimín, Yucatán from 1999 to 2003 (Comisión Nacional de Agua,Yucatán). (b) Forage dry matter available throughout the year in grazed pastures of unfertilized, unirrigated Guinea grass (*Panicum maximum*) and fertilized, irrigated African star grass (*Cynodon plectostachyus*) in eastern Yucatán (Magaña, 2000).

forage scarcity in the dry season and probably by chronic undersupplies of dietary nutrients throughout the year.

There are about 2000 cattle ranches in the Tizimín area ranging in size from 10 to 1000 ha and stocked with about 0.7 to 1.0 AU per hectare (personal communication, F. Duarte). In general, cow-calf systems in Yucatán rely almost entirely on the grazing of rarely-fertilized pastures. Cows are mostly crosses between *Bos indicus* (Brahman or Nelore) and *Bos taurus* (Brown Swiss or Charolais) breeds.

Length of calving interval is known to profoundly affect the profitability of beef cattle ranching (Kunkle et al., 1994). Average calving intervals in Tizimín herds are at least 14 mo for mature cows and 16 mo for primiparous cows (Magaña et al., 2002). In comparison, a study of Brahman herds in Texas showed an average calving interval between 12 mo and 13 mo (Browing Jr. et al., 1995), substantially shorter than for the target herds in this study. Therefore, extended calving interval probably leads to substantial economic sacrifice for Tizimín cattle producers.

2. Review of literature

Season of year is known to affect the chemical composition and nutritional quality of forages and, consequently, animal productivity. A diagnostic study in Mediterranean Italy (Licitra et al., 1998) illustrated large seasonal differences with poorest cow performance from lowest forage quality [i.e., high contents of neutral detergent fiber (NDF) and lignin and low content of crude protein (CP)]. Elevated ambient temperatures and a relatively short day length results in low forage quality as characterized by high NDF, high lignin, and marginal CP, which are frequent dietary constraints to animal productivity in tropical environments (Van Soest, 1994). Therefore, seasonal variation in the supply and quality of forage is likely a primary limitation on beef cattle productivity in Tizimín herds.

2.1. Dietary management

The Cornell Net Carbohydrate and Protein System (CNCPS) is a mathematical model that has proven useful in predicting animal nutrient requirements, in evaluating animal dietary potentials, and in predicting expected animal productivity for specified management (Fox et al., 2004). This model permits adjustments to animal requirements and feed chemical and kinetic parameters for tropical production environments (Fox et al., 2003; Tedeschi et al., 2002; Juarez-Lagunes et al., 1999; Rueda et al., 2003; Reynoso-Campos et al., 2004).

Juarez-Lagunes and colleagues (1999) utilized the CNCPS model to evaluate the potentials of an array of tropical grasses with varying chemical composition and NDF digestion rates to support milk production in dual-purpose (milk and beef) cattle herds in Veracruz, México. These authors concluded that with adequate forage chemical and kinetic information the CNCPS model can accurately describe animal nutrient requirements and the biological values of tropical feeds, and could usefully help determine feeding recommendations for lactating cows in similar tropical conditions.

Rueda and co-workers (2003) evaluated strategies for improving productivity and economic returns from beef and dual-purpose herds in the western Amazon region of Brazil. Milk yield and growth responses of cattle grazing *Brachiaria* grasses (*Brachiaria brizantha, Brachiaria decumbens*) and tropical kudzu legume (*Pueraria phaseoloides*) were evaluated based on the annual seasonal variation in chemical composition and NDF digestion rate of these forages using the CNCPS model. Subtle differences in forage chemical composition significantly affected the availability of dietary nutrients, especially metabolizable energy (ME) and animal growth rate throughout the year. Among the investment options considered, these authors concluded greater potential productivity and net economic margins from land (with judicious fertilization) and labor by increasing the stocking rate from two to four AU/ha to produce more beef, but not to produce more milk.

2.2. Dietary constraints on animal productivity

The dietary intake of energy is a key determinant of cattle productivity in all climatic zones, including the tropics (Nicholson et al., 1995). The intake of ME for body weight gain of Nelore cattle grazing *Brachiaria* grasses in the western Amazon of Brazil was always more limiting throughout the year than metabolizable protein (Rueda et al., 2003). A study of crossbred dairy cows (European and Zebu breeds) in Kenya also revealed that energy intake was the first limitation on milk production (Nherera, 2005). Conclusions were that greater availability of higher quality forages and more affordable energy-rich supplements for Kenyan dairy farmers would make greater milk production feasible. In addition to restricting milk production and animal growth, deficits of dietary energy also constrain reproductive performance.

Days to the postpartum nadir of negative energy balance is expected to be correlated with length of the interval to first ovulation. This phenomenon has been amply demonstrated in beef cattle (Wiltbank et al., 1962; Wiltbank, 1970) and dairy cows (Canfield et al., 1990) ($r = 0.75$, $P < .01$). The quantity of adipose tissue reserves in beef cows at various stages of the production cycle, or calving interval, is an important indicator of female reproductive performance and overall herd productivity. Consequently, body condition scoring (BCS) is a valuable herd management tool for identifying and monitoring the nutritional and body tissue reserve statuses of beef cows (Herd et al., 1987). A BCS at calving of five to six units for primiparous cows (beef BCS scale of 1 to 9 units) was required to achieve a 12-mo calving interval in Texas herds (Herd et al., 1995).

Delgado et al. (2004) evaluated relationships among seasonal variation in pasture availability, fluctuations in animal body weight and body tissue reserve status (e.g., BCS), and reproductive performance of cows in Yucatán beef herds. These authors concluded that ovarian cyclicity and, consequently, pregnancy rate at four months postpartum ($P<0.05$) were partly governed by body tissue reserve status (i.e., BCS) at calving and at two months postpartum, and by the total quantity of body tissue catabolized (i. e., change in BCS). Among parity groups, primiparous cows were thinnest and had poorest pregnancy performance.

Reynoso-Campos et al. (2004) demonstrated the usefulness of a dynamic nutrition model to continuously monitor and manage milk production, ME and MP balances, and fluctuations in body weight (BW) and BCS throughout the annual productivity cycles of cows in dual-purpose herds in Veracruz, México. A cow's productivity cycle comprises sequential physiological stages of a calving interval. This study demonstrated that accounting for cyclic patterns of change in tissue reserves can help achieve productivity and profitability goals. Herd management is facilitated by accurate predictions of animal nutrient requirements, predictions of probable animal performance, interactions from mobilization and repletion of body reserves, and estimates of the required dietary supplementation to achieve objectives.

Clearly, these studies indicate that body tissue energy balance is a key factor affecting the postpartum interval to re-initiation of ovarian cyclicity. Therefore, to obtain calving intervals of desirable length effective herd management requires analysis and monitoring of the energy balance of cows and dietary supplementation to replenish catabolized reserves of body tissues (i. e., the achievement of BCS goals at key physiological stages). Therefore, well-managed schedules of tissue mobilization and repletion fluxes, including the achievement of BCS goals at each parturition, and short calving intervals are necessary conditions for improving the productivity potentials of Yucatán beef herds.

2.3 A conceptual diagram of nutritional management

Figure 2 is a conceptual diagram of nutritional management in a beef cow-calf production system. It summarizes relationships among key variables, which include animal management, animal performance, and the stock-flow dynamics of body tissue mobilization and repletion. Specific relationships among maintenance, lactation and pregnancy requirement, and nutrient balance will be presented in the materials and methods section and in the discussion of results.

Key animal management policy such as daily grazing time, physical activity, forage quantity, energy supplementation and energy from tissue mobilization are illustrated in this figure. Physical activity, such as the amount of time standing, the number of body position changes and (flat and sloped) distance walked, increases the maintenance requirement. The other key animal management policy variables also affect total nutrient supply. Interactions among these variables follow the structure described by Nicholson et al. (1994) and Reynoso-Campos et al. (2004) for evaluating nutritional strategies based on forage quality and supply, supplementation, and explicit accounting of the stock-flow dynamics of body tissue mobilization.

Figure 2 also illustrates the relationships among body tissue reserves (BCS), length of the postpartum interval to the onset of estrus (re-establishment of ovarian

Key Animal Management Policy Variables Shown in Bold

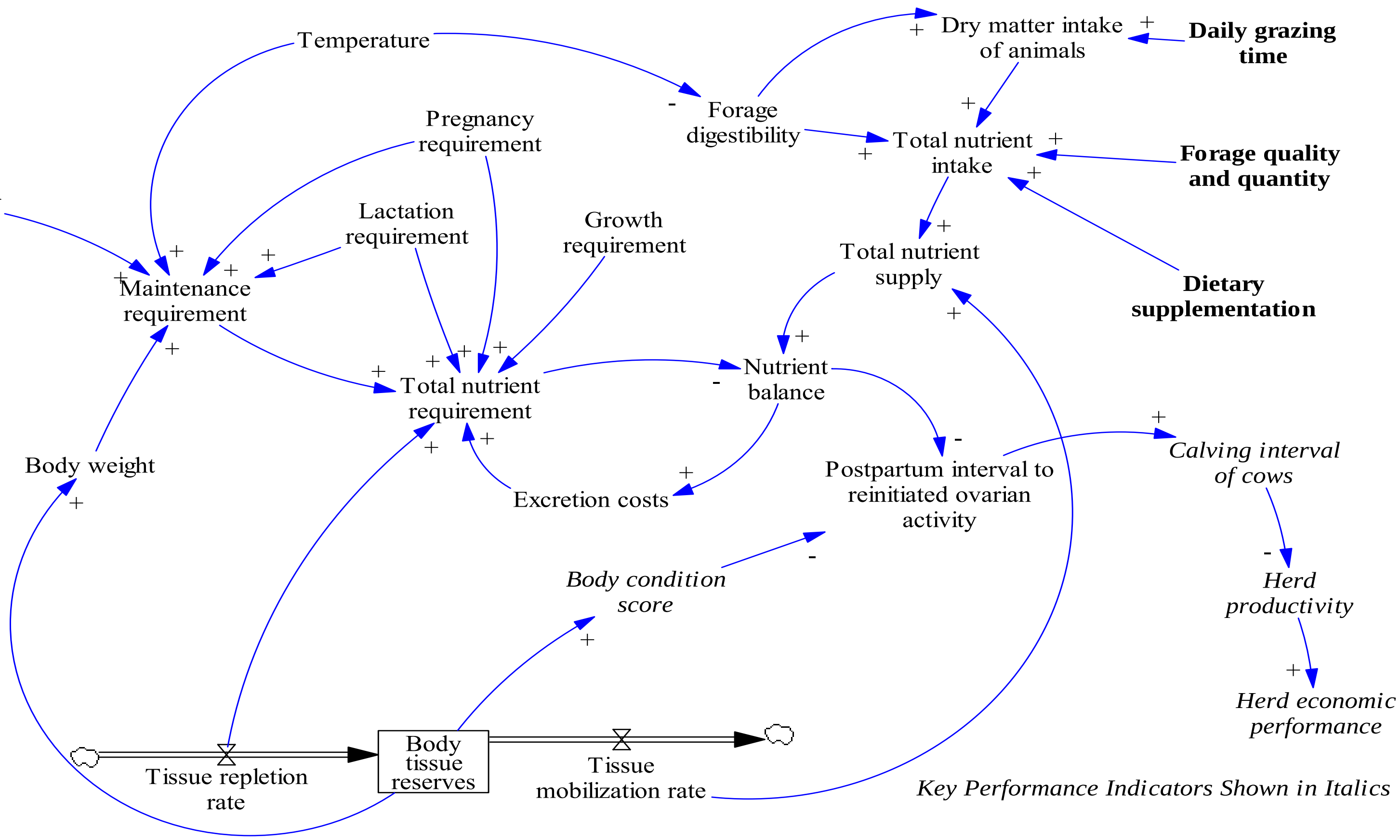

Figure 2. Conceptual representation of a beef production system and the relationships among management policy, cow performance and the stock-flow dynamics of body tissue reserves of animals.

cyclicity), and reproductive performance of beef cows and herds. A minimum, or threshold BCS is needed at calving to achieve a production goal of one calf per cow/yr (Herd et al., 1995). This conditional relationship connects the physiological status of cows to herd productivity and herd economic performance. Cows at our study site frequently have low BCS at calving, rely on body tissue reserves to produce milk for their calves and, consequently, incur prolonged calving intervals, which restrict herd productivity.

3. Objectives

Appropriate intensification of an agricultural system requires systematic determination of the probable objectives, information needs, and management actions of producers. Consequently, intensification goals for cattle systems vary with market opportunities and available inputs, including information and technology. Alternatives include high input-high output, or specialized, dairy or beef systems, dual-purpose (beef and milk) systems, extensive land use (i. e., land-plentiful) systems, and low-input systems of smallholders (Nicholson et al., 1995). The spectrum of production and market opportunities is also influenced by government policies. Alternative policy goals may include providing less expensive food to consumers with low or modest purchasing power (family incomes), generating rural employment (job creation), and spending less foreign exchange by importing less food or the agricultural inputs to produce it (Nicholson et al., 1995). Agricultural intensification in this study focuses on nutrition management so that cows in Tizimín beef herds may produce more calves per year.

The overall objectives of this study are to determine probable nutrient requirements and systematically evaluate productivity limitations and potentials in beef cattle herds with prolonged calving intervals. Specific management goals include prompt recovery from the postpartum nadir of energy balance to restore ovarian cyclicity, the subsequent achievement of conception for desired calving intervals, and assuring adequate body tissue reserves during the reproductive cycle, especially at next calving.

The first specific objective is to accurately depict current management in Tizimín cattle herds. Parameters include nutrient requirements, average productive performance and energy balance of cows, and chemical composition and predicted intake of forages and supplements utilized by herd owners. This nutrition management scenario includes a description of the interaction of mobilized and repleted body tissue reserves utilized for milk production and seasonal changes in feed composition throughout the calving intervals of cows**.** The second specific objective is to determine the weak links that constrain productivity of the current cow-calf system, and to identify strategic priority management considerations to improve herd performance.

The annual distribution of calvings by month of the year in Tizimín herds is in Figure 3 (Delgado and Magaña, 2004). Cows calve in all months of the year, which may reflect an opportunistic management scenario. Summarizing that a defined mating season is a rare practice in southeastern México, Magaña and Segura-Correa (2006) recommended that calvings be avoided during the period October through January and that weanlings and cows receive supplementation during the dry season from January through May. Further evaluation is needed to better determine the most (and least) appropriate calving seasons for Tizimín herds. Consequently, the final objective of this study is to evaluate best or worst calving seasons by their associated effects on a cow's feed energy balance profile.

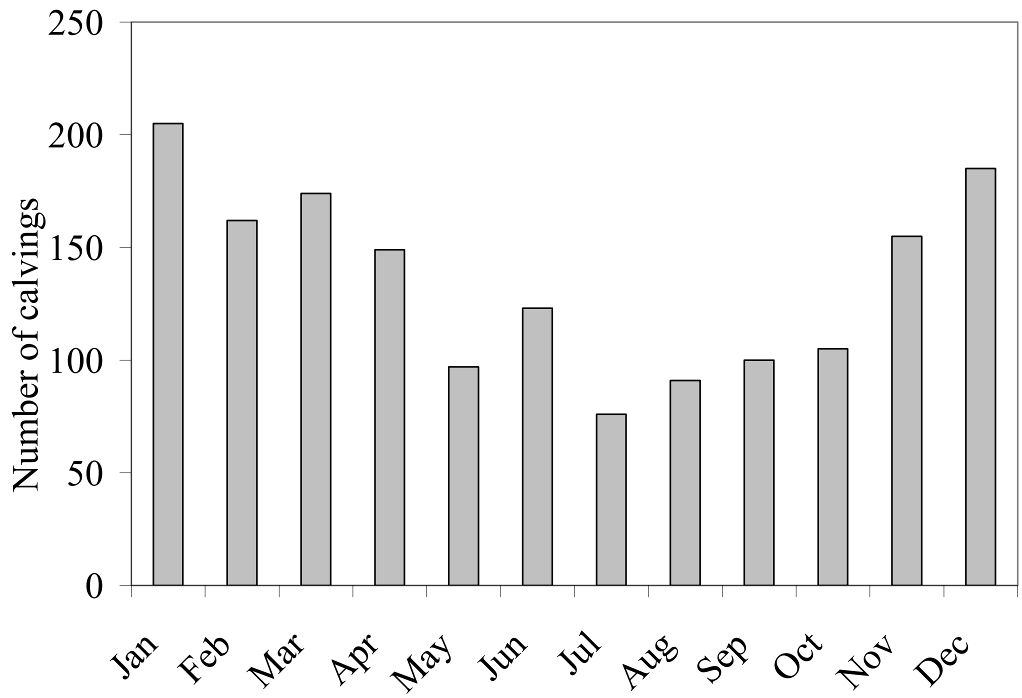

Figure 3. Monthly distribution of calvings in two Yucatán beef cattle herds from 1988 to 1993 (Delgado and Magaña, 2004).

4. Materials and methods

A farm household survey of 63 Tizimín beef cattle ranches was conducted in 2004-05 by a field research team (US-Mexico TIES Initiative, 2005). The survey data and a two-month follow-up appraisal of these herds in 2005 provided information about typical herd and dietary management, farmer objectives, nutritional constraints, and productivity potentials of these cattle systems. The information included husbandry practices, utilization of feeds and other inputs, input costs, and farmer perception of productivity constraints. Table 1 contains brief summary of herd nutrition constraints for a typical, or representative, Tizimín beef cattle herd based on this survey.

