

Limitations and potentials of dual-purpose cow herds in Central Coastal Veracruz, Mexico

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Abstract Feed chemical and kinetic composition and animal performance information was used to evaluate productivity limitations and potentials of dual-purpose member herds of the Genesis farmer organization of central coastal Veracruz, Mexico. The Cornell Net Carbohydrate and Protein System model (Version 6.0) was systematically applied to specific groups of cows in structured simulations to establish probable input–output relationships for typical management, and to estimate probable outcomes from alternative management based on forage-based dietary improvements. Key herd vulnerabilities were pinpointed: chronic energy deficits among dry cows of all ages in late gestation and impeded growth for immature cows. Regardless of the forage season of

calving, most cows, if not all, incur energy deficits in the final trimester of gestation; thus reducing the pool of tissue energy and constraining milking performance. Under typical management, cows are smaller and underweight for their age, which limits feed intake capacity, milk production and the probability of early postpartum return to ovarian cyclicity. The substitution of good-quality harvested forage for grazing increased predicted yields by about one-third over typical scenarios for underweight cows. When diets from first parturition properly supported growth and tissue repletion, milk production in second and third lactations was predicted to improve about 60%. Judiciously supplemented diets based on good quality grass and legume forages from first calving were predicted to further increase productivity by about 80% across a three-lactation cow lifetime. These dual-purpose herd owners have large incentives to increase sales income by implementing nutritional strategies like those considered in this study.

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Abbreviations

CNCPS Cornell Net Carbohydrate and Protein System
INIFAP National Institute of Forestry, Agriculture and
Livestock Research

Introduction

Animal agriculture is a key component of the economy of Mexico's Gulf region. The state of Veracruz is Mexico's premier supplier of beef, predominantly from its dual-purpose herd of 4 million cows, and the country's fifth largest milk producer (Román-Ponce 2005). Consequently,

dual-purpose cattle herds constitute an important livelihood for this rural citizenry.

Information for improving the productivity of dual-purpose cattle systems is scarce in Latin America and agroecosystems across the tropics (Blake 2004, 2008; Magaña-Monforte et al. 2006). The Mexican tropics typically have a 6-month dry season of forage scarcity with cows more likely to conceive in the more nutrient-plentiful rainy season, a scenario that probably limits lifetime cow productivity and overall herd efficiency.

We addressed this issue with a modeling approach to evaluate management alternatives for dual-purpose herds that have multiple feed, climatological and market challenges common in the Latin American tropics. Because of the many options to be examined, variables to be accounted and the infeasibility of carrying out experiments to evaluate each, a cattle nutrition model was utilized to conduct a biological and economical ex ante evaluation of alternative production systems. The specific objectives of this case study were (1) to investigate the best management practices that integrate animal nutritional requirements with the environmental potentials and limitations thereof and (2) to examine logical feed management options that would likely result in improved milk production. Complementary objectives were to inform about probable animal responses associated with growth, milk production and reproductive potential, and potentials from alternative management practices for farmers.

Materials and methods

Location, animals and management

The municipality of Medellín de Bravo, Veracruz (19°03'N and 96°09'W) exemplifies coastal cattle-based towns. Annual rainfall from 1996 to 2005 averaged about 1,700 mm with large seasonal variation (± 130 mm). Mean temperatures were 25°C (Comisión Nacional del Agua 2005). These environmental data were required by the cattle nutritional model. Early (June–July) and late (August–September) rainy seasons precede two seasons of pronounced low precipitation during the early dry season (October through December) that further diminishes in the late dry season (January through May) (Fig. 1). Correspondingly large fluctuations in forage supply result in an annual pattern of calvings (and milk sales) concentrated at the end of the early dry season (December and January).

The Genesis farmer organization in Medellín de Bravo is the product of individuals seeking to improve farm outcomes through officially recognized rural entities, thus qualifying for more directed support and advice from government. Herds (predominantly Brown Swiss \times Brahman crossbreds) are

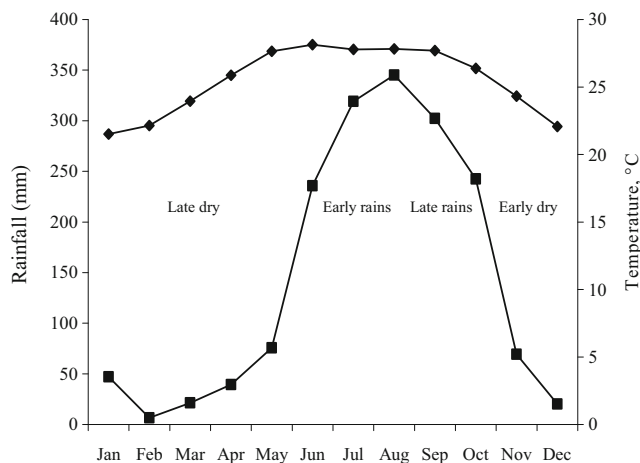


Fig. 1 Mean monthly temperature (°C; filled diamond) and rainfall (mm; filled square) in the Aw₂ climatic zone of the municipality of Medellín de Bravo, Veracruz from 1996 to 2005 (Comisión Nacional del Agua 2005). Annual rainfall during this period ranged from 1,500 to 1,800 mm, and was distributed across early (June–July) and late (August–September) rainy seasons and early (October–December) and late (January–May) dry seasons

principally managed by grazing rarely fertilized pastures and by purchasing hay during periods of low rainfall. Genesis members have responded to professional advice by producing their own hay and maize silage, and substituting or adding grass and legume species (e.g., *Brachiaria* spp.) to the forage portfolio.

Feeds and diets

Seasonal fluctuations in rainfall affect forage availability and thus herd performance is undoubtedly compromised, especially cows calving from October to December. Therefore, the early and late dry seasons constitute an extended period of low nutrient intake from grazed forage (Fig. 1), which is also when farmers typically make emergency purchases of hay. Forage chemical composition across seasons was obtained from Juárez et al. (2002a), whose samples were collected from farmers' paddocks. A detailed summary is given by Absalón-Medina (2008).

Diminished grazing from low rainfall precludes ad libitum dry matter (DM) intake. Assumptions of ad libitum feed intake during forage scarcity would undoubtedly overestimate feed energy intake. Therefore, we assumed 90% of model predicted forage intake during low rainfall months.

Other feedstuffs considered in this study were Mulato hay (*Brachiaria ruziziensis* \times *Brachiaria brizantha* cv., Mulato), maize silage, sugar cane bagasse, poultry bedding (comprising rice hulls, manure [feces and urine], feed waste and feathers), and sugar cane molasses. Feed composition values from the tropical feed library of the Net Carbohydrate and Protein System (CNCPS, v.6.0; Tylutki et al. 2008) were

used when local information was unavailable (Absalón-Medina 2008). Mulato hay is typically made from mature plants with about 90 days of regrowth. Maize is typically ensiled after the ears have been removed. Commercial concentrate composition was obtained by chemical analysis of a sample of a local brand frequently used by Genesis members (Table 1).

The most common forages, *Cynodon plectostachyus* (African star grass) and *Andropogon gayanus* (Llanero grass), are grazed during the rainy months while Llanero is mostly grazed during the dry months. Therefore, the assumed average chemical composition of grazed grass during the rainy months was the mean composition of these grasses, and exclusively Llanero composition during the dry season. The average chemical profile of foliage from two tree species (*Gliricidia sepium* and *Leucaena leucocephala*; Table 1, Juárez et al. 2002b) was used to evaluate the marginal benefit of adding legume to diets.

Assumptions about animals and management groups

Management groups of cows were specified by physiological status and parity based on available management information and professional consensus (Table 2). Alternative scenarios were established to describe calving groups of cows according to the onset of each of the above four forage seasons of the year. Typical average 270-day lactation milk production was assessed by parity and stage of lactation based on average milking performance by Genesis herds (Rodríguez-Morales et al. 2005) and the Instituto Nacional de Investigaciones Agrícolas y Pecuarias (INIFAP) milk production records. Expected yields for each group were consistent with the average milking performance for Brown Swiss \times Brahman cows of same parity for Genesis herds and from INIFAP records at the nearby La Posta research station. Expected body weights (BW) were similarly derived from INIFAP records.

Determination of maintenance requirement

The CNCPS v.6.0 (Tylutki et al. 2008) was used to predict energy and protein requirements, DM intake and feed energy balances for each management group. The basal maintenance requirement (MR) for net energy in a thermal-neutral environment with minimum physical activity was predicted for 3/4 *Bos taurus* \times 1/4 *Bos indicus* cows, where $\text{NEM (Mcal/day)} = \text{mean (BW)}^{0.75}$ times the weighted average required for the specified breeds.

Cows frequently mobilize 25% of BW (tissue reserves) to support milk production (Reynoso et al. 2004; Tedeschi et al. 2004; Baba 2007). For this study, the maximum allowable (MA) BW loss was 20% of calving weight for primiparous cows and those with BCS <3.0 units. For parities ≥ 2 and BCS ≥ 3.0 , MA loss was 25% of mature weight. Consequently,

the MR was adjusted according to expected changes in organ mass and BW from depressed dietary nutrient supplies, especially in the dry seasons. The CNCPS model simulates these relationships by increasing or decreasing the MR by 10% for each BCS unit above or below a score of 3 (Fox et al. 2004). The energy cost of excreting excess N (urea) was calculated by subtracting it from ME intake (Tylutki et al. 2008). The nighttime temperature at our study site is at the threshold (20°C) allowing for the dissipation of body heat accumulated during the day. Therefore, potential heat stress effects were ignored.

The MR for energy expended in daily physical activity was computed for the predicted amount of time standing, number of body position changes, and distance walked (Fox et al. 2004; Tedeschi et al. 2004). With intensive grazing cows were assumed to be standing for 16 h, to change body position six times, and to walk 1,000 m of flat distance per day. Terrain slope was considered inconsequential. During the early dry season cows consume mostly conserved forages and agricultural byproducts. Consequently, this diminished physical activity was assumed to be similar to animals in a feedlot (14 h standing, six position changes, 750 m walked). For the late dry season, cows were assumed to stand for 10 h with three body position changes and to walk 500 m.

Feed intake and body tissue status

The predicted mean voluntary feed intake for each management group was determined by BW, ambient temperature, milk production, forage quality and stage of gestation. Because Genesis cows are fed fixed amounts of supplements and non-grazed forages, these quantities were subtracted from the predicted total feed intake (Absalón-Medina 2008). The difference was assumed to be the amount of forage grazed. Cows mobilized body tissue to offset the feed energy deficit in early lactation to achieve the expected average milk production (if mature), or gained BW by replenishing tissues when energy intake exceeded requirements.