Table 1

Nutritional constraints and strategies for intensifying beef cow-calf systems in Yucatán (adopted from Reynoso-Campos et al., 2004).

Constraints	Actions to resolve the constraints	References
• There is no appropriate nutrient management plan to achieve production goals. • Little or no forage chemical composition information is available or utilized in management. • Dietary insufficiencies preclude optimum herd productivity.	• Describe animal requirements and the biological values of feeds. • Develop feeding recommendations. Formulate diets to optimize productivity. • Monitor and manage cyclic changes in energy and protein tissue reserves over the calving interval to achieve productivity and profitability goals.	Juarez et al. (1999) Tedeschi et al. (2000) Reynoso-Campos et al. (2004)
• Energy intake is the first limitation to animal productivity. • Low forage quality with high NDF and lignin constrains beef and milk production. • Chronic negative energy balance results in thin cows and long calving intervals	• Obtain better quality of forage and affordable energy supplements to increase animal production and reproductive performance. • Manage body condition throughout the CI with accounting for body tissue mobilization and repletion for the next parturition (minimum BCS:5 at calving). • Recover from the postpartum energy nadir as soon as possible with appropriate forages and dietary supplementation.	Townsend et al. (1989) Nherera (2005) Herd et al. (1995) Canfield et al. (1990) Reynoso-Campos et al. (2004)
• Supplementation cannot compensate the negative energy balance from low availability of poor quality forage, especially in early lactation and late gestation.	• Match breeding and calving seasons with forage availability and energy balance changes throughout the year to improve herd productivity.	Tedeschi et al. (2005) Magaña et al. (2006)
• Soil testing is rarely done.	• Judicious fertilizer (input) use for more intensive land use could increase herd productivity and profitability.	Rueda et al. (2003)

4.1. Definitions of management groups of cows

Logical management groups of cows for this simulation study were designated in accordance with differences in animal requirements and forage availability throughout the year. Energy requirements and feed intakes differed by body weight, physiological status (lactation or pregnancy), and growth stage (age or parity) of animals (Fox et al., 2004). Consequently, management groups were specified according to physiological status and parity of cows in a herd. Also, because forage availability differs by season of the year (Figure 1(b)), forage quality was assumed to decline progressively with the accumulation of older plant matter. The best-quality, vegetatively young forage is available at the beginning of a new rainy season while the dry season offers predominantly mature forage that is typically available for grazing in the dry season (Van Soest, 1994; Licitra et al., 1998).

Four scenarios were described for calvings occurring at the onset of each of four climatic seasons. Seasonal variations in rainfall foster differences in forage growth (Magaña et al., 2002). These forage growth seasons are shown in Figure 1(b). The season of early rains (June 1 to July 31) is when vegetatively young forage becomes available with the initiation of rains after a prolonged dry season. The supply of mature forage is high during the season of late rains (August 1 to September 30). A season of scarce rain (October 1 to January 31) marks the beginning of the dry season; when mature forage further declines in quality. The season of no rain (February 1 to May 31) corresponds to declining forage availability of poorest quality.

The CNCPS version 6.0 (Tylutki et al., 2006) was used to predict ME and MP requirements, intakes and feed energy balances for all animal groups considered. These simulations corresponded to combinations of forage seasons of calving, parity and physiological status of cows for a representative Tizimín herd (Table 2). A 14-mo calving interval was assumed for non-primiparous cows, and consistent with field observations by the panel of experts, primiparous cows were assumed to probably incur greater negative energy balance prior to conception because of greater nutrient requirements for growth and, consequently, to have a longer interval of 15 mo, based on the pattern of continuous calvings throughout the year (Figure 2) and the collective opinion of a panel of Mexican professionals [Panel members were J. Magaña, G. Ríos and A. Ayala (professors at the Universidad Autónoma de Yucatán (UADY)); F. Juárez (professor at the Universidad Veracruzana); B. Rueda and F. Duarte (researchers at the Instituto Nacional de Investigaciones Forestales, Agrícolas y Pecuarias)].

Table 2
Definitions of cow management groups by season of the year, parity and physiological stage of the calving interval.

Item	Value
Forage season of calving	
Early rains	June 1 to July 31
Late rains	August 1 to September 30
Scarce rain	October 1 to January 31
No rain	February 1 to May 31
Parity of cow	
Primiparous	1
Second-parity	2
Multiparous	>2
Physiological stage of calving interval (days in period)	
Early lactation	90
Mid-late lactation	150
Early dry	90[a]
	130[b]
	170[c]
Late dry	90

[a]Second-parity and multiparous cows in all seasons.
[b]Primiparous cows calving in early rains and late rains.
[c]Primiparous cows calving in scarce rain and no rain seasons.

Inputs for the CNCPS simulations (Table 3) were based on available information and consensus among panel members (Delgado, 2000; Delgado and Magaña, 2004; Magaña, 2000; Magaña et al., 2002, Magaña and Segura-Correa, 2006). Average daily milk production of mature cows (parity >2) in early lactation was

Table 3

Descriptions of cows in a representative herd to evaluate current nutritional status and cow performance.

Variable	Parity 1	2	>2
Body weight, kg	400	450	500[a]
Growth rate, kg/d	0.13	0.095	
Calf birth weight, kg	31.5	31.5	31.5
Calf weaning weight, kg	220[b]	220[b]	220[b]
	210[c]	210[c]	210[c]
Weaning age, d	240	240	240
Calving interval, d	460[d]	420	420
	500[e]		
Milk composition[f]			
Fat, %	4.0	4.0	4.0
True protein, %	3.3	3.3	3.3

[a]Mature weight is 500 kg at body condition score (BCS) =5.0
[b]Weaning weight at 240 d for calves born in early rains and late rains.
[c]Weaning weight at 240 d for calves born in scarce rain and no rain.
[d]Cows calving in early and late rains.
[e]Cows calving in scarce and no rain. Based on there general observation, the panel of experts suggested that the calving interval of primiparous cows would be affected by the lack of forage in the season of scarce and no rain. Therefore, it is longer than that in the season of early and late rains
[f]Based on NRC (2000).

assumed to be ≥5 kg peak daily yield, which is consistent with the milk intake required to achieve the calf weaning weights reported for a Yucatán herd (Parra-Bracamonte et al., 2005; Magaña et al., 2006) and those observed and accurately predicted by the CNCPS model (Abdelsamei et al., 2005). Average daily milk yields by parity (1, 2, >2) in early (90 d) and mid-late stages of lactation (150 d) are specified in Table 3.

4.2. Forage quality

Little forage quality information is available from Yucatán because of laboratory limitations and cost of analysis. Therefore, we framed a probable quality range throughout the year for forage chemical composition and NDF digestion rates based on available analyses of local samples at UADY, values in the CNCPS tropical feed library, the studies of Juarez et al. (1999) and Rueda et al. (2003), and the collective judgment of a panel of Mexican professionals (Table 4). Forage biological values for were primarily based on the few available analyses from Yucatán for African star grass (*Cynodon plectostachyus)* and Guinea grass (*Panicum maximum*) and information in the CNCPS version 6 feed library. The predicted ME content of forage in the no rain season based on the panel's opinion of probable chemical composition was 0.01 Mcal/ kg DM, much less than for wheat straw and that needed for animals to survive (NRC, 2000). Consequently, we assumed the scarce rain season forage composition for the no rain season also. This underscored the need for a forage composition database for cattle systems in this ecoregion.

The biological values for forage of highest quality (e.g., season of early rains) were averages of those reported in studies from the coastal plain of Veracruz, México for *C. plectostachyus*, *P. maximum* and *B. brizantha* (Juarez et al., 1999) and for *B. decumbens* and *B. brizantha* with similar composition grown in the western Brazilian Amazon (Rueda et al., 2003).

Table 4

Chemical composition and digestion rates assumed for Tizimín forages in different seasons of the year and dietary supplements.

Variable	Forage: Early rains	Forage: Late rains	Forage: Scarce and no rain	Forage: No rain	Dietary supplements[e]: Poultry manure	Dietary supplements[e]: Molasses[f]	Dietary supplements[e]: Sorghum[f]
Typical forage[a]							
CP, % of DM	9.0	8.0	7.0		15.8	4.2	10.4
Soluble CP, % of CP	28.7	35.7	28.7		53.0	98.0	14.9
NDF[b], % of DM	67.0	72.0	74.0		16.0	0.0	10.3
Lignin, % of NDF	6.0	7.0	8.0		2.3	0.0	12.8
Ash, %of DM	12.7	12.0	11.5		49.8	11.6	3.0
Ether extract, % of DM	3.0	2.6	2.2		0.5	2.2	3.6
NDF digestion rate, % /h	8.6	7.2	7.2		8.0	5.0	6.6
Sugar, % of DM	5.8	7.1	5.8		1.9	70.0	6.1
Starch, % of DM	4.2	2.1	4.2		0.0	0.0	68.6
ME, Mcal/kg of DM[c]	2.2	1.7	1.2		…	2.3	3.3
MP total supply, g/d[c]	795.0	718.0	613.0		…	…	…
High quality forage[d]							
CP, % of DM	9.0	8.0	8.0	7.0			
Soluble CP, % of CP	28.7	35.7	28.7	35.7			
NDF, % of DM	67.0	70.0	71.0	73.0			
Lignin, % of NDF	5.5	6.0	6.5	7.0			
Ash, %of DM	12.7	12.0	11.5	11.0			
Ether extract, % of DM	3.0	2.6	2.2	1.6			
NDF digestion rate , % /h	8.6	7.2	7.2	5.1			
Sugar , % of DM	5.8	7.1	5.8	7.1			
Starch , % of DM	4.2	2.1	4.2	2.1			
ME, Mcal/kg of DM	2.25	1.9	1.9	1.3			
MP total supply, g/d[c]	845.0	780.0	773.0	664.0			

Table 4 foot notes (continued)

[a] Based on analysis of (*C. plectostachyrus* and *P. maximum*) from Yucatán and the collective experience of a panel of Mexican professionals.

[b]NDF = neutral detergent fiber.

[c]MP total supply/d (rumen undegradable protein plus protein from bacteria) for multiparous cows with 500 kg of weight with *ad libitum* intake of forage

[d]Average values for *C. plectostachyus*, *P. maximum* and *B. brizantha* grown in Veracruz, México (Juarez et al., 1999) and *B. decumbens* and *B. brizantha* grown in the western Brazilian Amazon (Rueda et al., 2003).

[e]From the CNCPS feed library and Tedeschi et al. (2002).

[f]ME/kg DM of molasses and sorghum for multiparous cows with 500kg of weight consuming typical forage in the season of scarce and no rain.

[g] ME content is much less than for wheat straw and for animal homeostasis.

4.3. Feed intake assumption

Because Tizimín ranchers typically limit grazing time to a total of 10 to 14 hours per day, which precludes *ad libitum* forage intake, CNCPS simulations of typical, or baseline, herd management included a 10% depression in forage dry matter intake (DMI). Therefore, maximum daily forage DMI was set equal to 90% of the amount predicted by the CNCPS model for *ad libitum* conditions to reflect the forage intake penalty of this management practice and to evaluate the sensitivity of animal response to it. Even so, simulations with 90% *ad libitum* forage DMI especially during the end of the scarce-rain season (January) and the entire no-rain season probably overestimate actual forage nutrient intake.

Tizimín producers typically supplement forage diets with molasses and poultry manure during the periods of forage scarcity (personal communication, F. Duarte). Daily supplementation provides cows with about 2 kg of poultry manure and 1 kg of molasses (as fed basis) from January (the end of the scarce-rain season) through May (the end of the no-rain season). Therefore, the baseline representative herd management scenario was defined as forage consumed at 90% of predicted *ad libitum* DMI throughout the year with this poultry manure-plus-molasses supplementation from January to May. The feed chemical composition of poultry manure and molasses from the CNCPS feed library (Tedeschi et al., 2002) was utilized (Table 5). Detailed procedures for setting up CNCPS simulations are given in Appendix 7.1.

The allocations of forages to cows in each physiological stage of the calving interval (i.e., early and mid-late lactation, and early and late dry period) depend on the intersections with four forage growth seasons (early rains, late rains, scarce rain, or no rain) and the forage amounts that cows consumed during each stage. For example, for cows calving on June 1, the 90-d early lactation period from June 1 to August 31, involves 60 d of high quality forage consumed during the early rains, and 30 d of forage consumed during the season of late rains. Therefore, two-thirds of the forage consumed during early lactation is from the season of early rains, and one-thirds is from the late rains season, each with their respective average chemical composition.

Supplementation with poultry manure and molasses is allocated by the interaction of a cow's physiological status with the driest months of the year, which is the period of forage scarcity. Therefore, total DMI with supplementation could not always exceed 90% of predicted *ad libitum* intake.

4.4. Determination of the maintenance requirement

The CNCPS model contains a linked set of sub-models that predict nutrient requirements according to physiological function. These functions are body maintenance, growth, pregnancy, lactation and body tissue reserves (Fox et al., 2004). The maintenance requirement, which is largest among them for the conditions of this study, is determined by accounting for breed, body weight and composition, physiological status, physical activity, urea excretion, and heat stress (Fox et al., 1992: Fox and Tyltuki, 1998; Fox et al., 2004). The basal maintenance requirement of net energy in a thermal-neutral environment with minimum activity was defined for *Bos indicus* cattle (Fox et al., 1992) as NEm (Mcal/d) = mean $BW^{0.75}$ x 0.064.

The NRC (1996) indicates maintenance requirements of lactating beef cows average 20% higher than those of non-lactating cows because of greater visceral organ mass from greater nutrient intake than for non-lactating cows (Fox et al., 1992). An experiment with lambs consuming 25% less feed than their counterparts indicated organ mass shrinkage of 20 to 30% (in kidney and mesenteric tissues, but not the liver) at the sixth week accompanying a 20% loss in BW (Kabbali et al., 1992). Based on this information cows in this study were assumed to mobilize up to 25% of BW (tissue reserves) when BCS ≥5.0 at calving to support milk production. Losses of tissue reserves were restricted to 20% of BW in primiparous cows and for other cows with BCS <5.0 at calving. Consequently, maintenance requirements for cows at our study site were reduced in accordance with expected changes in organ mass and body weight from depressed dietary nutrient supplies, especially in the seasons of scarce and no rain.

Accordingly, organ mass varies with energy intake in all classes of cattle, and an animal's body condition score reflects previous energy intake at all physiological stages (NRC, 2000). The CNCPS model accounts for these relationships in any physiological stage by increasing (decreasing) the maintenance requirement 5% for each BCS unit above (below) a score of 5 (Fox et al., 2004). Finally, the energy cost of excreting excess N (urea) is accounted by subtracting it from ME intake (Fox and Tylutki, 1998).

The CNCPS model accounts for the energy cost of dissipating excess body heat (Fox et al., 2004) with the current effective temperature index (CETI) as described by Fox and Tylutki (1998). The Comisión Nacional de Agua (1960-2003) reported average monthly maximum temperature of about 35 ^{o}C with about 70% humidity. According to the CETI, the daytime climatic effect on animals at our study site is in the extreme caution range (32 to 37 ^{o}C). However, the mean minimum temperature decreases to 20 ^{o}C in the seasons of early and late rains, and to about 10 ^{o}C in the seasons of scarce rain and no rain. The night time temperature at our study site is at or below the threshold (20 ^{o}C) that allows for dissipation of body heat accumulated during the day. Furthermore, night time grazing and restricted feed intake at our study site signify less heat to dissipate compared to animals with continuous access to forage. Panting is seldom observed. Therefore, no heat stress was assumed for this study.

The CNCPS model adjusts for physical activity, which is computed from the amount of time standing, the number of body position changes, and the flat and sloped distance walked daily (Fox et al., 2004). Tedeschi et al. (2004) provided guidelines for these inputs for animals managed in different confinement and grazing conditions. These adjustments increased the maintenance requirement for energy by 9%, 16%, or 20% for *Bos indicus* cows kept in individual stalls, a small dry lot or intensive grazing, respectively. Total physical activity is reduced because cows at this study site are managed with nighttime grazing and daytime corralling without feed, each for about one-half day. Also, forage availability is especially limited when grazing in the seasons of scarce and no rain. It was observed that cows move less to seek forage when it is scarce and that they are relatively inactive when corralled, both of which would reduce the hours standing and distance walked from the guidelines provided by Tedeschi et al. (2004). For these reasons, we assumed a daily physical activity equal to the average of the allowance for stall-fed and intensive grazing conditions (i.e., 12 h standing, 6 body position changes and 500 m flat distance walked). This results in an activity-adjusted maintenance requirement that is 12% higher than the basal maintenance requirement.

4.5. Determination of milk yield, energy balance, growth, and changes in body weight and body tissue reserves

The panel of experts agreed that seasonal differences are expected in milk yield of cows with lowest yields occurring in the seasons of forage scarcity (i.e., scarce rain and no rain seasons). Information about milking performance is not available from this study site. However, Magaña and Segura-Correa (2006) reported seasonal and parity differences in calf growth rate, which is partly due to milk supplies by their dams. Therefore, the CNCPS model was used to predict probable milk production for cows calving in each season of the year from ME available for milk production.

Changes in body weight were determined first. Lacking databases of changes in BCS, it is not clear how much body tissue cows actually mobilize in Tizimín herds. Therefore, based on measurements by Neidhardt et al. (1979) cows in this study were assumed to mobilize up to 25% of BW at calving (with BCS = 5) to support milk production. Losses in tissue reserves were restricted to 20% of BW (with BCS = 5) for primiparous cows and for cows whose BCS is less than 5.0 at calving. For example, multiparous cows with BCS = 4.5 are expected to weigh 484 kg at calving on June 1 (mature BW = 500 kg with a BCS = 5). In this case, cows were allowed to mobilize 84 kg of BW in early lactation, decreasing their BW to 400 kg by the end of early lactation (i.e., by 90-d postpartum).

Expected changes in BCS were determined based on its relationships with energy content of BW gain and loss as described by Fox et al. (1999, 2004). The BCS at calving was the consensus of the panel of professionals (Appendix table 7.2). Calculations for the determination of cow energy balance, feed energy balance of cows, energy supplied from BW losses at varying BCS, and total energy associated with unit changes in BCS at varying body weights are in the following equations and summarized in Table 5 (NRC, 2000; Fox et al., 2004).

Cow energy balance = [MEI (metabolizable energy intake) + ME reserves catabolized - (maintenance + lactation + pregnancy + growth + ME tissue repletion requirements)]

Feed energy balance = (MEI - total ME requirement without contribution from tissue reserves)

NEdlw (Mcal of net energy per kg of daily live weight change) = 0.5381 x BCS + 3.2855

DLW gain, kg/d = ME balance x 0.60/NEdlw (the kg live weight gain from a positive ME balance)

ME/kg DLW loss= NEdlw/ 0.60 (the Mcal ME provided by the mobilization of body tissue)

The values in Table 5 are expected to be similar to the requirements for new tissue growth of primiparous and second parity cows (Fox et al., 1999; NRC, 2000). In addition, during tissue repletion for immature animals, body cells from previous growth are probably restored (compensatory growth). New growth is assumed to occur only if energy supply exceeds maintenance plus the tissue repletion requirement. In other words, new tissue growth occurs at BW greater the initial weight at calving.

Table 5
Energy reserves for determining the body condition scores at the beginning and end of each physiological stage of a cow's calving interval.

Calculations for BCS					
	BCS				
Item	2.0	3.0	4.0	5.0	6.0
NEdlw[a]	4.36	4.9	5.44	5.98	6.51
ME required per kg body weight gain or available from 1 kg body weight loss	7.27	8.17	9.06	9.96	10.86
Mcal NE[b]/BCS change[a]					
400 kg	112	126	144	165	193
450 kg	126	141	162	186	217
500 kg	140	157	180	207	242

[a]Net energy for daily liveweight change
[b]Net energy = ME x 0.6 (Fox et al., 2004)

The ME supply from body weight loss or gain was interpolated from the values in Table 5 (Fox et al., 1999, 2004; tables 3 to 6 in NRC [2000] for supplies and requirements for body tissue changes). Average expected daily milk production of cows in each season of calving was obtained for each parity class of cow with the CNCPS. Predicted milk yield corresponded to the point of zero cow energy balance (i.e., allowing for tissue energy to support milk production in early lactation).

The BW and BCS at calving for each forage season for all parities of cows are in Table 6. The initial BCS are assumptions by the panel of experts (Appendix Table 7.2). The BW and corresponding BCS were calculated based on BW loss and gain (NRC, 2000; Fox et al., 2004) as previously discussed. These BCS and BW values were CNCPS inputs at the beginning of the early stage of lactation (e.g., BCS at calving for multiparous cows on June 1, the season of early rains, is 4.5 with BW = 484 kg).

Table 6
Expected body weights (BW) and body condition scores (BCS) at calving of Brahman beef cows in Tizimín herds.

Calving season	(Early rains[a])		(Late rains[b])		(Scarce rain[c])		(No rain[d])	
Parity	BW[e]	BCS[f]	BW	BCS	BW	BCS	BW	BCS
1	386	4.5	400	5.0	432.0	6.0	400.0	5.0
2	434	4.5	486	6.0	486.0	6.0	450.0	5.0
>2	484	4.5	535	6.0	535.0	6.0	535.0	6.0

[a]Early rains = June 1 to July 31. [b]Late rains = August 1 to September 30. [c]Scarce rain = October 1 to January 31. [d]No rain = February 1 to May 31.
[e]Mature BW (kg) is 500 kg with a BCS 5.0. A 450 kg second parity cow and a 400 kg primiparous cow have a BCS 5.0. Maximum BW loss is 20% of calving weight for primiparous cows and for others when BCS<5.0. For parities ≥2 with BCS ≥5.0 maximum BW loss is 25% of mature weight at BCS=5.0, based on the measurements of Neidhardt et al. (1979) on Brahman beef cows.
[f]The BCS at calving were the consensus judgments of a panel of Mexican professionals. Using these reference scores other BCS were predicted based on expected BW losses and net energy obtained from tissue reserves, and expected BW gains resulting from positive energy balances allowing the recovery of body energy reserves based on NRC (2000) and Fox et al. (2004).

5. Results and discussion

5.1. Analysis of current management and productivity outcomes

Reported and discussed in this section are the nutritional and tissue reserve statuses and predicted milk production responses throughout calving intervals of cows calving in each forage season of the year and receiving baseline dietary management. First established is the general effect of reduced daily intake of forage from the practice of daytime corralling, which is illustrated for a single parity and season of calving. In reporting findings by parity and season of calving attention is devoted to the homeostatic adjustments to body maintenance requirements which enable cow-calf productivity in this nutrient-limited environment. Probable milk production by parity and season of calving is verified by the predicted weaning weights of calves using the CNCPS model based on dams' milk yield and forage consumption. These predicted values were compared to the adjusted weaning weights from a Yucatán beef herd (Magaña and Segura-Correa, 2006).

5.1.1. General effect of daytime corralling on forage intake

The typical, or baseline, nutrition management scenario in Tizimín herds involves daytime corralling, which likely severely restricts daily forage intake of cows. Because the forage intake penalty from this practice is not known accurately, we evaluated the sensitivity of nutrient-allowable milk, especially energy, to a modest arbitrary 10% decrease in forage intake compared to *ad libitum* consumption. Consequently, dietary intake of feed dry matter was established at 90% of predicted *ad libitum* intake throughout the entire year, including the season of forage scarcity when farmers supplement cows with molasses and poultry manure (from January through May). This feed intake penalty likely is a conservative one that is less than the actual deviation from *ad libitum* consumption, especially when forage growth and supplies diminish with low rainfall.

The effect of daytime corralling on ME allowable and MP allowable milk production is illustrated in Table 7 for primiparous cows calving in the season of scarce rain (October 1). About one-fourth less energy allowable milk in early lactation and one-third less milk in mid-lactation are expected because of this feed intake penalty compared to management to obtain *ad libitum* forage consumption. Reduced forage energy intake undoubtedly results in significant decreases in milking performance of dams and in growth of their calves and immature cows. Furthermore, *ad libitum* forage intake by non-lactating cows provides needed energy for repletion of body tissue reserves that are needed for the next lactation.

Table 7
Expected metabolizable energy (ME) and metabolizable protein (MP) allowable milk production[a] for primiparous[b] Brahman cows calving on October 1 (season of scarce rain) consuming forage either *ad libitum* or 90% of predicted *ad libitum* intake.

	ME allowable milk, kg/d		MP allowable milk, kg/d	
	Early[c] lactation	Mid-late[d] lactation	Early lactation	Mid-late lactation
Ad libitum intake	5.7	2.8	4.7	2.9
90% *ad libitum* intake	4.4	1.9	4.4	2.6

[a]Body weight loss was 1.24 kg/d in early lactation, and nil in mid-late lactation.
[b]The normal expected growth of 0.13 kg/d (Table 3) was ignored in this simulation.
[c]Early lactation period = days 1 to 90 postpartum.
[d]Mid-late lactation = days 91 to 240 postpartum.

5.1.2. Primiparous cows

5.1.2.1. Season of early rains

Predicted feed intakes, body weights and condition scores, animal energy requirements and dietary supplies, energy allowable milk production, and feed energy balances throughout the calving interval of primiparous cows calving in the season of highest forage quality (early rains) are summarized in Table 8. Cows of all ages calving in this season are typically thinner and, consequently, have lower maintenance requirements than at other times of the year. This results from low forage consumption during the preceding extended dry season of feed scarcity. Average expected body weight at calving was 386 kg with a BCS of 4.5.

The season of early rains supplies animals' diets with vegetatively young forage of highest quality during the year (Table 4). For this reason, daily dietary ME supply from forage is expected to be greatest during this season. A predicted forage DMI of 6.8 kg/d was expected to supply about 14.0 Mcal ME/d, or 82%, of the energy required for the predicted average daily milk production during early lactation (energy allowable milk yield = 6.3 kg/d, ignoring growth requirement). The balance of the average amount of required energy for milk production during this 60-day period, 3 Mcal ME/d, was provided by catabolized body tissue reserves—the accompanying negative feed energy balance. Consequently, cows in first lactation were predicted to mobilize 66 kg of body tissues to support milk production and to conclude the early lactation stage with a lighter body weight of 320 kg and BCS ~2.5. Assuming that there is a higher physiological priority for lactation than for body growth, it seems unlikely that nutrients either from the diet or catabolism would be allocated to support growth. If this assumption is false, then the expected energy allowable milk production after satisfying the energy requirement for growth would be 20% less,

Table 8
Expected body weights, body condition scores, metabolizable (ME) energy allowable milk production, energy requirements and supplies, and feed energy balances throughout the calving interval for primiparous cows calving in the season of early rains (June 1) under baseline nutrition management.

	Lactation		Dry period	
Item	Early	Late	Early	Late
Forage season	Early rains	Scarce rain	No rain[a]	Early rains
Forage DMI, kg/d	6.8	5.9	3.6	6.9
Forage ME intake, Mcal/d	14.0	10.9	5.8	14.3
Total DMI[b], kg/d	6.8	6.4	5.9	6.9
Total dietary energy, Mcal ME/d	14.0	12.0	10.3	14.3
Total ME supply[c], Mcal/d	17.0	12.0	10.3	14.3
Initial BW[d], kg	386.0	320.0	320.0	328.0
Mean BW, kg	353.0	320.0	324.0	335.0
End BW, kg	320.0	320.0	328.0	342.0
Initial BCS[e]	4.5	2.5	2.5	2.5
End BCS	2.5	2.5	2.5	3.5
Total energy requirement[f], Mcal ME/d	17.0	12.0	10.3	14.3
Maintenance requirement[g] Mcal ME/d	9.8	8.8	9.5	8.8
Energy allowable milk yield Without growth requirement, kg/d	6.3	2.8	…	…
Energy allowable milk yield With growth requirement, kg/d	5.0	1.3	…	…
Feed energy balance[h], Mcal ME/d	-3.0	0.0	0.5	1.2

[a]Forage quality from the season of scarce rain was used for cows in the season of no rain.
[b]Forage diets supplemented with 2 kg of poultry manure and 1 kg of molasses from January to May.
[c] Total ME supply = dietary ME plus ME from body tissue reserves.
[d]Maximum body weight loss for primiparous cows was 20% of BW with a BCS <5.
[e]BCS at calving was the consensus judgment of a professional panel. Other BCS were predicted from assumed BW changes based on NRC (2000) and Fox et al. (2004).
[f] Total ME requirement includes ME allowable milk for lactating cows. During the dry period, it also includes the ME required for growth in first and second parity cows and for reserves replenishment. A positive energy balance was used to determine the ME allowable BW gain.
[g] Total maintenance requirement was based on a basal maintenance requirement of mean $BW^{0.75}*0.064$. Mcal NEm (NRC, 2000; Fox et al., 2004). Basal maintenance is adjusted for the effect of plane of nutrition as indicated by changes in BW and BCS. The activity requirement increased the basal maintenance requirement by 12%.
[h]Feed energy balance = total energy supply minus total energy requirements (excludes changes in body tissue reserves).

or 5 kg/d. Therefore, the expected average milk production in early lactation probably ranges from 5.0 to 6.3 kg/d.

In the mid-late stage of lactation lighter cows with a 10% lower average maintenance requirement consume forage principally from the season of scarce rain supplemented in the dry months by poultry manure (2 kg/d) and molasses (1 kg/d). This forage is less digestible than pasture supplies during early rains (Table 4), which results in about a 15% lower daily supply of dietary ME compared to early lactation (12.0 *vs.* 14.0 Mcal ME/d). Corresponding energy allowable milk production is about 2.8 kg/d (1.3 kg/d if growth is assumed) with no dietary energy available for tissue repletion or growth (feed energy balance = 0).

Dietary energy during the cow's early dry (non-lactating) period is from forage of lowest quality with poultry manure and molasses supplementation to compensate for the scarce forage supply during the dry months (January through May). The modest predicted feed energy balance, 0.5 Mcal ME/d, is insufficient to significantly replete tissue reserves. Nor is there sufficient energy to support growth. Hence, little or no growth occurs and these immature cows remain thin throughout the early dry period (with BCS ~2.5). If DMI is less than the assumed 90% of predicted *ad libitum* consumption, which is likely, then this scenario over-represents cow nutritional status under forage scarcity.

Late gestation for these cows coincides with a returned supply of high quality forage when plant growth is re-initiated during the subsequent season of early rains. Consequently, the increased total energy requirement in this stage of rapid fetal growth (requiring 4.3 Mcal ME/d; Fox et al., 2004) is exceeded by 1.2 Mcal ME/d (i.e., positive feed energy balance), which permits repletion of one-fifth of catabolized tissue reserves. Nonetheless, in the absence of an extended calving interval to replenish tissue energy stores, cows are predicted to be lighter and thinner at their second calving (approximate BW = 342 kg and BCS = 3.5) than they were at first calving. This portends delayed growth, less tissue available to support milk production and delayed postpartum interval to re-initiation of ovarian cyclicity in the next lactation.

5.1.2.2. Season of late rains

Table 9 summarizes predicted feed intake, body weight and condition scores, animal energy requirements and dietary supplies, energy allowable milk production, and feed energy balances throughout the calving interval of primiparous cows calving in the season of late rains (August 1). Cows calving in this season, having consumed forage of high quality during early rains, initiate lactation with greater tissue reserves than those calving in the previous forage season (BCS = 5.0 vs. 4.5). Consequently, average expected body weight at calving was 400 kg.

The season of late rains supplies animals' diets with mature forage of moderate quality (Table 4), which is expected to supply less ME than in the season of early rains. A predicted forage DMI of 6.6 kg/d was expected to supply about 12.6 Mcal ME/d, or 77%, of the energy required for the predicted average daily milk yield during early lactation (energy allowable milk yield = 4.9 kg/d, ignoring growth requirement). The balance of the average amount of required energy for milk production during this 90-day period, 3.7 Mcal ME/d, was provided by catabolism of body tissue reserves—the corresponding negative feed energy balance. Consequently, cows in first lactation were predicted to mobilize 80 kg of body tissues to support milk synthesis with one-third of the total energy required. These animals conclude the stage of early lactation in thin body condition (BCS ~2.5) with a lighter body weight of 320 kg. As previously assumed, it seems unlikely that nutrients either from the diet or catabolism

Table 9
Expected body weights, body condition scores, metabolizable energy (ME) allowable milk production, energy requirements and supplies, and feed energy balances throughout the calving interval for primiparous cows calving in the season of late rains (August 1) under baseline nutrition management.

	Lactation		Dry period	
Item	Early	Late	Early	Late
Forage season	Late rains	Scarce rain	Early rains	Late rains
Forage DMI, kg/d	6.6	5.1	7.2	8.3
Forage ME intake, Mcal/d	12.6	9.3	14.3	16.2
Total DMI[b], kg/d	6.6	6.6	8.4	8.3
Total dietary energy, Mcal ME/d	12.6	12.3	16.4	16.2
Total ME supply[c], Mcal/d	16.3	12.3	16.4	18.0
Initial BW[d], kg	400.0	320.0	320.0	450.0
Mean BW, kg	369.0	320.0	385.0	435.0
End BW, kg	320.0	320.0	450.0	419.0
Initial BCS[e]	5.0	2.5	2.5	4.5
End BCS	2.5	2.5	4.5	4.0
Total energy requirement[f], Mcal ME/d	16.3	12.3	16.4	18.0
Maintenance requirement[g], Mcal ME/d	10.7	8.8	10.0	13.7
Energy allowable milk yield, kg/d without growth requirement	4.9	3.1	…	…
Energy allowable milk yield , kg/d with growth requirement	3.3	1.5	…	…
Feed energy balance[h], Mcal ME/d	-3.7	0.0	5.9	-1.9

[a]Forage quality from the season of scarce rain was used for cows in the season of no rain.
[b]Forage diets supplemented with 2 kg of poultry manure and 1 kg of molasses from January to May.
[c] Total ME supply = dietary ME plus ME from body tissue reserves.
[d]Maximum body weight loss for primiparous cows was 20% of BW with a BCS <5.
[e]BCS at calving was the consensus judgment of a professional panel. Other BCS were predicted from assumed BW changes based on NRC (2000) and Fox et al. (2004).
[f] Total ME requirement includes ME allowable milk for lactating cows. During the dry period, it also includes the ME required for growth in first and second parity cows and for reserves replenishment. A positive energy balance was used to determine the ME allowable BW gain.
[g] Total maintenance requirement was based on a basal maintenance requirement of mean $BW^{0.75}*0.064$. Mcal NEm (NRC, 2000; Fox et al., 2004). Basal maintenance is adjusted for the effect of plane of nutrition as indicated by changes in BW and BCS. The activity requirement increased the basal maintenance requirement by 12%.
[h]Feed energy balance = total energy supply minus total energy requirements (excludes changes in body tissue reserves).

of adipose tissue would be allocated to support growth of these cows during early lactation. If this assumption is false, then the expected energy allowable milk production after satisfying the energy requirement for growth would be approximately one-third less, or 3.3 kg/d. Therefore, the expected average milk production in early lactation probably ranges from 3.3 to 4.9 kg/d.