Gains in BW by immature cows were assumed to comprise tissue repletion and new growth. Double counting was avoided. A separate growth requirement for achieving the target BW at next calving was included after tissue repletion to a BCS of 3.0. It was not included if repletion was incomplete. Therefore, new growth was assumed only if energy consumed exceeded maintenance plus the requirement for tissue repletion. The final pool of tissue energy and BW for cows at the end of late gestation corresponded to the expected values at next calving. The BW and BCS (from panel consensus) at calving for each forage season and parity are in Table 2. Subsequent BW and BCS were calculated from predicted tissue energy losses and gains (Fox et al. 2004; Absalón-Medina 2008).

Table 1 Chemical composition^a and predicted contents of metabolizable energy and total digestible nutrients of typical grasses, legumes and supplemental feedstuffs used in the simulation model analysis for Genesis members

Variable	Grasses ^b				Legumes			Other forage				Dietary supplements			
	Early rainy season ^c	Late rainy season ^c	Early dry season ^c	Late dry season ^c	<i>Leucaena leucocephala</i>	<i>Gliricidia sepium</i>	Average	Mulato hay ^d	Pangola hay ^e	Maize silage ^f	Cane bagasse ^g	Poultry bedding ^g	Molasses ^g	Commercial concentrate ^h	
% DM ⁱ	18.69	17.26	25.54	20.34	34.56	27.30	25.0	23.6	24.3	89.88	90.03	23.50	15.60	85.80	92.92
CP, % of DM	11.94	9.22	6.08	8.32	4.33	6.93	22.1	20.9	21.5	4.10	4.04	8.32	2.60	4.20	17.03
Soluble protein % of CP	92.94	93.32	93.38	91.17	92.53	28.21	21.2	22.1	21.7	25.08	20.64	43.08	20.00	100.00	26.06
NPN % of SP	24.85	16.91	25.98	20.39	6.06	75.86	80.1	54.4	67.3	61.23	100.00	83.25	95.00	100.00	83.10
ADIP % of CP	3.36	3.39	2.48	6.65	2.73	12.50	13.1	12.4	12.8	37.20	35.45	25.26	65.00	0.00	4.33
NDIP % of CP	7.07	6.68	6.63	8.85	7.47	46.23	52.1	61.0	56.6	70.49	64.55	33.77	75.00	0.00	9.00
NFC % of DM	4.92	9.46	22.41	9.67	6.97	13.42	29.4	24.0	26.7	10.69	14.65	13.25	20.05	82.00	56.60
ADF % of DM	36.44	33.28	36.81	43.95	39.75	40.78	13.5	22.5	18.0	48.96	43.04	33.20	0.00	0.00	4.91
NDF % of DM	70.27	67.37	58.62	68.86	76.75	70.44	39.6	38.7	39.2	73.06	69.48	68.57	75.60	39.10	9.74
Lignin % of NDF	7.77	7.95	14.70	7.22	14.05	7.89	7.7	16.0	11.9	5.90	7.20	8.10	11.30	9.40	3.47
Ash % of DM	9.52	9.62	9.50	9.88	8.75	6.08	6.7	10.0	8.4	8.94	10.23	6.40	1.90	18.50	9.77
Ether extract, % of DM	3.36	4.34	3.39	3.27	3.20	3.13	2.2	6.4	4.3	3.21	1.60	3.46	1.80	1.30	2.20
ME, Meal/kg of DM ^j	1.87	1.99	1.69	2.07	1.24	2.03	2.6	2.5	2.6	1.61	1.51	1.80	1.25	2.01	3.01
TDN ^k	51.74	55.04	46.70	57.26	34.30	56.15	71.1	70.5	70.8	44.53	41.77	49.79	34.57	2.01	2.72

^a From Juárez et al. (2002a, b), 60-day-old cut legume samples^b During the seasons of early and late rains, Genesis herds mostly rotationally graze paddocks of African Star (*Cynodon plectostachyus*) and Llanero (*Andropogon gayanus*) grasses. Llanero grass is mostly grazed during the dry season. Mean composition of these grasses represent the average composition of forages consumed during these seasons. In late rains Llanero grass was used as the improved high quality forage^c Chemical composition of Llanero grass at the beginning of late dry season at the farm of Jacobo Muñiz^d Chemical composition of a sample of Mulato (*Brachiaria ruziziensis* × *Brachiaria brizantha* cv., Mulato) hay obtained at the farm of Jacobo Muñiz. The age of plant regrowth was 90 days when it was made into hay^e Chemical composition of Pangola hay (*Digitaria decumbens*) obtained from the forage market at El Tejar. The assumed plant age at the time of haymaking was 90 days^f Chemical composition of a sample of maize silage from a farm (Las Maravillas) near to the INIFAP–La Posta station. The chemical analysis was conducted at INIFAP^g CNCPS version 6.0 tropical feed library^h The commercial concentrate consists of corn grain ground meal, soybean meal, molasses, urea and minerals and vitaminsⁱ Percentage of dry matter^j Metabolizable energy. Meal per kg of DM predicted by CNCPS v.6.0 model^k Total digestible nutrients estimated from CNCPS-predicted ME as follows: 1 kg TDN=4.409 Meal DE, and DE = ME/.82. % TDN = ((ME/.82)/4.409) × 100