In mid-late lactation lighter cows have an 18% lower average maintenance requirement and consume low-quality forage (Table 4) principally from the season of scarce rain supplemented in the dry months by poultry manure and molasses. The combined effects of less digestible forage and less forage DMI result in about one-fourth less daily ME consumption than during early lactation (9.3 *vs*. 12.6 Mcal ME/d). Corresponding energy allowable milk production is about 3.1 kg/d (1.5 kg/d if growth is assumed) with no dietary energy available for tissue repletion or growth (feed energy balance = 0).

The daily supply of dietary energy during the early dry (non-lactating) period is from high intake of high-quality forage in the season of early rains. Consequently, the predicted positive feed energy balance, 5.9 Mcal ME/d, is sufficient not only to fully replete tissue reserves but also to support growth. Average daily gain in body weight is 1 kg during this stage of the calving interval with an ending body weight of 450 kg.

The period of late gestation for these cows coincides with supplies of modest-quality forage in the season of late rains. The resultant dietary energy supply is insufficient to maintain body weight and to satisfy the increased fetal growth requirement. Consequently, cows are expected to catabolize about 1.9 Mcal ME/d to provide energy to the fetus, which likely arrests the cow's own growth. After repleting reserves with body weight gained (i. e., growth) during the early dry period, cows would initiate next lactation lighter and thinner than in the previous stage of the calving interval (predicted BW = 419 kg with BCS ~4.0). This decreased BCS, much less than the minimum target BCS of 5.0 (Herd et al., 1995), signifies less milk production and delayed reinitiation of ovarian cyclicity in the next lactation.

5.1.2.3. Season of scarce rain

Table 10 follows the previously established format to report expected nutritional and animal statuses and milking performance of primiparous cows throughout calving intervals initiated in the season of scarce rain (October 1). Cows of all ages calving in this season were assumed to initiate lactation in excellent body condition (BCS = 6, BW = 432 kg) after consuming abundant supplies of forage of highest quality during the seasons of early and late rains.

However, these desirable reserves of tissue energy are mismatched by a forage supply of low and declining digestibility in the season of scarce rain. The predicted forage DMI (6.4 kg/d) was expected to supply 11.7 Mcal ME/d, or two-thirds, of the energy required for the average daily milk yield predicted during early lactation (energy allowable milk yield = 4.4 kg/d, ignoring growth requirement). The remainder of the average amount of energy required for milk production during this 90-day period, 5.3 Mcal ME/d, was provided from catabolized body tissue reserves—the negative feed energy balance. Consequently, these immature cows were predicted to mobilize 112 kg of body tissues to support milk production and to conclude the early stage of lactation in thin body condition (BCS ~2.0) weighing about 320 kg. Under these conditions it seems unlikely that much tissue accretion, if any, could occur. If normal growth were to occur, the predicted energy allowable milk production would be 40% less, or 2.7 kg/d. Therefore, the expected average milk production in early lactation probably ranges from 2.7 to 4.4 kg/d.

Table 10
Expected body weights, body condition scores, metabolizable energy (ME) allowable milk production, energy requirements and supplies, and feed energy balances throughout the calving interval for primiparous cows calving in the season of scarce rain (October 1) under baseline nutrition management.

	Lactation		Dry period	
Item	Early	Late	Early	Late
Forage season	Scarce rain	No rain[a]	Late rains	Scarce rain
Forage DMI, kg/d	6.4	3.4	7.3	6.5
Forage ME intake, Mcal/d	11.7	6.3	14.4	12.7
Total DMI[b], kg/d	6.4	5.9	7.3	7.8
Total dietary energy, Mcal ME/d	11.7	11.0	14.4	15.2
Total ME supply[c], Mcal/d	17.0	11.0	14.4	16.8
Initial BW[d], kg	432.0	320.0	320.0	408.0
Mean BW, kg	376.0	320.0	364.0	400.0
End BW, kg	320.0	320.0	408.0	392.0
Initial BCS[e]	6.0	2.0	2.0	5.0
End BCS	2.0	2.0	4.5	4.0
Total energy requirement[f], Mcal ME/d	17.0	11.0	14.4	16.8
Maintenance requirement[g], Mcal ME/d	12.0	8.8	9.4	12.5
Energy allowable milk yield, kg/d Without growth requirement	4.4	1.9	…	…
Energy allowable milk yield, kg/d with growth requirement	2.7	0.3	…	…
Feed energy balance[h], Mcal ME/d	-5.3	0.0	4.6	-1.6

[a]Forage quality from the season of scarce rain was used for cows in the season of no rain.
[b]Forage diets supplemented with 2 kg of poultry manure and 1 kg of molasses from January to May.
[c] Total ME supply = dietary ME plus ME from body tissue reserves.
[d]Maximum body weight loss for primiparous cows was 20% of BW with a BCS <5; and 25% otherwise.
[e]BCS at calving was the consensus judgment of a professional panel. Other BCS were predicted from assumed BW changes based on NRC (2000) and Fox et al. (2004).
[f] Total ME requirement includes ME allowable milk for lactating cows. During the dry period, it also includes the ME required for growth in first and second parity cows and for reserves replenishment. A positive energy balance was used to determine the ME allowable BW gain.
[g] Total maintenance requirement was based on a basal maintenance requirement of mean $BW^{0.75}$*0.064. Mcal NEm (NRC, 2000; Fox et al., 2004). Basal maintenance is adjusted for the effect of plane of nutrition as indicated by changes in BW and BCS. The activity requirement increased the basal maintenance requirement by 12%.
[h]Feed energy balance = total energy supply minus total energy requirements (excludes changes in body tissue reserves).

In mid-late lactation much lighter cows incurring a 30% lower average maintenance requirement would be consuming forage primarily from the no rain season of greatest feed scarcity. Producers typically supplement cows with poultry manure and molasses during these months of scarce pasture supply of lowest digestibility. Despite this supplementation, the energy allowable milk production is low, about 1.9 kg /d (0.3 kg/d if growth is assumed), and without dietary energy for tissue repletion, growth, or support of persistent lactation.

Dietary energy during the cow's 170-d early dry period is from best-quality forages grown in the seasons of early and late rains. These forages permit greater DM consumption and a positive feed energy balance, 4.6 Mcal ME/d. Consequently, a portion of previously mobilized tissues are repleted during this period, which results in a still-low BCS of 4.5 from an 88 kg gain in body weight (BW = 408 kg), and which could permit some accretion of new body tissue.

Late gestation for these cows is mismatched with forage of rapidly declining digestibility from the season of scarce rain. As a result, total energy requirements are unmet and cows are forced to mobilize body tissues, about 1.6 Mcal ME/d, to support rapid fetal growth. Again, in the absence of a prolonged dry period (i. e., calving interval) this situation leads to thin cows at second calving, weighing less than 400 kg with BCS ~4.0.

5.1.2.4. Season of no rain

Table 11 provides expected nutritional and animal statuses and milking performance throughout calving intervals for cows calving in the season of no rain (February 1) when forage quality and supply are lowest. Primiparous cows calving in this season initiate lactation in good body condition (BCS = 5) weighing about 400 kg.

Table 11

Expected body weights, body condition scores, metabolizable energy (ME) allowable milk production, energy requirements and supplies, and feed energy balances throughout the calving interval for primiparous cows calving in the season of no rain (February 1) under baseline nutrition management.

	Lactation		Dry period	
Item	Early	Late	Early	Late
Forage season	No rain[a]	Early rains	Scarce rain	No rain
Forage DMI, kg/d	3.9	5.7	6.1	6.44
Forage ME intake, Mcal/d	7.2	11.3	11.2	12.9
Total DMI[b], kg/d	6.5	6.2	7.5	8.5
Total dietary energy, Mcal ME/d	12.0	12.3	14.0	16.8
Total ME supply[c], Mcal/d	15.7	12.3	14.0	16.8
Initial BW[d], kg	400.0	320.0	320.0	450.0
Mean BW, kg	360.0	320.0	385.0	450.0
End BW, kg	320.0	320.0	450.0	450.0
Initial BCS[e]	5.0	2.5	2.5	5.0
End BCS	2.5	2.5	5.0	5.0
Total energy requirement[f], Mcal ME/d	15.7	12.3	14.0	16.8
Maintenance requirement[g], Mcal ME/d	11.1	7.9	10.1	12.5
Energy allowable milkyield, kg/d Without growth requirement	4.1	3.8	…	…
Energy allowable milk yield , kg/d with growth requirement	2.3	2.6	…	…
Feed energy balance[h], Mcal ME/d	-3.7	0.0	3.6	0.0

[a]Forage quality from the season of scarce rain was used for cows in the season of no rain.
[b]Forage diets supplemented with 2 kg of poultry manure and 1 kg of molasses from January to May.
[c] Total ME supply = dietary ME plus ME from body tissue reserves.
[d]Maximum body weight loss for primiparous cows was 20% of BW with a BCS <5; and 25% otherwise.
[e]BCS at calving was the consensus judgment of a professional panel. Other BCS were predicted from assumed BW changes based on NRC (2000) and Fox et al. (2004).
[f] Total ME requirement includes ME allowable milk for lactating cows. During the dry period, it also includes the ME required for growth in first and second parity cows and for reserves replenishment. A positive energy balance was used to determine the ME allowable BW gain.
[g] Total maintenance requirement was based on a basal maintenance requirement of mean $BW^{0.75}$*0.064. Mcal NEm (NRC, 2000; Fox et al., 2004). Basal maintenance is adjusted for the effect of plane of nutrition as indicated by changes in BW and BCS. The activity requirement increased the basal maintenance requirement by 12%.
[h]Feed energy balance = total energy supply minus total energy requirements (excludes changes in body tissue reserves).

The expected forage DMI (3.9 kg/d) was expected to supply about 7.2 Mcal ME/d, or 46%, of the total energy required for the predicted average daily milk yield during early lactation (energy allowable milk yield = 4.1 kg/d, ignoring growth requirement). The supplements supplied about 4.8 Mcal/d, or 30%, of the energy required for this milk production. If DMI in this season is less than the assumed 90% of predicted *ad libitum* consumption, which is likely, then the scenario reported here over-represents energy intake and cow nutritional status.

The remaining amount of energy required for milk synthesis during this 90-day period, 3.7 Mcal ME/d, was provided by catabolized body tissues (negative feed energy balance). Consequently, first-lactation cows calving in this season were expected to mobilize about 80 kg of body tissue reserves to support milk production with about one-fourth of the total energy required. These cows were predicted to conclude the early stage of lactation weighing about 320 kg with BCS = 2.5. Growth during this stage is unlikely. If nutrients were partitioned to support growth then expected milk production would be approximately 55% less, or 2.3 kg/d.

In mid-late lactation these cows, which have a 30% smaller average maintenance requirement, would encounter young forage of highest quality during the year. The result is about 55% greater daily dietary ME from forage compared to early lactation (11.3 *vs* 7.2 Mcal ME/d). Consequently, energy allowable milk production is about 3.8 kg/d (2.6 kg/d if growth is assumed), which is the highest mid-lactation milk yield predicted among calving seasons but without sufficient energy also for tissue repletion or growth (feed energy balance = 0).

Dietary energy during the cow's early dry period coincides with the season of scarce rain and supplementation with poultry manure and molasses. Assuming that the predicted DMI is realized, the resulting feed energy balance, 3.6 Mcal ME/d, would be sufficient to significantly replete tissue reserves and to support new tissue growth, achieving average body weight of 450 kg with BCS ~5.0.

Late gestation for these cows coincides with the depressed supply and quality of forage in the subsequent no rain season. Even with supplementation and, more importantly, if predicted DMI is achieved—a doubtful outcome—total dietary energy is just enough to meet fetal growth requirements and to maintain body weight. This is the only case where, if all conditions are satisfied, cows could initiate second lactation with a condition score of at least 5.0.

5.1.3. Second-parity cows

5.1.3.1. Season of early rains

Table 12 summarizes expected nutritional and animal statuses and milking performance throughout calving intervals for second-parity cows calving in the season of early rains. As for primiparous cows, the initial BCS of 4.5 (BW = 434 kg) at calving results from consumption of forage of low quality during the preceding extended season of feed scarcity.

The predicted forage energy intake was about 15.3 Mcal ME/d, or 80%, of the energy required for milk production during early lactation (energy allowable milk yield = 7.2 kg/d, ignoring growth requirement). This milk yield is nearly 1 kg/d more than for primiparous cows in early lactation and calving in this season. The remainder of required energy for milk production in this stage of lactation, 3.7 Mcal ME/d, was obtained from body tissue reserves. Consequently, cows in second lactation were expected to mobilize 74 kg of body tissues to support milk production and to conclude their early lactation in thin body condition (BCS ~2.0) weighing about 360 kg. Assuming higher physiological priority for lactation than for body growth, it seems unlikely that nutrients from either the diet or catabolism would be allocated to

Table 12
Expected body weights, body condition scores, metabolizable energy (ME) allowable milk production, energy requirements and supplies, and feed energy balances throughout the calving interval for second-parity cows calving in the season of early rains (June 1) under baseline nutrition management.

Item	Lactation		Dry period	
	Early	Late	Early	Late
Forage season	Early rains	Scarce rain	No rain[a]	Early rains
Forage DMI, kg/d	7.4	6.5	4.8	6.8
Forage ME intake, Mcal/d	15.3	11.9	8.8	13.2
Total DMI[b], kg/d	7.4	7.0	7.3	7.6
Total dietary energy, Mcal ME/d	15.3	13.0	13.5	14.7
Total ME supply[c], Mcal/d	19.0	13.0	13.5	14.9
Initial BW[d], kg	434.0	360.0	360.0	390.0
Mean BW, kg	397.0	360.0	375.0	389.0
End BW, kg	360.0	360.0	390.0	388.0
Initial BCS[e]	4.5	2.0	2.0	3.5
End BCS	2.0	2.0	3.5	3.5
Total energy requirement[f], Mcal ME/d	19.0	13.0	13.5	14.9
Maintenance requirement[g], Mcal ME/d	10.8	9.5	10.0	10.6
Energy allowable milk yield, kg/d Without growth requirement, kg/d	7.2	3.0	…	…
Energy allowable milk yield with growth requirement, kg/d	6.2	1.8	…	…
Feed energy balance[h], Mcal ME/d	-3.7	0.0	2.7	-0.2

[a]Forage quality from the season of scarce rain was used for cows in the season of no rain.
[b]Forage diets supplemented with 2 kg of poultry manure and 1 kg of molasses from January to May.
[c] Total ME supply = dietary ME plus ME from body tissue reserves.
[d]Maximum body weight loss for second parity cows is 20% of BW with a BCS <5 and 25% of BW with BCS ≥5.0.
[e]BCS at calving was the consensus judgment of a professional panel. Other BCS were predicted from assumed BW changes based on NRC (2000) and Fox et al. (2004).
[f] Total ME requirement includes ME allowable milk for lactating cows. During the dry period, it also includes the ME required for growth in first and second parity cows and for reserves replenishment. A positive energy balance was used to determine the ME allowable BW gain.
[g] Total maintenance requirement was based on a basal maintenance requirement of mean $BW^{0.75}$*0.064. Mcal NEm (NRC, 2000; Fox et al., 2004). Basal maintenance is adjusted for the effect of plane of nutrition as indicated by changes in BW and BCS. The activity requirement increased the basal maintenance requirement by 12%.
[h]Feed energy balance = total energy supply minus total energy requirements (excludes changes in body tissue reserves).

growth. If this assumption is false, the expected energy allowable milk production would be approximately 14% less, or 6.2 kg/d. Therefore, the expected average milk production in early lactation of second-parity cows probably ranges from 6.2 to 7.2 kg/d.

In mid-lactation these thin cows consume forage that is less digestible than pasture supplies during early rains, which results in about a one-fourth decrease in the daily supply of forage ME compared to early lactation (11.9 *vs* 15.3 Mcal ME/d). Corresponding energy allowable milk production is about 3.0 kg/d (1.8 kg/d if growth is assumed) without sufficient energy for tissue repletion, growth or persistent lactation. The dietary supply of energy during a cow's 90-d early dry period is from forage of lowest quality supplemented with poultry manure and molasses. The modest predicted feed energy balance, 2.7 Mcal ME/d, is insufficient to replete more than 40% of the tissue reserves that were mobilized for milk synthesis. Neither is there sufficient energy to support growth. Hence, growth is restricted and these immature cows remain thin throughout the early dry period (with BCS ~3.5). If DMI is less than the assumed 90% of predicted *ad libitum* consumption, which is likely, then this scenario over-represents cow nutritional status with forage scarcity.

Late gestation for these cows coincides with a renewed supply of high quality forage when plant growth is re-initiated by onset of the next season of early rains. However, the increased total energy requirement in this stage of rapid fetal growth is unmet (negative feed energy balance = -0.2 Mcal ME/d), and cows may need to supplement the fetus with energy from catabolized tissue. Consequently, cows are too thin for next lactation with approximate body weight of 388 kg with BCS ~3.5, lighter and thinner than they were at first calving. This scenario portends delayed growth, less tissue available to support milk production, and delayed postpartum interval to re-initiation of ovarian cyclicity in the next lactation.

5.1.3.2. Season of late rains

Table 13 summarizes expected nutritional and animal statuses and milking performance throughout calving intervals for second-parity cows calving in the season of late rains. According to the panel of professionals, cows calving in this season are considered to be in good body condition. The assumed average expected body weight at calving was about 486 kg with a BCS of 6.0.