Table 2 Description of three parity groups of cows in Genesis herds^a

Variable	Parity		
	1	2	>2
Body weight at calving, kg	440	506	550 ^e
Average daily gain ^b , kg	0.13	0.10	
Calf birth weight, kg	39	41	42
Calving interval, days	488	427	427
Average daily milk yield, ^{c,d} kg			
Early lactation (90 days)	8.5	9.0	10.0
Mid lactation (90 days)	7.0	8.0	8.5
Late lactation (90 days)	5.0	5.5	6.0
Early dry (128 days ^f)	0.0	0.0	0.0
(67 days ^g)	0.0	0.0	0.0
Late dry (90 days ^h)	0.0	0.0	0.0
Body weight ⁱ (and body condition ^j)			
Early rainy season (Jun 1–July 31)	426 (2.75)	506 (3.00)	550 (3.00)
Late rainy season (Aug 1–Sep 30)	440 (3.00)	506 (3.00)	550 (3.00)
Early dry season (Oct 1–Dec 31)	426 (2.75)	469 (2.75)	550 (3.00)
Late dry season (Jan 1–May 31)	410 (2.50)	470 (2.50)	532 (2.75)

^a The primary breed group is $\frac{3}{4}$ Brown Swiss \times $\frac{1}{4}$ Brahman

^b Average growth rate to reach target weights at subsequent calving

^c Average daily milk yields correspond to the mid-points of each physiological stage of lactation (45, 135, 225 days post-partum). These means correspond to 270-day lactation yields of 1,850, 2,000 and 2,200 kg for these parity groups, consistent with the overall herd average milk yield reported by Genesis members

^d Expected average composition of milk in coastal Veracruz herds: milk fat=3.4%, true protein=3.1%, lactose=4.7% (Cervantes-Acosta et al. 2005)

^e Mature weight is 550 kg with a body condition score of 3.0 units (5-point scale)

^f Average calving interval for primiparous cows calving in all forage seasons (16 months)

^g Average calving interval for second parity and mature cows calving in all forage seasons (14 months)

^h The 90-day period preceding parturition (late gestation)

ⁱ Mature BW is 550 kg with BCS=3.0. A 440-kg primiparous cow and a 506-kg second parity cow have a BCS 3.0. Maximum BW loss is 20% of calving weight for primiparous cows and for others when BCS <3.0. For parities ≥ 2 and BCS ≥ 3.0 , maximum BW loss is 25% of mature weight

^j The BCS at calving were the consensus judgments of a panel of Mexican professionals. Using these reference scores for the season of early rains other BCS were predicted based on expected tissue dynamics and energy balances based on Fox et al. (2004)

Alternative diets to improve herd productivity

Evaluating the potential of alternative diets such as harvested forages of good quality was particularly relevant when seeking

to complement grazed forages and to reduce the need for purchased supplements. Diets including legumes were also evaluated for their potential to improve milk production with more rumen degradable nitrogen and less neutral detergent fiber (NDF), which may enhance feed passage rate and DM intake. Juárez et al. (2002b) provided information on promising legumes for coastal Veracruz. The adoption of better quality feedstuffs implies additional investments in improved grass (i.e., seeds) and capital and labor to establish protein banks (i.e., legume paddocks).

Results and discussion

Typical herd management

We believe this is the first published tropical case study to systematically evaluate interactions among energy balance, milk production and expected growth and, indirectly, their potential effects on calving intervals. Simulation analyses revealed a repeating pattern of key constraints common to all parities and forage seasons of the year. Tables 3 and 4 report results for immature cows: expected BW, body growth, predicted average daily milk production, energy supplies from diet and body tissue and feed energy status throughout calving intervals. Our discussion focuses on primiparous cows calving in the early dry season because this was the most limiting season for every management group.

Primiparous animals (Table 3) typically initiate lactation in the early dry season with a BCS of 2.75 from modest feed energy intake (unsupplemented grazing) during preceding rainy months. Average expected BW at calving was 426 kg. Total dietary intake from grazed forage and feed supplements (molasses, poultry bedding, commercial concentrate and Mulato hay) was predicted to supply about 18.5 Mcal/day of ME. Tissue catabolism contributed another 2.2 Mcal/day of ME to support the average daily allowable milk production (ADAMP) of 9.3 kg during the first 90 days of lactation. Therefore, about 11% of total energy for milk synthesis in early lactation of these cows (and also those in second parity; Table 4) was from the mobilization of 41 kg of body tissue reserves. As a result, immature cows in both parities would conclude this stage of lactation in yet thinner body condition (BCS ~2.00).

In addition to grazing and dietary supplementation, primiparous cows in mid-lactation consumed other forages (4.7 kg/day), including Mulato hay, maize silage and bagasse. This resulted in about 20% greater dietary ME intake in mid-lactation compared to early lactation (22.2 vs. 18.5 Mcal/day of ME). Corresponding ADAMP during this 90-day mid-lactation period was 7.5 kg with 2.8 Mcal ME (3.3 Mcal in second parity; Table 4) also available for tissue repletion.