The daily dietary supply of ME from forage was about 14.3 Mcal ME/d, or 70%, of the energy required for the predicted average daily milk yield during early lactation (energy allowable milk yield = 6.6 kg/d, ignoring growth requirement). The remaining amount of energy required for milk production, 6.2 Mcal ME/d, was obtained from body tissue reserves. Consequently, cows in second lactation were expected to mobilize 112 kg of body tissues to support milk production, and to conclude the early stage of lactation in thin body condition (BCS = 2.0) weighting 374 kg. Again, it is unlikely that nutrients from either the diet or catabolism would be allocated to growth of these cows. If normal growth were to occur, predicted energy allowable milk production would be approximately 20% less, or 5.3 kg/d. Therefore, the expected average milk production in early lactation probably ranges from 5.3 to 6.6 kg/d.

In mid-lactation thin cows incurring a 25% lower average maintenance requirement would be consuming forage principally from the season of scarce rain supplemented in the dry months by poultry manure and molasses. Corresponding energy allowable milk production is about 3.4 kg/d (2.2 kg/d if growth is assumed) without sufficient dietary energy for tissue repletion or growth.

Table 13
Expected body weights, body condition scores, metabolizable energy (ME) allowable milk production, energy requirements and supplies, and feed energy balances throughout the calving interval for second parity cows calving in the season of late rains (August 1) under baseline nutrition management.

	Lactation		Dry period	
Item	Early	Late	Early	Late
Forage season	Late rains	Scarce rain	No rain[a]	Late rains
Forage DMI, kg/d	7.5	5.9	5.6	7.8
Forage ME intake, Mcal/d	14.3	10.8	9.8	15.6
Total DMI[b], kg/d	7.5	7.4	7.2	7.8
Total dietary energy, Mcal ME/d	14.3	13.8	13.0	15.6
Total ME supply[c], Mcal/d	20.5	13.8	13.0	15.6
Initial BW[d], kg	486.0	374.0	374.0	393.0
Mean BW, kg	430.0	374.0	383.5	397.5
End BW, kg	374.0	374.0	393.0	402.0
Initial BCS[e]	6.0	2.0	2.0	3.5
End BCS	2.0	2.0	3.5	4.0
Total energy requirement[f], Mcal ME/d	20.5	13.8	13.0	15.6
Maintenance requirement[g], Mcal ME/d	12.9	9.9	10.4	10.5
Energy allowable milk yield, Without growth requirement, kg/d	6.6	3.4	…	…
Energy allowable milk yield with growth requirement, kg/d	5.3	2.2	…	…
Feed energy balance[h], Mcal ME/d	-6.2	0.0	1.8	0.9

[a]Forage quality from the season of scarce rain was used for cows in the season of no rain.
[b]Forage diets supplemented with 2 kg of poultry manure and 1 kg of molasses from January to May.
[c] Total ME supply = dietary ME plus ME from body tissue reserves.
[d]Maximum body weight loss for second parity cows is 25% of BW with BCS ≥5.0.
[e]BCS at calving was the consensus judgment of a professional panel. Other BCS were predicted from assumed BW changes based on NRC (2000) and Fox et al. (2004).
[f] Total ME requirement includes ME allowable milk for lactating cows. During the dry period, it also includes the ME required for growth in first and second parity cows and for reserves replenishment. A positive energy balance was used to determine the ME allowable BW gain.
[g] Total maintenance requirement was based on a basal maintenance requirement of mean $BW^{0.75}*0.064$. Mcal NEm (NRC, 2000; Fox et al., 2004). Basal maintenance is adjusted for the effect of plane of nutrition as indicated by changes in BW and BCS. The activity requirement increased the basal maintenance requirement by 12%.[h]Feed energy balance = total energy supply minus total energy requirements (excludes changes in body tissue reserves).

Dietary energy during the cow's early dry period, yielding a modest predicted feed energy balance of 1.8 Mcal ME/d, is insufficient to significantly replete tissue reserves. Neither is there sufficient energy to support growth. Hence, growth is restricted and these immature cows remain thin throughout the early dry period. If DMI is less than the assumed 90% of predicted *ad libitum* consumption, which is likely, then this scenario over-represents cow nutritional status under forage scarcity.

In late gestation the total energy requirement is slightly exceeded by about 0.9 Mcal ME/d, which permits repletion of a small quantity of body weight. Cows are predicted to be lighter and thinner at their second calving (approximate BW = 402 kg and BCS ~4.0) than they were at first calving. This again signifies delayed growth, less tissue available to support milk production, and delayed postpartum interval to reinitiation of ovarian cyclicity in the next lactation.

5.1.3.3. Season of scarce rain

Table 14 summarizes expected nutritional and animal statuses and milking performance throughout calving intervals for second-parity cows calving in the season of scarce rain. Average expected body weight at calving was 486 kg with BCS = 6.0.

The predicted forage DMI was expected to supply 12.8 Mcal ME/d, or two-thirds, of the energy required for the predicted average daily milk yield in early lactation of 4.9 kg/d (ignoring growth requirement). The remaining energy required for milk synthesis, 7.8 Mcal ME/d, was obtained from body tissues. Consequently, cows in second lactation were expected to mobilize about 112 kg of body tissues to support milk production, which provides 40% of the total energy requirement. These cows conclude the early stage of lactation in thin body condition (BCS ~2.0) weighing 320 kg. It is unlikely that nutrients from either the diet or catabolism would be allocated to growth. If normal growth were permissible, the expected milk production

Table 14
Expected body weights, body condition scores, metabolizable energy (ME) allowable milk production, energy requirements and supplies, and feed energy balances throughout the calving interval for second parity cows calving in the season of scarce rain (October 1) under baseline nutrition management.

	Lactation		Dry period	
Item	Early	Late	Early	Late
Forage season	Scarce rain	No rain[a]	Early rains	Scarce rain
Forage DMI, kg/d	7.1	4.2	8.0	8.0
Forage ME intake, Mcal/d	12.8	7.7	16.4	14.9
Total DMI[b], kg/d	7.1	6.7	8.0	8.0
Total dietary energy, Mcal ME/d	12.8	12.4	16.4	14.9
Total ME supply[c], Mcal/d	19.0	12.4	16.4	16.9
Initial BW[d], kg	486.0	374.0	374	431
Mean BW, kg	430.0	374.0	403.0	422
End BW, kg	374.0	374.0	431.0	413
Initial BCS[e]	6.0	2.0	2.0	4.5
End BCS	2.0	2.0	4.5	4.0
Total energy requirement[f], Mcal ME/d	19.0	12.4	16.4	16.9
Maintenance requirement[g], Mcal ME/d	13.4	10.0	10.1	12.6
Energy allowable milk yield, kg/d Without growth requirement	4.9	2.1	…	…
Energy allowable milk yield with growth requirement, kg/d	3.4	0.8	…	…
Feed energy balance[h], Mcal ME/d	-7.8	0.0	5.5	-2.0

[a]Forage quality from the season of scarce rain was used for cows in the season of no rain.
[b]Forage diets supplemented with 2 kg of poultry manure and 1 kg of molasses from January to May.
[c] Total ME supply = dietary ME plus ME from body tissue reserves.
[d]Maximum body weight loss for second parity cows is 25% of BW with BCS ≥5.0.
[e]BCS at calving was the consensus judgment of a professional panel. Other BCS were predicted from assumed BW changes based on NRC (2000) and Fox et al. (2004).
[f] Total ME requirement includes ME allowable milk for lactating cows. During the dry period, it also includes the ME required for growth in first and second parity cows and for reserves replenishment. A positive energy balance was used to determine the ME allowable BW gain.
[g] Total maintenance requirement was based on a basal maintenance requirement of mean $BW^{0.75}$*0.064. Mcal NEm (NRC, 2000; Fox et al., 2004). Basal maintenance is adjusted for the effect of plane of nutrition as indicated by changes in BW and BCS. The activity requirement increased the basal maintenance requirement by 12%.
[h]Feed energy balance = total energy supply minus total energy requirements (excludes changes in body tissue reserves).

would be approximately 30% less, or 3.4 kg/d. Therefore, the probable average milk production in early lactation was 3.4 to 4.9. kg/d.

In mid-lactation thin cows are expected to produce about 2.1 kg /d (0.8 kg/d if growth is assumed). There is insufficient dietary energy either for tissue repletion or growth.

Dietary energy supply during the early dry period is from forage of good quality in the seasons of early and late rains. Nonetheless, the resulting feed energy balance, 5.5 Mcal ME/d, is still insufficient to completely replete tissue reserves. Ending body condition score is ~4.5 units.

Late gestation for these cows coincides with the forage season of rapidly declining digestibility (scarce rain). The resultant negative feed energy balance (-2.0 Mcal ME/d), requires cows to supplement fetal growth with their own body tissue energy. Cows are predicted to be lighter and thinner at their third calving (approximate BW = 413 kg and BCS = 4.0) than they were at second calving. This portends delayed growth, less tissue available to support milk production and delayed postpartum interval to reinitiation of ovarian cyclicity in the next lactation.

5.1.3.4. Season of no rain

Table 15 summarizes expected nutritional and animal statuses and milking performance throughout calving intervals for second-parity cows calving in the season of no rain. At calving these cows were assumed to weigh 450 kg with BCS = 5.0.

The predicted dietary energy supply for this scenario provided for an energy allowable milk yield of 4.1 kg/d (ignoring growth requirement). The remaining energy required for milk production was obtained from body tissues. Consequently, cows in second lactation were expected to mobilize 90 kg of tissue reserves to support milk production and to conclude early lactation in thin body condition (BCS ~2.0) weighing

Table 15
Expected body weights, body condition scores, metabolizable energy (ME) allowable milk production, energy requirements and supplies, and feed energy balances throughout the calving interval for second parity cows calving in the season of no rain (February 1) under baseline nutrition management.

	Lactation		Dry period	
Item	Early	Late	Early	Late
Forage season	No rain[a]	Early rains	Scarce rain	No rain
Forage DMI, kg/d	4.5	6.3	7.2	4.8
Forage ME intake, Mcal/d	8.3	12.5	13.0	8.8
Total DMI[b], kg/d	7.1	6.8	7.2	7.3
Total dietary energy, Mcal ME/d	13.1	13.5	13.0	13.6
Total ME supply[c], Mcal/d	17.8	13.5	13.0	15.0
Initial BW[d], kg	450.0	360.0	360.0	383.0
Mean BW, kg	405.0	360.0	372.0	377.0
End BW, kg	360.0	360.0	383.0	371.0
Initial BCS[e]	5.0	2.0	2.0	3.5
End BCS	2.0	2.0	3.5	2.5
Total energy requirement[f], Mcal ME/d	17.8	13.5	13.0	15.0
Maintenance requirement[g], Mcal ME/d	12.1	9.0	10.0	10.7
Energy allowable milk yield without growth requirement, kg/d	5.0	3.9	…	…
Energy allowable milk yield with growth requirement, kg/d	3.6	2.9	…	…
Feed energy balance[h], Mcal ME/d	-4.7	0.0	2.2	-1.3

[a]Forage quality from the season of scarce rain was used for cows in the season of no rain.
[b]Forage diets supplemented with 2 kg of poultry manure and 1 kg of molasses from January to May.
[c] Total ME supply = dietary ME plus ME from body tissue reserves.
[d]Maximum body weight loss for second parity cows was 25% of BW with BCS≥5.0.
[e]BCS at calving was the consensus judgment of a professional panel. Other BCS were predicted from assumed BW changes based on NRC (2000) and Fox et al. (2004).
[f] Total ME requirement includes ME allowable milk for lactating cows. During the dry period, it also includes the ME required for growth in first and second parity cows and for reserves replenishment. A positive energy balance was used to determine the ME allowable BW gain.
[g] Total maintenance requirement was based on a basal maintenance requirement of mean $BW^{0.75}*0.064$. Mcal NEm (NRC, 2000; Fox et al., 2004). Basal maintenance is adjusted for the effect of plane of nutrition as indicated by changes in BW and BCS. The activity requirement increased the basal maintenance requirement by 12%.
[h]Feed energy balance = total energy supply minus total energy requirements (excludes changes in body tissue reserves).

about 360 kg. If normal growth occurred, milk production would be reduced about 30%, to 3.6 kg/d.

Cows in mid-lactation encounter pasture of high quality, which provides about 50% greater daily supply of energy than was available from lower quality forage in early lactation (12.5 *vs* 8.3 Mcal ME/d). The resulting expected milk production was 3.9 kg/d (2.9 kg/d assuming growth), which was the largest predicted milk yield in mid-late lactation.

Dietary energy during the dry period was from low-quality forage grown in the season of scarce rain. The corresponding modest predicted feed energy balance, 2.2 Mcal ME/d, was sufficient to replete only one-fourth of the tissue reserves previously mobilized to support milk synthesis, leaving cows undesirably thin with a BCS ~3.5.

Late gestation for these cows coincides with a regression to nutrient scarcity with the next no rain season. This situation impinges on the dam-fetal unit: the unmet total nutrient requirement results in the dam diverting 1.3 Mcal ME/d from body tissues to support fetal growth. Cows are predicted to be much lighter (371 kg) and thinner (BCS ~2.5) at their third calving than they were at second calving. This is a frequently predicted scenario signifying delayed growth among immature cows, insufficient tissue to support next lactation, and accompanied by a probable delayed postpartum interval to the reinitiation of ovarian cyclicity.

5.1.4. Multiparous cows

5.1.4.1. Season of early rains

The nutritional and animal statuses and milking performance expected throughout calving intervals for multiparous cows calving in the season of early rains are summarized in Table 16. The assumed average body weight at calving was 484 kg with a BCS of 4.5 units.

Table 16
Expected body weights, body condition scores, metabolizable energy (ME) allowable milk production, energy requirements and supplies, and feed energy balances throughout the calving interval for multiparous cows calving in the season of early rains (June 1) under baseline nutrition management.

	Lactation		Dry period	
Item	Early	Late	Early	Late
Forage season	Early rains	Scarce rain	No rain[a]	Early rains
Forage DMI, kg/d	8.0	7.0	5.4	7.6
Forage ME intake, Mcal/d	16.6	12.8	9.9	15.4
Total DMI[b], kg/d	8.0	7.5	7.9	8.4
Total dietary energy, Mcal ME/d	16.6	13.9	14.7	16.9
Total ME supply[c], Mcal/d	21.2	13.9	14.7	16.9
Initial BW[d], kg	484.0	400.0	400.0	435.0
Mean BW, kg	442.0	400.0	418.0	442.0
End BW, kg	400.0	400.0	435.0	449.0
Initial BCS[e]	4.5	1.5	1.5	3.5
End BCS	1.5	1.5	3.5	4.0
Total energy requirement[f], Mcal ME/d	21.2	13.8	14.7	16.9
Maintenance requirement[g], Mcal ME/d	11.7	10.1	10.7	11.4
Energy allowable milk yield, kg/d	8.3	3.2	…	…
Feed energy balance[h], Mcal ME/d	-4.6	0.1	3.2	1.2

[a]Forage quality from the season of scarce rain was used for cows in the season of no rain.
[b]Forage diets supplemented with 2 kg of poultry manure and 1 kg of molasses from January to May.
[c] Total ME supply = dietary ME plus ME from body tissue reserves.
[d]Maximum body weight loss for multiparous cows was 20% of the BW with a BCS <5.
[e]BCS at calving was the consensus judgment of a professional panel. Other BCS were predicted from assumed BW changes based on NRC (2000) and Fox et al. (2004).
[f] Total ME requirement includes ME allowable milk for lactating cows. During the dry period, it also includes the ME required for growth in first and second parity cows and for reserves replenishment. A positive energy balance was used to determine the ME allowable BW gain.
[g] Total maintenance requirement was based on a basal maintenance requirement of mean $BW^{0.75}$*0.064. Mcal NEm (NRC, 2000; Fox et al., 2004). Basal maintenance is adjusted for the effect of plane of nutrition as indicated by changes in BW and BCS. The activity requirement increased the basal maintenance requirement by 12%.
[h]Feed energy balance = total energy supply minus total energy requirements (excludes changes in body tissue reserves).

The predicted forage DMI supplied about 80% of the energy required for the predicted average daily milk production during early lactation of 8.3 kg/d, about two kilograms more milk than from primiparous cows also calving in this season. The balance of the energy required for this amount of milk, 4.6 Mcal ME/d, was supplied by catabolized body tissue. Cows in early lactation were expected to mobilize about 84 kg of body tissues, concluding this stage of lactation in thin body condition (BCS ~1.5) weighing about 400 kg.

During mid-lactation these cows consume forage principally from the season of scarce rain supplemented by poultry manure and molasses in the dry months. This less digestible forage provided sufficient ME for about 3.2 kg of milk production.

Dietary energy during the early dry period is from lowest quality forage and poultry manure and molasses supplementation. The resulting modest predicted feed energy balance, 3.2 Mcal ME/d, is only sufficient to replete about 40% of previously mobilized tissue reserves. Body weight at the end of this stage of the calving interval was about 435 kg with a BCS of 3.5 units.

Nutrient requirements for these cows in late gestation were supported by forage of high quality with return of the next rainy season. Correspondingly, the total energy requirement, including rapid fetal growth, was exceeded by 1.2 Mcal ME/d, which permitted modest additional repletion of tissue reserves. However, at next calving cows are expected to be lighter (about 450 kg) and thinner (BCS ~4.0). This means less tissue available to support milk production and early reinitiation of ovarian cyclicity in the next lactation.