Table 3 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 in Genesis^a herds calving in the season of scarce rain (October 1) under baseline nutrition management

Item	Lactation			Dry period	
	Early	Mid	Late	Early	Late
Forage season	Early dry	Late dry	Early rains	Late rains	Early dry
Dry matter intake (DMI), kg/day					
Grazed forage ^b	0.0	2.7	4.3	8.7	8.1
Other forage ^c	4.4	4.7	0.6		
Supplement ^d	3.9	3.1	4.8		
Total DMI, kg/day	8.3	10.5	9.7	8.7	8.1
Total dietary energy, Mcal ME/day	18.5	22.2	21.2	15.7	16.2
Total ME supply, Mcal/day ^e	20.7	22.2	21.2	16.9	17.4
Initial body weight (BW), kg ^f	426	385	430	446	415
Mean BW, kg	406	408	438	431	407
End BW, kg	385	430	446	415	398
Initial body condition score (BCS) ^g	2.75	2.00	2.75	2.75	2.50
End BCS ^h	2.00	2.75	2.75	2.50	1.50
ME allowable growth, kg/day ⁱ			0.17		
Total energy requirement, Mcal ME/day ^j	20.8	19.4	21.2	16.9	17.4
Maintenance requirement, Mcal ME/day ^k	11.9	11.5	13.7	16.0	12.4
Pregnancy requirement, Mcal ME/day				0.90	5.00
ME allowable milk production, kg/day ^l	9.3	7.5	5.3		
Feed energy balance, Mcal ME/day ^m	-2.3	2.8	0.0	-1.2	-1.2

^a The Genesis farmer organization is part of a larger association called Grupo Ganadero para la Validación y Transferencia de Tecnología (Cattlemen's Validation and Technology Transfer Group)

^b Average chemical composition of *Cynodon plectostachyus* and *Andropogon gayanus* grasses for the seasons of early and late rains, and *Andropogon gayanus* for scarce and little rain seasons

^c *Brachiaria ruziziensis* × *Brachiaria brizantha* (Mulato) hay, maize silage and sugar cane bagasse for late rains, scarce rain and little rain seasons, respectively

^d Forage-based diets supplemented with poultry manure, molasses and commercial concentrate

^e Total ME supply = dietary ME plus ME from catabolized body tissue reserves

^f Body weight at calving corresponded to the expected weight and BCS for a primiparous cow with mature BW=550 kg and BCS=3.0. Average body weight loss in early lactation was 0.75 units of BCS

^g BCS at calving was the consensus judgment of a professional panel. Other BCS were predicted from assumed BW changes based on Fox et al. (2004)

^h The ending BCS during late gestation corresponds to the expected score at next (second) calving

ⁱ Growth was assumed to be enabled (could occur) after recovery of initial BW and BCS at calving

^j Total ME requirement during lactation includes the energy required for body maintenance and milk production. During the dry period, it includes the ME required for maintenance, repletion of tissue reserves, growth (if it is enabled), and pregnancy

^k Maintenance requirement was a weighted average of those for the parental (Brahman, Brown Swiss) breeds (Fox et al. 2004). Basal maintenance was adjusted for changes in BW and BCS

^l Predicted 270-day lactation milk production was 1,989 kg

^m Feed energy balance = feed energy supply (intake) minus total energy requirements for maintenance, lactation, pregnancy and growth (if allowed). A negative value during lactation represents the expected amount of ME supplied from catabolized body tissues to support milk synthesis. Positive feed energy balance signifies the amount of dietary ME available for tissue repletion (and growth). During late gestation (dry period), a negative value signifies a dietary energy deficit, which means diverting maternal tissue energy to the fetus

Cows in late lactation in this management group coincide principally with the season of early rains, when grazing is supplemented with poultry bedding, molasses, commercial concentrate and bagasse. The dietary supply of ME was

predicted to support an ADAMP of 5.3 kg (5.6 kg for second parity; Table 4). In addition, modest daily growth of about 0.17 kg (0.15 kg/day for second parity) was expected during this stage of lactation, increasing BW by

Table 4 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 in Genesis^a herds calving in the early dry season (October 1) under baseline nutrition management

Item	Lactation			Dry period	
	Early	Mid	Late	Early	Late
Forage season	Early dry	Late dry	Early rains	Late rains	Early rains
Dry matter intake (DMI), kg/day					
Grazed forage ^b	0.5	3.5	5.1	10.2	9.2
Other forage ^c	4.4	4.7	0.6		
Supplement ^d	4.2	3.3	5.0		
Total DMI, kg/day	9.1	11.5	10.7	10.2	9.2
Total dietary energy, Mcal ME/day	20.2	24.6	23.3	18.3	18.4
Total ME supply, Mcal/day ^e	22.7	24.6	23.3	19.0	20.0
Initial body weight (BW), kg ^f	489	445	495	508	497
Mean BW, kg	467	470	502	503	487
End BW, kg	445	495	508	497	476
Initial body condition score (BCS) ^g	2.75	2.00	2.75	2.75	2.75
End BCS ^h	2.00	2.75	2.75	2.75	2.00
ME allowable growth, kg/day ⁱ			0.15		
Total energy requirement, Mcal ME/day ^j	22.7	21.3	23.3	19.0	20.0
Maintenance requirement, Mcal ME/day ^k	13.2	12.9	15.3	18.1	14.7
Pregnancy requirement, Mcal ME/day			0.20	0.90	5.30
ME allowable milk production, kg/day ^l	9.9	8.0	5.6		
Feed energy balance, Mcal ME/day ^m	-2.5	3.3	0.0	-0.7	-1.6

^a The Genesis farmer organization is part of a larger association called Grupo Ganadero para la Validación y Transferencia de Tecnología (Cattlemen's Validation and Technology Transfer Group)

^b Average chemical composition of *Cynodon plectostachyus* and *Andropogon gayanus* grasses for the seasons of early and late rains, and *Andropogon gayanus* for scarce and little rain seasons

^c *Brachiaria ruziziensis* × *Brachiaria brizantha* (Mulato) hay, maize silage and sugar cane bagasse for late rains, scarce rain and little rain seasons, respectively

^d Forage-based diets supplemented with poultry manure, molasses and commercial concentrate

^e Total ME supply = dietary ME plus ME from catabolized body tissue reserves

^f Body weight at calving corresponded to the expected weight and BCS for a primiparous cow with mature BW=550 kg and BCS=3.0. Average body weight loss in early lactation was 0.75 units of BCS

^g BCS at calving was the consensus judgment of a professional panel. Other BCS were predicted from assumed BW changes based on Fox et al. (2004)

^h The ending BCS during late gestation corresponds to the expected score at next (third) calving

ⁱ Growth was assumed to be enabled (could occur) after recovery of initial BW and BCS at calving

^j Total ME requirement during lactation includes the energy required for body maintenance and milk production. During the dry period, it includes the ME required for maintenance, repletion of tissue reserves, growth (if it is enabled), and pregnancy

^k Maintenance requirement was a weighted average of those for the parental (Brahman, Brown Swiss) breeds (Fox et al. 2004). Basal maintenance was adjusted for changes in BW and BCS

^l Predicted 270-day lactation milk production was 2,115 kg

^m Feed energy balance = feed energy supply (intake) minus total energy requirements for maintenance, lactation, pregnancy and growth (if allowed). A negative value during lactation represents the expected amount of ME supplied from catabolized body tissues to support milk synthesis. Positive feed energy balance signifies the amount of dietary ME available for tissue repletion (and growth). During late gestation (dry period), a negative value signifies a dietary energy deficit, which means diverting maternal tissue energy to the fetus

16 kg (13 kg for second parity). Predicted average milk production for a 270-day lactation was 1,989 kg (2,115 kg for second parity).

Dietary energy during the 128-day dry period (67 days for second parity) following the first (second) lactation came

from unsupplemented grazing during rainy months. This diet was insufficient to meet the total energy requirement. Consequently, 31 kg (11 kg for second parity) of BW loss was predicted from an average daily ME deficit of 1.2 Mcal (0.7 Mcal for second parity), which resulted in an ending

BW of 415 kg (497 kg). Also associated with this diet for both parity groups were 370% more peptides and 120% more rumen ammonia than required, which resulted in a daily urea excretion penalty of 0.29 Mcal (0.34 Mcal for second parity) ME.

Late gestation for immature cows coincides with the subsequent early dry season when the grazed forage supply is limited. Consequently, primiparous cows were expected to be unable to obtain the target BW of 500 kg with a BCS of 3.0 at second calving. Predicted intake was insufficient to support the expected rapid fetal growth of late gestation, which forced cows in this stage of the calving interval to catabolize tissue reserves. This period of negative feed energy balance resulted in thinner cows at second and third calvings than at their previous parturitions. Other things being equal, milk production and postpartum interval to the reinitiation of ovarian cyclicity in second and third lactations likely would be jeopardized by smaller pools of body tissue reserves.

The same pattern of input–output relationships and dry period energy deficit identified in young cows was also repeated in mature cows (Absalón-Medina 2008). The predicted average 270-day milk production of mature cows was 2,331 kg. This and other predictions were consistent with the observed overall Genesis herd milk production of 2,000 kg/lactation per cow.

This analysis clearly revealed vulnerabilities in young cows, especially low feed energy status during the dry period and slow growth rates. These outcomes represent major direct and indirect constraints (e.g., physiological transition) on subsequent lactation and reproductive performance. Furthermore, most second parity cows (i.e., those calving in late and scarce rains) ended gestation in thinner body condition (or arrested growth) than they were in the previous reproductive cycle. Consequently, mature cows (except those calving in the late dry season) encountered the same bottleneck as immature ones. All cows were forced to mobilize tissue energy reserves to support increased demands by the fetus, which resulted in thin animals at next lactation. In turn, depressed tissue reserves predispose cows to longer calving intervals with diminished milking performance.

Under the assumptions for typical management, preponderant energy deficits during the dry period revealed nonlactating cows of all ages as a particularly vulnerable management group. Although our Veracruz scenario is of different scale, this result is in general agreement with findings by Overton and Waldron (2004) for underfed transition cows in US dairy herds. Another indication of this finding is that calving intervals in these Veracruz herds frequently may be longer than the assumed mean values of 14 and 16 months, in agreement with Reynoso et al. (2004).

Dietary supplies of ME were chronically insufficient for desired growth of immature cows, portending smaller cows

with less DMI capacity, curtailed milk production and probable delays in postpartum return to ovarian cyclicity (Butler 2003). Therefore, insufficient energy for growth probably reduces cow productivity in the coastal region. Excess dietary protein may further aggravate this due to the energy costs of ammonia-to-urea conversion.

Alternative diets based on harvested forage of good quality

The early dry season of calving was the target scenario for dietary improvement to provide all cows with more ME and more MP. Consequently, alternative diets consisted of either hay or maize silage equivalent in feeding quality to the Llanero hay already produced by Genesis farmers. Diets supplemented with good quality harvested forage (Table 5) supplied 16% more ME in early lactation than typical ones for primiparous cows, resulting in a one-third increase in daily yield to about 12.2 kg. Furthermore, this milk would be obtained with less reliance on body tissue reserves to support milk synthesis compared to typical management.