5.1.4.2. Season of late rains

The nutritional and animal statuses and milking performance expected throughout calving intervals for multiparous cows calving in the season of early rains are summarized in Table 17. The assumed average body weight at calving was 535 kg with a BCS of 6.0.

Table 17
Expected body weights, body condition scores, metabolizable energy (ME) allowable milk production, energy requirements and supplies, and feed energy balances throughout the calving interval for multiparous cows calving in the season of late rains (August 1) under baseline nutrition management.

	Lactation		Dry period	
Item	Early	Late	Early	Late
Forage season	Late rains	Scarce rain	No rain[a]	Late rains
Forage DMI, kg/d	8.1	6.5	6.5	8.6
Forage ME intake, Mcal/d	15.4	11.8	12.6	17.2
Total DMI[b], kg/d	8.1	8.0	8.2	8.6
Total dietary energy, Mcal ME/d	15.4	14.8	15.8	17.2
Total ME supply[c], Mcal/d	22.8	14.8	15.8	17.2
Initial BW[d], kg	535.0	410.0	410.0	454.0
Mean BW, kg	472.5	410.0	432.0	459.0
End BW, kg	410.0	410.0	454.0	464.0
Initial BCS[e]	6.0	2.0	2.0	4.0
End BCS	2.0	2.0	4.0	4.0
Total energy requirement[f], Mcal ME/d	22.8	14.8	15.8	17.2
Maintenance requirement[g], Mcal ME/d	14.0	10.4	10.8	12.1
Energy allowable milk yield, kg/d	7.7	3.8	…	…
Feed energy balance[h], Mcal ME/d	-7.4	0.0	4.2	0.9

[a]Forage quality from the season of scarce rain was used for cows in the season of no rain.
[b]Forage diets supplemented with 2 kg of poultry manure and 1 kg of molasses from January to May.
[c] Total ME supply = dietary ME plus ME from body tissue reserves.
[d]Maximum body weight loss for multiparous cows was 25% of BW with a BCS ≥5.
[e]BCS at calving was the consensus judgment of a professional panel. Other BCS were predicted from assumed BW changes based on NRC (2000) and Fox et al. (2004).
[f] Total ME requirement includes ME allowable milk for lactating cows. During the dry period, it also includes the ME required for growth in first and second parity cows and for reserves replenishment. A positive energy balance was used to determine the ME allowable BW gain.
[g] Total maintenance requirement was based on a basal maintenance requirement of mean $BW^{0.75}*0.064$. Mcal NEm (NRC, 2000; Fox et al., 2004). Basal maintenance is adjusted for the effect of plane of nutrition as indicated by changes in BW and BCS. The activity requirement increased the basal maintenance requirement by 12%.
[h]Feed energy balance = total energy supply minus total energy requirements (excludes changes in body tissue reserves).

Daily dietary ME supply from forage was expected to supply about 70% of the energy required to obtain the expected average daily milk production of 7.7 kg/d. The balance of the required energy for milk synthesis, 7.4 Mcal ME/d, came from catabolized body tissue. Consequently, cows in early lactation were expected to mobilize about 125 kg of body tissues to support milk production, which would result in animals in thin condition (BCS ~2.0) weighing about 410 kg.

In mid-late lactation thin cows which have a 25% lower average maintenance requirement would be consuming forage principally from the season of scarce rain supplemented in the dry months with poultry manure and molasses. This situation results in about one-fourth less forage ME compared to early lactation (11.8 vs 15.4 Mcal ME/d). The concomitant expected milk production was about 3.8 kg/d without energy for tissue repletion.

In the early dry period dietary energy is from a scarce supply of forage of lowest quality and poultry manure and molasses supplementation (January through May). The predicted feed energy balance of 4.2 Mcal ME/d, was sufficient to replete only about 35% of the tissue previously mobilized for milk synthesis. Even if DMI was equal to the assumed 90% of predicted *ad libitum* consumption, which is likely, mature cows are too thin at the end of this stage of the calving interval.

Late gestation for these cows coincides with forages grown in the seasons of early and late rains. Consequently, the resultant positive feed energy balance of 0.9 Mcal ME/d would permit repletion of a small quantity of tissue reserves. Nonetheless, mature cows are predicted to be too thin (BCS ~4.0) and light (~464 kg) for their next calving.

5.1.4.3. Season of scarce rain

The nutritional and animal statuses and milking performance expected throughout calving intervals for multiparous cows calving in the season of scarce rain are summarized in Table 18. The assumed average body weight at calving was 535 kg with a BCS of 6.0.

Table 18
Expected body weights, body condition scores, metabolizable energy (ME) allowable milk production, energy requirements and supplies, and feed energy balances throughout the calving interval for multiparous cows calving in the season of scarce rain (October 1) under baseline nutrition management.

	Lactation		Dry period	
Item	Early	Late	Early	Late
Forage season	Scarce rain	No rain[a]	Early rains	Scarce rain
Forage DMI, kg/d	7.6	4.7	8.6	8.7
Forage ME intake, Mcal/d	13.7	8.6	17.6	16.1
Total DMI[b], kg/d	7.6	7.2	8.6	8.7
Total dietary energy, Mcal ME/d	13.7	13.3	17.6	16.1
Total ME supply[c], Mcal/d	21.1	13.3	17.6	17.7
Initial BW[d], kg	535.0	410.0	410.0	476.0
Mean BW, kg	472.5	410.0	443.0	468.5
End BW, kg	410.0	410.0	476.0	461.0
Initial BCS[e]	6.0	2.0	2.0	4.5
End BCS	2.0	2.0	4.5	4.0
Total energy requirement[f], Mcal ME/d	21.1	13.3	17.6	17.7
Maintenance requirement[g], Mcal ME/d[g]	14.5	10.5	10.6	13.4
Energy allowable milk yield, kg/d	5.8	2.5	…	…
Feed energy balance[h], Mcal ME/d	-7.4	0.0	6.3	-1.5

[a]Forage quality from the season of scarce rain was used for cows in the season of no rain.
[b]Forage diets supplemented with 2 kg of poultry manure and 1 kg of molasses from January to May.
[c] Total ME supply = dietary ME plus ME from body tissue reserves.
[d]Maximum body weight loss for multiparous cows was 25% of BW with a BCS ≥ 5.
[e]BCS at calving was the consensus judgment of a professional panel. Other BCS were predicted from assumed BW changes based on NRC (2000) and Fox et al. (2004).
[f] Total ME requirement includes ME allowable milk for lactating cows. During the dry period, it also includes the ME required for growth in first and second parity cows and for reserves replenishment. A positive energy balance was used to determine the ME allowable BW gain.
[g] Total maintenance requirement was based on a basal maintenance requirement of mean $BW^{0.75}$*0.064. Mcal NEm (NRC, 2000; Fox et al., 2004). Basal maintenance is adjusted for the effect of plane of nutrition as indicated by changes in BW and BCS. The activity requirement increased the basal maintenance requirement by 12%.

5.1.4.4. Season of no rain

The nutritional and animal statuses and milking performance expected throughout calving intervals for multiparous cows calving in the season of no rain are summarized in Table 19. The assumed average body weight at calving was 535 kg with a BCS of 6.0.

The predicted forage DMI (7.6 kg/d) would supply about two-thirds of the energy required for a daily milk yield of 5.8 kg/d. The remaining energy required energy for milk synthesis, 7.4 Mcal ME/d, was obtained from body tissue reserves. Consequently, cows in early lactation were expected to mobilize about 125 kg of body tissues to support milk production. This weight loss results in thin cows (BCS ~2.0) weighing about 410 kg.

These thin cows have a one-fourth smaller average maintenance requirement in mid-late lactation when they would be consuming low quality forage from the no-rain season. Despite this reduced maintenance requirement, the energy allowable milk production was about 2.5 kg/d without dietary energy for tissue repletion.

Dietary energy during the early dry period is from forage grown in the seasons of early and late rains. Nonetheless, the substantial predicted positive feed energy balance, 6.3 Mcal ME/d, was insufficient to adequately replete tissue reserves. Cows were thin with a BCS ~4.5 at the end of this stage of the calving interval.

Late gestation for these cows coincides with a forage supply of rapidly declining digestibility. Consequently, the total energy requirement during this stage of rapid fetal growth was unmet by dietary supply and cows were forced to mobilize body reserves to provide the fetus with the required 1.5 Mcal ME/d. These circumstances resulted in cows with too few tissue reserves for next lactation (BCS ~4.0 and BW ~461 kg).

Table 19
Expected body weights, body condition scores, metabolizable energy (ME) allowable milk production, energy requirements and supplies, and feed energy balances throughout the calving interval for multiparous cows calving in the season of no rain (February 1) under baseline nutrition management.

	Lactation		Dry period	
Item	Early	Late	Early	Late
Forage season	No rain[a]	Early rains	Scarce rain	No rain
Forage DMI, kg/d	5.4	6.9	7.8	5.6
Forage ME intake, Mcal/d	9.9	13.8	14.1	16.8
Total DMI[b], kg/d	7.9	7.4	7.8	8.1
Total dietary energy, Mcal ME/d	14.9	14.8	14.1	15.1
Total ME supply[c], Mcal/d	22.2	14.8	14.1	16.0
Initial BW[d], kg	535.0	410.0	410.0	437.0
Mean BW, kg	472.5	410.0	423.5	432.5
End BW, kg	410.0	410.0	437.0	428.0
Initial BCS[e]	6.0	2.0	2.0	3.0
End BCS	2.0	2.0	3.0	2.5
Total energy requirement[f], Mcal ME/d	22.2	14.8	14.1	16.0
Maintenance requirement[g], Mcal ME/d[g]	14.3	9.9	11.0	11.7
Energy allowable milk yield, kg/d	6.9	4.2	…	…
Feed energy balance[h], Mcal ME/d	-7.3	0.1	2.4	-0.9

[a]Forage quality from the season of scarce rain was used for cows in the season of no rain.
[b]Forage diets supplemented with 2 kg of poultry manure and 1 kg of molasses from January to May.
[c] Total ME supply = dietary ME plus ME from body tissue reserves.
[d]Maximum body weight loss for multiparous cows was 25% of BW with a BCS ≥5.
[e]BCS at calving was the consensus judgment of a professional panel. Other BCS were predicted from assumed BW changes based on NRC (2000) and Fox et al. (2004).
[f] Total ME requirement includes ME allowable milk for lactating cows. During the dry period, it also includes the ME required for growth in first and second parity cows and for reserves replenishment. A positive energy balance was used to determine the ME allowable BW gain.
[g] Total maintenance requirement was based on a basal maintenance requirement of mean $BW^{0.75}$*0.064. Mcal NEm (NRC, 2000; Fox et al., 2004). Basal maintenance is adjusted for the effect of plane of nutrition as indicated by changes in BW and BCS. The activity requirement increased the basal maintenance requirement by 12%.
[h]Feed energy balance = total energy supply minus total energy requirements (excludes changes in body tissue reserves).

If the predicted DMI of 7.9 kg/d from forage and supplements is achieved then about two-thirds of the energy required for the expected average daily milk yield in early lactation of 4.1 kg/d would be supplied by the diet. The balance of energy required for milk production, 7.3 Mcal ME/d, would be provided by catabolized body tissues. Consequently, mature cows are predicted to mobilize 125 kg of body tissue reserves to support milk synthesis, and to conclude the period of early lactation in lighter condition with a body weight of 410 kg and BCS ~2.0.

Energy allowable milk production in mid-late lactation is 4.2 kg/d, which is the highest yield among all age groups in this stage of lactation. This lactation performance precludes tissue repletion.

The modest predicted feed energy balance, 2.4 Mcal ME/d, during the early dry period was insufficient to significantly replete tissue reserves. Ending body weight was ~437 kg with BCS ~3.0.

Dietary energy supply in late gestation falls short of total requirements by 0.9 Mcal ME/d, again forcing cows to mobilize tissues in support of fetal growth. At next calving cows are predicted to be much thinner than at the beginning of this lactation with BCS ~2.5 and weighing about 428 kg.

5.2. Predicted weaning weights of calves

Probable weaning weights of calves were calculated based on expected energy allowable milk yields and forage intake, using the CNCPS model. This exercise had two objectives. The first objective was to determine whether calf growth based on expected consumption of milk and pasture forage was reasonable and whether it agreed with the 240-d weaning weights recently reported for a Yucatán beef herd (Magaña and Segura-Correa, 2006). The second objective was to evaluate the interaction of parity and calving season with weaning d objective was to weight. A third objective was to ascertain the likelihood that cows in mid-late lactation were indeed probably not repleting tissue reserves in this stage of the calving interval, as inferred previously.

Table 20 contains predicted weaning weights of calves by parity and forage season of calving. The overall average predicted weaning weight across seasons was about 205 kg, which was nearly the same as the overall mean of 202 kg (SD = 25 kg) reported by Magaña and Segura-Correa (2006). Most predicted weaning weights were within two standard deviations of the mean in that report. Therefore, these predicted values can be used to evaluate the impact of calving season on weaning weight.

The first observation is the predicted weaning weights indicate that dams in mid-late lactation would have had to devote all dietary energy to milk synthesis rather than to tissue repletion for the nursing calves to achieve the observed weaning weight.

Table 20
Predicted weaning weights[a] (kg) of calves born in alternative forage seasons of the year[b] to primiparous, second parity and multiparous cows.

Parity of dam	Early rains	Late rains	Scarce rain	No rain
1 (ignoring growth)	228	203	169	232
1 (with growth requirement[c])	188	154	114	191
2 (ignoring growth)	242	229	179	245
2 (with growth requirement[c])	210	192	133	212
>2	257	250	200	274

[a]240 d of age, predicted by the Cornell Net Carbohydrate and Protein System model.
[b]Early rains = June 1 to July 31. Late rains = August 1 to September 30. Scarce rain = October 1 to January 31. No rain = February 1 to May 31.
[c]Primiparous cows are normally expected to grow 0.13 kg/d, and second parity cows are normally expected to grow 0.095 kg/d.

In accordance with the differences in expected milk production, there are clear differences in predicted calf weaning weight by parity. Offspring of multiparous dams are expected to be heaviest at weaning. Calves from primiparous dams are expected to be the lightest.

Seasonal variation in forage quality (and supply) has an important concomitant effect on calf growth from dam's milk production, which depends heavily on tissue mobilization, and forage intake by the nursing calves. Lightest weaning weights were predicted for calves born in the season of scarce rain. Heavy weaning weights resulted from good quality forage for the dams of calves born in the season of early rains. Good weaning weights for calves born in the season of late rains were aided by the large body tissue reserves of their dams. Heaviest predicted weaning weights corresponded to calves born in the season of no rain. This was due to the large quantity of body tissue reserves assumed at calving, which underwrote milk production in early lactation, the assumed unrestricted DMI in this season of forage scarcity (i. e., 90% of predicted *ad libitum* intake), and the plentiful supply of dietary energy in mid-late lactation from high-quality forage provided with the next rainy season. These assumptions may be flawed. Pasture dry matter availability in the no rain season in eastern Yucatán is less than one-half of that on offer in the seasons with rain (Figure 1 (b)). Therefore, a DMI equal to 90% *ad libitum* is probably, if not undoubtedly, generous, which leads to overestimations of dams´ milk production and the weaning weights of calves born in this season.

Predicted weaning weights indicate that lactation typically must be of higher priority than growth in immature cows, which is almost always restricted. Extended calving interval is a probable mechanism for all cows to replenish tissue reserves and for immature cows to slowly grow to obtain mature weight. Therefore, the lengths of average calving interval assumed in this study (15 or 16 mo for primiparous cows;

14 mo for others) may underestimate real herd situations about which there is little information.

5.3. Calving season effects

Tables 21, 22 and 23 summarize for cow age groups the expected daily milk production, dry matter intake, and feed energy and protein balances throughout calving intervals initiated by alternative forage seasons of calving. Columns correspond to physiological stages of cows. For each season of calving, the expected nutritional status of cows in each season of the year and physiological stage of the calving interval is read from the table horizontally in the same sequence: early lactation (emboldened values on the block diagonal corresponding to parturition in each calving season), late lactation, early dry period and late dry period. (Note: some physiological stages appear out of sequence when reading values in a row from left to right because the calving interval is longer than one year.) For example, cows calving in the season of early rains will be in late lactation in the season of scarce rain, in the early dry period during the no-rain season, and in late gestation in the next early rains season.

The focus of this study was on energetic status and limitations, which are frequently first-limiting in cattle diets in the tropics. Collectively, the analyses in this study revealed severe productivity limitations from insufficient dietary supplies of energy. Note that dietary supplies of protein were also deficient. Feed protein balance varied in accordance with feed energy balance.

Results from this study provide basic lessons about universal limitations affecting cow-calf performance in Tizimín herds for dams of all ages and their associations with forage season of calving. Especially important was the heavy reliance on catabolism of body tissue reserves predicted during lactation for all parities. Cows initiated lactation by mobilizing from 3 Mcal ME/d to 8 Mcal ME/d to support 4 kg/d to 8 kg/d of milk production in early lactation. One-fourth to more than one-third of the total energy required for milk synthesis was obtained from tissue reserves. Corresponding body weight losses ranged from 66 to 125 kg with one-half of the twelve parity-calving season scenarios requiring >100 kg of tissue mobilization. This far exceeds, in absolute and especially in relative terms, the required adipose tissue contributions by dairy cows producing six times more milk in the simulation study by Reyes et al. (1981; table 3). In that study total body weight losses across calving seasons ranged from 52 to 130 kg with a body tissue contribution >100 kg occurring in only one season.