During mid-lactation primiparous cows were predicted to consume about 14% more energy than under typical management. Corresponding average ADAMP was 9.9 kg with about 25% more ME available for repleting lost tissues compared to the baseline scenario.

In late lactation, these cows were predicted to produce an average of 7.0 kg/day from a dietary energy supply that was also sufficient to support about 25 kg of growth, or 25% more than under typical management. About one-third more total milk was expected during first lactation compared to typical management, increasing from 1,989 to 2,614 kg.

The expected daily dietary energy supply during the early dry period was about 24% more than from typical management, which supported about 36 kg of body growth for this management group. Furthermore, primiparous cows receiving this management did not require supplementation with grain.

Cows in late gestation were predicted to consume sufficient energy to maintain BW and to satisfy fetal growth requirements. Expected BW and BCS at second calving were 506 kg and 3.0 units. In this case about one-half as much sorghum grain supplementation, 2.2 vs. 5.0 kg/day, was required to achieve this goal compared to baseline management (Absalón-Medina 2008).

Like primiparous cows, the predicted dietary intakes (Table 5) in second lactation were expected to supply about 16% more ME than the baseline diet (23.4 vs. 20.2 Mcal/day of ME). As a result, these cows were expected to improve ADAMP in early lactation by about one-third, yielding about 13.0 instead of 9.9 kg. Moreover, they also relied less on the mobilization of body tissue reserves to support lactation than counterparts with baseline management. Increased dietary energy intakes in mid and late lactation provided sufficient energy to support an ADAMP

Table 5 Expected dry matter intakes, metabolizable energy (ME) allowable milk production, and feed energy balances throughout the calving interval for all parity cows in Genesis^a herds calving in the early dry season (October 1) fed good quality harvested forage during lactation and harvested forage supplemented by sorghum grain during the cow's dry period

Item	Lactation			Dry period	
	Early	Mid	Late	Early	Late
Forage season	Early dry	Late dry	Early rains	Late rains	Early dry
Primiparous cows					
Dry matter intake (DMI), kg/day					
High quality harvested forage ^b	4.4	4.7	0.6	8.5	5.7
Supplement ^c	3.9	3.1	4.8		
Sorghum ^d					2.2
Total DMI, kg/day	8.3	10.5	9.7	8.5	7.9
ME allowable milk production, kg/day ^e	12.2	9.9	7.0		
ME allowable growth, kg/day ^f			0.27	0.27	
Feed energy balance, Mcal ME/day ^g	-1.7	3.5	0.0	0.0	0.0
Second parity cows					
Dry matter intake (DMI), kg/day					
High quality harvested forage ^b	4.4	4.7	0.6	7.7	7.8
Supplement ^c	4.2	3.3	5.0		
Sorghum ^d				0.4	1.5
Total DMI, kg/day	9.1	13.1	12.3	8.1	9.3
ME allowable milk production, kg/day ^e	13.0	10.5	7.4		
ME allowable growth, kg/day ^f		0.78	0.36		
Feed energy balance, Mcal ME/day ^g	-1.8	6.3	0.0	0.0	0.0
Multiparous cows					
Dry matter intake (DMI), kg/day					
High quality harvested forage ^b	4.4	4.7	0.6	7.9	8.8
Supplement ^c	4.4	3.5	5.2		
Sorghum ^d					0.5
Total DMI, kg/day	10.4	12.2	11.0	7.9	9.3
ME allowable milk production, kg/day ^e	15.1	12.4	9.2		
Feed energy balance, Mcal ME/day ^g	-2.2	2.3	1.5	0.0	0.0

^aThe Genesis farmer organization is part of a larger association called Grupo Ganadero para la Validación y Transferencia de Tecnología (Cattlemen's Validation and Technology Transfer Group)

^bHarvested forage was assumed to have the same chemical composition as *Andropogon gayanus* of season two; it could be fed as hay or silage.

^cForage-based diets supplemented with poultry manure, molasses and commercial concentrate (amounts shown in Table 8 in Absalón-Medina 2008)

^dSorghum chemical information is from CNCPS v. 6.0 Tropical feed library

^ePredicted 270-day lactation milk production for first parity, second parity and mature cows was 2,614, 2,768 and 3,303 kg, respectively.

^fGrowth was assumed to be enabled (could occur) after recovery of initial BW and BCS at calving

^gFeed energy balance = feed energy supply (intake) minus total energy requirements for maintenance, lactation, pregnancy and growth (if enabled). A negative value during lactation represents the expected amount of ME supplied from catabolized body tissues to support milk synthesis. Positive feed energy balance signifies the amount of dietary ME available for tissue repletion (and growth). During late gestation (dry period), a negative value signifies a dietary energy deficit, which means diverting maternal tissue energy to the fetal unit

of 10.5 and 7.4 kg, respectively. In addition, sufficient ME and MP were available for tissue repletion and growth. The predicted average 270-day milk yield in second lactation was 2,768 kg, about one-third more than under typical management.

The predicted dietary energy supply in the early dry period (18.7 Mcal/day of ME) was sufficient to maintain the already-

achieved target BW for third calving. A small average daily amount (0.4 kg) of sorghum grain was required to obtain this goal. The target BW and BCS were maintained during late gestation. About 1.5 kg/day of sorghum grain was required during this stage of the calving interval.