Least reliance on tissue reserves in early lactation occurred consistently in the season of early rains. This coincides with animals that typically have low adipose reserves (BCS ~4.5). Greatest reliance occurs when cows calve in the season of scarce rain. Negative feed energy balance, causing dams' to divert body reserves to fetal growth, also occurred in late gestation for cows initiating lactation in the seasons of late, scarce and no rain. These negative feed energy balances probably preclude, or at least impede, growth of immature cows. Therefore, the analyses in this study indicate it may be wise to synchronize parturitions with the rainy seasons and to control proportions of the herd that would calve at other times of the year, depending upon management capacity to provide the needed dietary support (e.g., supplies of digestible hay and supplements). This suggestion is consistent with the recommendation by Magaña and Segura-Correa (2006) to avoid calvings in the season of scarce rain.

Table 21
Expected daily milk yield, dry matter intake (DMI) and feed energy (FE) and feed protein (FP) balances throughout calving intervals[a] of primiparous Brahman cows calving in alternative forage seasons[b,c] under baseline management in Tizimin ranches.

	Early rains				Late rains				Scarce rain				No rain			
	Lactation		Dry		Lactation		Dry		Lactation		Dry		Lactation		Dry	
Calving season	Early	Late	Early	Late	Early	Late	Early	Late	Early	Late	Early	Late	Early	Late	Early	Late
Early rains (June 1)																
Milk yield, kg/d[d]	**6.3**	…	…	…	…	…	…	…	…	2.8	…	…	…	…	…	…
DMI predicted, kg/d	**6.8**	…	…	6.9	…	…	…	…	…	6.4	…	…	…	…	5.9	…
FE balance, Mcal ME/d	**-3.0**	…	…	1.2	…	…	…	…	…	0.0	…	…	…	…	0.5	…
FP balance, g MP/d	**-148.0**	…	…	36.0	…	…	…	…	…	-42.0	…	…	…	…	73.0	…
Late rains (August 1)																
Milk yield, kg/d	…	…	…	…	**4.9**	…	…	…	…	3.1	…	…	…	…	…	…
DMI predicted, kg/d	…	…	8.4	…	**6.6**	…	…	8.3	…	6.6	…	…	…	…	…	…
FE balance, Mcal ME/d	…	…	5.9	…	**-3.7**	…	…	-1.9	…	0.0	…	…	…	…	…	…
FP balance, g MP/d	…	…	197.0	…	**-145.0**	…	…	22.0	…	-27.0	…	…	…	…	…	…
Scarce rain (October 1)																
Milk yield, kg/d	…	…	…	…	…	…	…	…	**4.4**	…	…	…	…	1.9	…	…
DMI predicted, kg/d	…	…	…	…	…	…	7.3	…	**6.4**	…	…	7.8	…	5.9	…	…
FE balance, Mcal ME/d	…	…	…	…	…	…	4.6	…	**-5.3**	…	…	-1.6	…	0.0	…	…
FP balance, g MP/d	…	…	…	…	…	…	142.0	…	**-165.0**	…	…	55.0	…	37.0	…	…
No rain (February 1)																
Milk yield, kg/d	…	3.8	…	…	…	…	…	…	…	…	…	…	**4.1**	…	…	...
DMI predicted, kg/d	…	6.2	…	…	…	…	…	…	…	…	7.5	…	**6.5**	…	…	8.5
FE balance, Mcal ME/d	…	0.0	…	…	…	…	…	…	…	…	3.6	…	**-3.7**	…	…	0.0
FP balance, g MP/d	…	-50.0	…	…	…	…	…	…	…	…	137.0	…	**-65.0**	…	…	99.0

[a]Early lactation period = days 1 to 90 postpartum. Mid/late lactation = days 91 to 240. Early dry = variable length period commencing on day 241. Late dry = final 90 d of calving interval (late gestation).
[b]Early rains = June 1 to July 31. Late rains = August 1 to September 30. Scarce rain = October 1 to January 31. No rain = February 1 to May 31.
[c]Chemical composition and kinetic digestion parameters of Yucatán forages were based on the collective opinion of a panel of local professionals and available laboratory analyses.
[d]Predicted milk yields in this table ignore nutrient requirement for growth.

Table 22
Expected daily milk yield, dry matter intake (DMI) and metabolizable energy (FE) and metabolizable protein (FP) balances throughout calving intervals[a] of second parity Brahman cows calving in alternative forage seasons[b,c] under baseline management in Tizimin ranches.

	Early rains				Late rains				Scarce rain				No rain			
	Lactation		Dry		Lactation		Dry		Lactation		Dry		Lactation		Dry	
Calving season	Early	Late	Early	Late	Early	Late	Early	Late	Early	Late	Early	Late	Early	Late	Early	Late
Early rains (June 1)																
Milk yield, kg/d[d]	**7.2**	…	…	…	…	…	…	…	…	3.0	…	…	…	…	…	…
DMI predicted, kg/d	**7.4**	…	…	7.6	…	…	…	…	…	7.0	…	…	…	…	7.3	…
FE balance, Mcal ME/d	**-3.7**	…	…	-0.2	…	…	…	…	…	0.0	…	…	…	…	2.7	…
FP balance, g MP/d	**-175.0**	…	…	23.0	…	…	…	…	…	-45.0	…	…	…	…	138.0	…
Late rains (August 1)																
Milk yield, kg/d	…	…	…	…	**6.6**	…	…	…	…	3.4	…	…	…	…	…	…
DMI predicted, kg/d	…	…	…	…	**7.5**	…	…	7.8	…	7.4	…	…	…	…	7.2	…
FE balance, Mcal ME/d	…	…	…	…	**-6.2**	…	…	0.9	…	0.0	…	…	…	…	1.8	…
FP balance, g MP/d	…	…	…	…	**-214.0**	…	…	44.0	…	-26.0	…	…	…	…	87.0	…
Scarce rain (October 1)																
Milk yield, kg/d	…	…	…	…	…	…	…	…	**4.9**	…	…	…	…	2.1	…	…
DMI predicted, kg/d	…	…	8.0	…	…	…	…	…	**7.1**	…	…	8.0	…	6.7	…	…
FE balance, Mcal ME/d	…	…	5.5	…	…	…	…	…	**-7.8**	…	…	-2.0	…	0.0	…	…
FP balance, g MP/d	…	…	186.0	…	…	…	…	…	**-182.0**	…	…	-23.0	…	40.0	…	…
No rain (February 1)																
Milk yield, kg/d	…	3.9	…	…	…	…	…	…	…	…	…	…	**5.0**	…	…	...
DMI predicted, kg/d	…	6.8	…	…	…	…	…	…	…	…	7.2	…	**7.1**	…	…	7.3
FE balance, Mcal ME/d	…	0.0	…	…	…	…	…	…	…	…	2.2	…	**-4.7**	…	…	-1.3
FP balance, g MP/d	…	-41.0	…	…	…	…	…	…	…	…	51.0	…	**-99.0**	…	…	27.0

[a]Early lactation period = days 1 to 90 postpartum. Mid/late lactation = days 91 to 240. Early dry = variable length period commencing on day 241. Late dry = final 90 d of calving interval (late gestation).
[b]Early rains = June 1 to July 31. Late rains = August 1 to September 30. Scarce rain = October 1 to January 31. No rain = February 1 to May 31.
[c]Chemical composition and kinetic digestion parameters of Yucatán forages were based on the collective opinion of a panel of local professionals and available laboratory analyses.
[d]Predicted milk yields in this table ignore nutrient requirement for growth.

Table 23

Expected daily milk yield, dry matter intake (DMI) and metabolizable energy (FE) and metabolizable protein (FP) balances throughout calving intervals[a] of multiparous Brahman cows calving in alternative forage seasons[b,c] under baseline management in Tizimin ranches.

	Early rains				Late rains				Scarce rain				No rain			
	Lactation		Dry		Lactation		Dry		Lactation		Dry		Lactation		Dry	
Calving season	Early	Late	Early	Late	Early	Late	Early	Late	Early	Late	Early	Late	Early	Late	Early	Late
Early rains (June 1)																
Milk yield, kg/d	**8.3**	…	…	…	…	…	…	…	…	3.2	…	…	…	…	…	…
DMI predicted, kg/d	**8.0**	…	…	8.6	…	…	…	…	…	7.5	…	…	…	…	7.9	…
FE balance, Mcal ME/d	**-4.6**	…	…	0.9	…	…	…	…	…	0.0	…	…	…	…	3.2	…
FP balance, g MP/d	**-211.0**	…	…	80.0	…	…	…	…	…	-62.0	…	…	…	…	151.0	…
Late rains (August 1)																
Milk yield, kg/d	…	…	…	…	**7.7**	…	…	…	…	3.8	…	…	…	…	…	…
DMI predicted, kg/d	…	…	…	…	**8.1**	…	…	8.6	…	8.0	…	…	…	…	8.2	…
FE balance, Mcal ME/d	…	…	…	…	**-7.4**	…	…	0.9	…	0.0	…	…	…	…	4.2	…
FP balance, g MP/d	…	…	…	…	**-258.0**	…	…	65.0	…	-36.0	…	…	…	…	167.0	…
Scarce rain (October 1)																
Milk yield, kg/d	…	…	…	…	…	…	…	…	**5.8**	…	…	…	…	2.5	…	…
DMI predicted, kg/d	…	…	8.6	…	…	…	…	…	**7.6**	…	…	8.7	…	7.2	…	…
FE balance, Mcal ME/d	…	…	6.3	…	…	…	…	…	**-7.4**	…	…	-1.5	…	0.0	…	…
FP balance, g MP/d	…	…	210.0	…	…	…	…	…	**-221.0**	…	…	-12.0	…	29.0	…	…
No rain (February 1)																
Milk yield, kg/d	…	4.2	…	…	…	…	…	…	…	…	…	…	**6.9**	…	…	…
DMI predicted, kg/d	…	7.4	…	…	…	…	…	…	…	…	7.8	…	**7.9**	…	…	8.1
FE balance, Mcal ME/d	…	0.1	…	…	…	…	…	…	…	…	2.4	…	**-7.3**	…	…	-0.9
FP balance, g MP/d	…	-40.0	…	…	…	…	…	…	…	…	59.0	…	**-178.0**	…	…	42.0

[a]Early lactation period = days 1 to 90 postpartum. Mid/late lactation = days 91 to 240. Early dry = variable length period commencing on day 241. Late dry = final 90 d of calving interval (late gestation).

[b]Early rains = June 1 to July 31. Late rains = August 1 to September 30. Scarce rain = October 1 to January 31. No rain = February 1 to May 31.

[c]Chemical composition and kinetic digestion parameters of Yucatán forages were based on the collective opinion of a panel of local professionals and available laboratory analyses.

Under the stated assumptions, including dietary composition, the results of this study emphasize that body tissue reserves are probably rarely fully repleted during the average length calving intervals specified for Tizimín herds. Findings indicate that cows would remain thin for long periods, which invites postpartum delays in reinitiating ovarian activity. Immature cows with BCS = 4 had a 12 to 22% lower pregnancy rate than mature cows with the same condition score (Kunkle et al., 1994). Immature cows are further disadvantaged because their growth is undoubtedly impeded. Therefore, it appears unlikely that cows achieve desirable body condition at calving (i. e., BCS ≥5.0), or needed growth, without having more time from longer calving intervals for opportunistic accrual of body tissues with plentiful supplies of digestible forage when nutrient requirements are low.

Figure 4 summarizes this pattern of tissue mobilization and repletion and the concomitant body condition scores across alternative seasons of calving. With one exception, body condition scores in late gestation (late dry period) prior to the next lactation ranged from 2.5 to 4.0. Condition scores ≤2.5 were frequently predicted in mid-late lactation when diets were too deficient to permit repletion or to support persistent lactation. Furthermore, total energy requirements were unmet in one-half of the late gestation scenarios considered. Figure 5 illustrates these scenarios with a typical Brahman cow and her calf in a Tizimín herd in week six of the scarce rain season. This cow has a BCS ~2.0 with gauntness resulting from daytime corralling without the provision of feed.

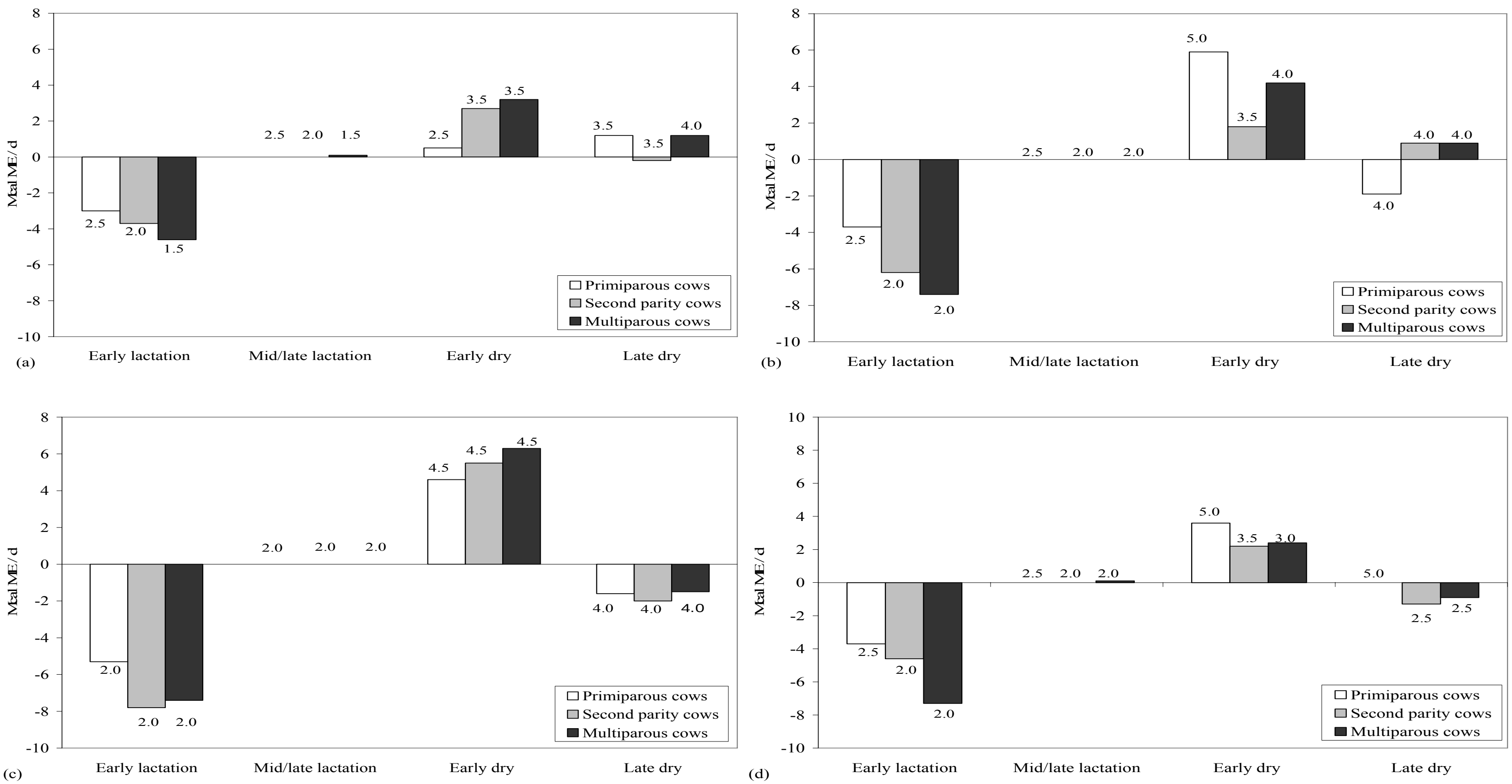

Figure 4

Expected feed energy balances and body condition scores (to nearest half unit) at the end of each physiological stage throughout calving intervals of primiparous, second parity and multiparous cows under baseline management in Tizimin ranches. (a) cows calving on June 1 (season of early rains); (b) cows calving on August 1 (late rains); (c) cows calving on October 1 (scarce rain); (d) cows calving on February 1 (no rain).

Figure 5. A typical lactating Brahman cow (on right) with her calf in a Tizimin herd six weeks into the season of scarce rain (photograph taken 3:00 pm, November 12, 2003). This cow demonstrates a body condition score of 2.0 or less and gauntness from being unable to eat during daytime corralling. (Photo courtesy of R.W. Blake)

5.4. Evaluation of the current dry-season supplementation strategy

Ruminal nitrogen is required to support the fermentation of fiber and non-fiber carbohydrates. The results showed that rumen N requirement was between 97% and 100% of requirements in the season of early rains, and approximately 90% of requirement in the season of late rains and scarce rain during lactation. This deficiency constrains digestibility of NDF in the CNCPS simulations (Fox et al., 2004). Reduced DMI (i. e., 90% of *ad libitum* consumption) reduces the available NDF for ruminal bacteria. In the season of early rains, the CP content of forage is probably sufficient and N balance may not be limiting at this time.

The CNCPS predicted that the rumen N supply for the cows under the baseline herd management in the season of no rain is approximately 110% of requirement. The simulation showed that the 2 kg/d of poultry manure improves (or exceeds) the MP status, but does not overcome the ME deficiency. Molasses, which contains ~70% sugar, plus poultry manure, yields a supplement with ~15% CP (Table 4). Feed components in the baseline diets during these periods contain less carbohydrate and more protein. Diets with excess protein result in high endogenous concentrations of urea in blood, milk, and urine. There is a negative relationship between energy intake and plasma urea N (Roseler et al., 1993). Excretion of excess N increases the energy (maintenance) requirement of cows, which reduces animal performance (Fox et al., 2003). Moreover, feeding diets with a high concentration of CP decreases reproductive efficiency (Ferguson et al., 1989). Reynoso-Campos et al. (2004) concluded that the energy and protein available for production depends on the proportion required for maintenance. Thus, there is need to determine the expected requirement and performance associated with energy and protein balances in tropical situations.

Nherera (2005) reported that over the past decade in east Africa studies have focused on correcting protein deficiencies in rations for lactating cows by using leguminous fodder without sufficiently addressing adequacy of the energy supply. Her simulation results indicated that energy was first limiting, often resulting in diets with excessive ruminal N. At our study site, managers frequently focus on increasing the supply of protein in the seasons of scarce and no rain by daily feeding up to 3 kg of poultry manure and 1 kg of molasses. Our results clearly indicated that ruminal N exceeded the ruminal bacterial requirement with these diets. Therefore, increasing dietary supplementation with poultry manure at our study site does not address the primary problem of energy deficiency because it provides little energy. Further additions would be expected to further decrease reproductive performance because energy is required to excrete excess N. Therefore, it is recommended to reassess the supplementation strategy to better achieve herd productivity and reproduction goals. Larger quantities of more highly digestible forages are needed. These could be supplemented with carbohydrate sources, such as sorghum and molasses.

A study aimed at dual-purpose cattle systems in Venezuela indicated that adding urea with an energy source to the forage-based diet compensated the negative ruminal N (Townsend et al., 1990). The authors recommended feeding well-mixed energy supplements fortified with urea to avoid ammonia toxicity and to maximize the utilization of nitrogen. The results from this study indicate that urea supplementation would be beneficial when rumen N balance is inadequate.

5.5. Priority management considerations to improve cow-calf performance

The analysis in this study clearly identified key biological limitations affecting cow-calf systems in Tizimín, Yucatán, México. This may be the first study to systematically evaluate the interactions of energy balance with cow parity and calving season and bottlenecks of cow productivity and to integrate them across production cycles (i. e., calving intervals) for a tropical environment. With biological parameters understood the remaining challenge is principally a management one: decisions about priorities for investments and the implementation of appropriate practices to improve herd productivity and profit.

It is fundamentally important that Tizimín managers evaluate options to achieve *ad libitum* forage consumption by their animals. Achieving greater feed intake would reduce the heavy reliance on the tissue turnover system subsidy for cow-calf production. Other things equal, greater dietary energy intake portends greater productivity in any cattle system. As illustrated in Table 7, a one-third increase in milk production is expected from providing cows with the opportunity to eat during the day. Certainly, daytime grazing (or other feeding method) would be a major change in herd management. Such a modification also requires managing agronomic aspects of producing adequate forage to meet the greater feed consumption by the herd. Producers should be educated on the productivity tradeoffs associated with current practices and compare them with viable alternatives and expected payoffs.

A key complementary consideration, in addition to greater supply, is to provide forages of high feeding value throughout the year to further improve nutrient intakes of cows and calves. Achieving these objectives signifies making investments to graze high quality forages and to produce, or purchase, hays of good nutritional value to feed management groups of animals in a herd. (Appropriate diets differ substantially among management groups, which should comprise animals with similar nutritional requirements, e. g., immature cows, mature cows, heifers of breeding age, young stock, weanlings, creep-fed calves.) Greater consumption of higher quality forage would have multiple favorable impacts. These include reduced reliance on tissue mobilization, improved milk production of dams and growth of their calves, satisfying nutrient requirements for fetal development in late gestation and growth of immature cows (and other animal age classes), repletion of previously mobilized body reserves in support or earlier conception for an annual calving interval, and assuring the energy reserves that will be needed in early lactation during the next productivity cycle (i. e., achieving target BCS ≥5.0 at next calving). This management consideration therefore requires the inclusion of strategies to coordinate the annual calving schedule with forage seasons of the year. Certain benefits are expected when calvings by cows with target BCS of 5 or 6 are synchronized with plentiful supplies of forage energy, which means the seasons of early and late rains. As Magaña and Segura-Correa (2006) recommended, without better dietary support from improved supplies of good quality forage (e.g., hay), cows calving in the season of scarce rain are substantially disadvantaged. Tedeschi et al. (2005) and Magaña et al. (2006) recommended matching breeding and calving seasons with forage availability to improve cattle system productivity. Nutritional management is critical for obtaining calving intervals of desirable length (Odde, 1990).

6. Conclusions

This case study clearly identified key biological and management limitations affecting Brahman beef herds in Tizimín, Yucatán. It is believed to be the first published study for a tropical environment to systematically evaluate the interactions of energy balance, calf weaning weights and calving interval with cow parity and calving season (forage quantity and quality), and integrate them across production cycles. The evaluation utilized 48 simulations describing status and productivity of cows of three parity classes calving in four seasons of the year, and in each of four distinct physiological stages during a calving interval.

Results provided basic lessons about factors determining cow-calf performance for dams of first, second, and mature parities and their associations with season of calving. The management practice of corralling without daytime provision of feed certainly does not allow *ad libitum* forage energy intake, which substantially reduces milking performance of dams (by one-third or more), growth of calves and immature cows, and tissue repletion in dams. Greater feed intake would reduce the heavy reliance on the tissue turnover subsidy of cow-calf production. Other things being equal, *ad libitum* feed consumption supports greater productivity in any cattle system. Producers should be apprised of such productivity tradeoffs from current and alternative practices.

In addition to restricted feed intake, poor quality forage was another fundamental limitation. Forages of higher feeding value throughout the year are needed to improve nutrient intakes of cows and calves. This involves considering investments to improve forage quantity and quality (chemical composition and fermentation rates), grazing management, and hay-making or hay-contracting options.

There was heavy reliance in all parities on catabolism of body tissue reserves to support milk production. Cows initiated lactation by mobilizing from 3 Mcal ME/d to 8 Mcal ME/d to support synthesis of 4 kg/d to 8 kg/d of milk. One-fourth to one-third of the total energy required for milk synthesis is obtained from body reserves, which far exceeds adipose tissue contributions in dairy systems with much higher milk production (Reyes et al., 1981).

Least reliance on tissue reserves in early lactation consistently occurred in the season of early rains. Greatest reliance occurs when cows calve in the season of scarce rain. Dams frequently incurred energy deficits in late gestation, causing them to divert body reserves to assure fetal growth. Consistent with the recommendation by Magaña and Segura-Correa (2006), findings indicate it may be wise to synchronize calvings with the rainy seasons (early and late rains) and to control proportions of the herd that would calve at other times.

The predicted weaning weights of calves based on expected milk production of their dams agreed with measurements in a Yucatán herd from a recent report (Magaña and Segura-Correa, 2006). With similar overall means (across parities and calving seasons), most weaning weight means for the parity-season combinations considered were within the range of two standard deviations given in that report. Therefore, the expected milking performance in this study emulates the amounts required to achieve calf growth like that measured in this Yucatán herd: a kind of validation by construct. Furthermore, the predicted weaning weights indicate that dams in mid-late lactation would have had to devote all dietary energy to milk synthesis with nil energy for tissue repletion.

Under the assumptions of this study, findings indicate that body tissue reserves are probably rarely fully replenished during the average calving intervals considered for these Tizimín herds: cows are thin for a long period, which invites postpartum delays in the reinitiation of ovarian cyclicity. Body condition scores ≤2.5 were frequently predicted in mid-late lactation when diets were too deficient to permit repletion or to assure persistent lactation (Figure 4). Immature cows are further disadvantaged because their growth is undoubtedly severely restricted. It appears unlikely that cows can achieve desirable tissue reserve status (i. e., BCS ≥5.0, Herd et al., 1995), or needed growth, without incurring longer calving intervals for opportunistic accrual of body tissues when requirements are low and supplies of digestible forage are high.

The typical practice of poultry manure and molasses supplementation during the dry months of scarce supplies of low-quality forage does not address the primary limitation of dietary energy. Cow energy status is aggravated by excess N because its excretion diverts energy from other uses.

Priority research and outreach considerations for the Yucatán (and Mexican) beef industry should be established using a holistic, integrative strategy to generate, and evaluate, management opportunities for, and with, farmers. This approach is similar to those described by Licitra et al. (1998) for dairy producers in Mediterranean Sicily and by Reynoso et al. (2004) for dual-purpose cattle systems in the Gulf region of México. These considerations include chemical evaluation of forages and other feedstuffs, making this information available to farmers and their advisors, use of high quality hays, better formulation of diets with greater nutrient density for specific management groups of animals, shifting calving patterns to better exploit supplies of high quality forage, quantifying seasonal variation in body weights and monitoring body condition scores in management groups of animals, and using nutritional and dietary evaluation tools like the CNCPS model in herd dietary management.

7. Appendices

Appendix 7.1. Procedures for setting up CNCPS version 6 simulations

7.1.1. Management groups of animals

Parity and different physiological stages

Different female management groups by physiological stage and parity of cows were created because the energy requirements and feed intakes differ at each physiological (lactation or pregnancy) and growth stage (age or parity and body weight; Fox et al., 2004).

i) Parity

- Primiparous (1 st lactation) cows
- Young (2 nd lactation) cows
- Mature (Parity >2) cows

ii) Physiological stage of calving interval

- Early lactating stage (90 d from calving)
- Mid-late lactation (91-240 d)
- Early dry (241-330 d for young and mature cows. 241-370 d for 1 st lactation cows calving in the early rain and late rain season. 241 d- 410 d for 1 st l actation cows calving in the dry season). It depends on the calving interval.
- Late dry (last 90 d to calving)

Forage availability differs by season (Figure 2). Forage quality was assumed to progressively decline starting with immature pasture at the beginning of the rainy season to the accumulation of mature forage, typically available for grazing, in the dry season. Therefore, a representative herd was described according to each of four calving seasons of the year.

i) Seasons

- Early rain season: June1 to July 31(Forage quality is the best.

-Late rain season: August 1 to September 31 (Plants become mature)

-Early dry season: October 1 to January 31 (Rain is scarce)

-Late dry season: February 1 to May 31(The worst season of the year)

7.1.2. Input information for the CNCPS

The cattle information for the simulation was determined based on (Magaña et al., 2002 and 2006) with local panel of professionals.

Procedure about age

(i) Calving interval

-CI of primiparous cows calving in the rainy season
=460 days=460/30.5days=15.1 mo

-CI of the primiparous cows calving in the dry season
=500 days=500/30.5days= 16.4 mo

-CI of the other cows=420 days=420/30.5 days=13.8 mo

(ii) Age

-Early lactation for primiparous cows= {1085 d (age at first calving)+45 d (the middle of the early lactation)}/30.5 d=37 mo

-Early lactation for young cows= {1545 d (age at second calving)+45 d (the middle of the early lactation)}/30.5 d=52 mo

-Early lactation for mature cows= {1965 d (age at 3 rd lactation)+45 (the middle of the early lactation)}/30.5 d=66 mo

-Mid-late lactation for primiparous cows= {1175 d+75 d (the middle of the mid- late lactation)/30.5 d} =41mo

-Mid- late lactation for young cows= (1635 d+75 d)/30.5 d=56mo

-Mid-late lactation for mature cows= (2055 d+75 d)/30.5 d=70mo

We defined the period of the dry status of the cows as the followings;
The early dry period is 240-370 d for primiparous cows calving in the rainy season.
The early dry period is 240-410 d for primiparous cows calving in the rainy season.
The 240-330 d for multiparous cows.
The late dry status of the cows is last 90 d of the CI, which the cow's energy requirements are higher (370 d-460 d for primiparous cows calving in the rainy season, and 410- 500 d for primiparous cow calving in the dry season, 330-420 d for multiparous cows.

The calculation of age is the following;

-Early dry primiparous cows calving in the rainy season
= {1325+130 (the length of the early dry period)/2/30.5}=46 mo

-Early dry primiparous cows calving in the dry season=
{1325+170 (the length of the early dry period)/2/30.5}=47 mo

-Early dry young cows= (1785+90/2)/30.5=60mo

-Early dry mature cows= (2205+90/2)/30.5=74mo

-Late dry primiparous cows calving in the rainy season
= (1085+370+90/2)/30.5=50.5=49mo

-Late dry primiparous cows calving in the dry season
= (1085+410+90/2)/30.5=50.5=51mo

-Late dry young cows= (1875+90/2)/30.5=62.9=63mo

-Late dry mature cows= (2295+90/2)/30.5=76.72=77mo

(iii) Days pregnant

-Primiparous cows, calving in the rainy season get pregnant at 170 d after calving {460 d (CI)-290(the lenghth of the pregnancy of Brahman cows}, which is 1295 d-age

-Primiparous cows, calving in the dry season get pregnant at 210d after calving (500d- 290 d), which is 1295 d-age

Other cows get pregnant at 130 d after calving (420d-290d)

-Young cows get pregnant at 1675 d (1545 d+130 d)

-Mature lactation cows=2095 d-age (1965 d+130 d)

-All the cows are not pregnant in the early lactating stage

-Primiparous cows are not pregnant in the mid-late lactation stage

-Young lactation and mature cows get pregnant at 130 d after calving. Therefore, in the middle of the mid-late lactation stage, which is 165 days after calving, young cows are 35 d of pregnant.

-Primiparous cows calving in the rainy season get pregnant at 170 days after calving. Primiparous cows are 135 d of pregnant {290 d-90 d(late dry)+65 (a half of the early dry period)}.

-Primiparous cows calving in the dry season get pregnant at 210 d after calving. In the middle of the early dry stage, which is 325 d after calving, primiparous cows are 115 d of pregnant (290 d-90d-85d).

-Young and mature cows get pregnant at 130 d after calving. In the middle of the early dry lactation stage which is 285 d after calving, they are 155 d of pregnant. (290 d- 90 d-45 d)

-Primiparous cows in the middle of the late dry stage, which is 455 d after calving, 1^{st} lactating cows are 245 d of pregnant.

-Young and mature cows in the middle of the late dry stage which is 375 days after calving, they are 245 days of pregnant.

7.1.3. Procedure for body weight for the cattle description for the simulations

i) Calf weight

-ADG (Average Daily Gain) for calves

ADG of calves (male) = {220 (weaning weight)-33(birth weight)}/240d (lactation period) = 0.78kg/d

-ADG of calves (female) = {200(weaning weight)-30(birth weight)}/240d (lactation period) = 0.71 kg/day

-Male calf weight at early lactation (the middle of the early lactation is 45 d) =33(BW) +0.78*45=68

-Female calf weight at early lactation (the middle of the early lactation is 45 days) =30(BW) +0.71*45=62

-Male calf weight at mid/late lactation

(the middle of 240 d= 120 d)=0.78*120+68=162kg

-Female calf weight at mid/late lactation

(the middle of 240 d = 120 d)=0.71*120+62=147kg

(ii) Cows body weight (SBW)

- Primiparous cows=400 kg
- Young cows=460 kg
- Mature cows=500 kg
- ADG for primiparous cows calving in the rainy season{460 (SBW of the young cows)-400(SBW of the primiparous cows/460 d (the CI for the primiparous cows calving in the rainy season)}=0.13 kg/d
- ADG for primiparous cows calving in the dry season {460 (SBW of the young cows)-400(SBW of the primiparous cows/500 d (the CI for the primiparous cows calving in the dry season)}=0.12 kg/d

- ADG for young cows calving in the dry season {500 (SBW of the mature cows)-460 (SBW of the primiparous cows/420 d (the CI for the young cows calving in the dry season)}= 0.095 kg/d

Appendix Table 7.2

Body condition scores throughout the calving interval of cows in a typical Tizimín, Yucatán beef cattle herd as recommended by a panel of professionals[a]

Early rains[b]					
	Lactation			Dry period	
Parity	Calving[f]	Early[g]	Mid-late[h]	Early[i]	Late[j]
1	4.5	4.0	4.0	4.5	5.0
2	4.5	4.0	4.5	5.0	5.5
>2	4.5	4.0	4.5	5.0	5.5

Late rains[c]					
	Lactation			Dry period	
Parity	Calving[f]	Early	Mid-late	Early	Late
1	5.5	4.5	4.0	5.0	6.0
2	6.0	5.0	4.0	5.0	6.0
>2	6.0	5.0	5.0	6.0	6.0

Scarce rain[d]					
	Lactation			Dry period	
Parity	Calving[f]	Early	Mid-late	Early	Late
1	6.0	5.0	4.5	4.5	5.0
2	6.0	5.0	4.5	4.5	5.5
>2	6.0	5.0	4.5	4.5	5.5

No rain[e]					
	Lactation			Dry period	
Parity	Calving[f]	Early	Mid-late	Early	Late
1	5.0	3.5	3.5	4.0	5.0
2	5.0	4.0	3.0	4.0	6.0
>2	6.0	5.0	4.0	4.5	6.0

[a]Panel members are J. Magaña, G. Ríos and A. Ayala (professors at the Universidad Autónoma de Yucatán (UADY)); F. Juárez (professor at the Universidad Veracruzana); B. Rueda and F. Duarte (researchers at the Instituto Nacional de Investigaciones Forestales, Agrícolas y Pecuarias)]

[b]Early rains = June 1 to July 31.

[c]Late rains = August 1 to September 30.

[d]Scarce rain = October 1 to January 31.

[e]No rain = February 1 to May 31.

[f] BCS at calving was utilized in the CNCPS simulations; others were not. [g]Early lactation period = days 1 to 90 postpartum. [h]Mid-late lactation = days 91 to 240.

[i]Early dry = variable length period (table 2) commencing on day 241. [j]Late dry period = 90 days prior to calving (late gestation).

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