As for young cows, mature cows also benefited from greater energy intake by repleting tissue reserves and

producing more milk (Absalón-Medina 2008; Aguilar-Pérez et al. 2009). About 40% more milk, 3,303 kg, was expected for a 270-day lactation compared to cows receiving typical management.

For all management groups, predicted intakes for diets containing good quality harvested forage supplied about 16% more ME than those typically consumed. Consequently, ADAMP in early lactation was expected to increase by one-third and with less reliance on tissue reserves.

All cows in mid-lactation were predicted to consume from 11% to 25% more ME than counterparts receiving typical management. Corresponding average energy available milk production was predicted to be about 30% to 40% greater than for the baseline scenario. In addition, all parity groups were expected to have sufficient ME to replete catabolized tissues and for young cows to have sufficient ME to support growth. Similar milking responses were observed by Fujisaka et al. (2005) and Argel (2006) from improved forage quality.

Scenarios including legume forage

The substitution of legume forage for poultry bedding was predicted to result in about one-fifth more milk in all parity groups compared to diets based on good quality grass supplemented with sorghum grain. Compared to typical management the combination of good quality grass and legume forages resulted in about 60% more milk. Consequently, predicted 270-day milk production was 3,129 kg for primiparous cows, 515 kg more than from diets with good-quality harvested grass only; 3,313 kg for cows in second parity, an increase of 545 kg; and 3,699 kg for mature cows, 396 kg more milk than from grass only. Although dietary protein in typical diets was in excess under typical management, legume addition supports greater milk yields by enhancing dietary protein content and digestibility (Ramírez-Restrepo and Barry 2005). Other things equal, expected outcomes include greater total feed intake and more milk.

Cumulative effects of good quality harvested forage

Greater intake of dietary energy from better quality harvested grass resulted in cows expected to obtain larger body size, desirable tissue status and more milk production than with typical management (Table 6). As a result, the predicted second lactation performance of 3,536 kg increased by two-thirds, or 1,421 kg, compared to the typical scenario. Predicted milk in third lactation was 3,929 kg, an increase of 1,598 kg. Thus, results show that larger cows were less vulnerable than their counterparts to energy deficiencies throughout productive lifetime by growing and consuming more forage, and obtaining heavier BW with desirable pools of tissue reserves. Greater feed intake capacity by larger cows of all ages,

especially from good quality forage, should be expected to underwrite higher lifetime milk production also with more calves per cow lifetime (Overton and Waldron 2004; Blake 2008; Szabó and Dákay 2009).

Cumulative effects of legume forage

In these simulations, second parity and multiparous cows received good quality harvested grass alone or with forage legume instead of poultry bedding. Cows were predicted to consume more dietary energy than counterparts not receiving legume forage (Table 6). As a result, 8% more milk in second parity was predicted (3,834 vs. 3,536 kg) compared to the cumulative case with high-quality harvested grass only. Likewise, third parity cows receiving high-quality grass plus legume improved lactation performance from 3,929 to 4,260 kg compared to the grass diet. Consequently, the forage quality substitution for mediocre grazing is expected to potentially increase milking performance by about one-third (625 kg in first, 653 in second and 972 kg more milk in third lactation) over typical scenarios for underweight cows. However, if cows grow from first parturition to achieve desirable BW, milk production in second and third lactations would improve substantially, about 60%, with predicted increases of 1,421 and 1,598 kg. Judiciously supplemented diets based on forage of good quality, including legumes, starting at first calving were predicted to further improve animal performance. About 80% more milk would be expected (i.e., from group management with CNCPS monitoring and properly supplemented diets based on good forage quality) compared to the typical nutritional regime.

Conclusions

Our findings pinpointed key biological (energy) and management limitations in dual-purpose cattle herds in the central coastal region of Veracruz. Results showed accurate representation of typical lactation productivity scenarios for Genesis herds, and revealed cow herd vulnerabilities from chronic energy deficits among dry cows of all ages and impeded growth among immature cows. Regardless of the forage season of calving, most, if not all, cows incur energy deficits in their dry periods, especially the last trimester of gestation. These energy deficits signify less total milk per cow over their productive lifetimes.

High-quality harvested forage increased milk yields by about one-third over typical management. When diets from first parturition properly supported cow growth and tissue repletion to obtain desirable BW, milk production in second and third lactations was improved about 60%. Judiciously supplemented diets that also incorporated legume forages starting at first calving were predicted to further increase

Table 6 Expected dry matter intakes, metabolizable energy (ME) allowable milk production, and feed energy balances throughout the calving interval for second and third parity cows calving in the early dry season (October 1) and receiving supplemental higher quality harvested forage and sorghum grain without^a or with^b legumes since their first calving interval in Genesis^c herds

Item	Lactation			Dry period	
	Early	Mid	Late	Early	Late
Forage season	Scarce rain	Little rain	Early rains	Late rains	Scarce rain
Second parity cows ^a					
Dry matter intake (DMI), kg/day					
High quality harvested forage ^d	4.4	4.7	0.6	7.1	7.3
Supplement ^e	4.2	3.3	5.0		
Sorghum ^f				0.3	1.7
Total DMI, kg/day	11.1	13.0	11.6	7.4	9.0
ME allowable growth, kg/day ^g		0.12	0.22		0.09
ME allowable milk production, kg/day ^h	16.5	13.4	9.4		
Feed energy balance, Mcal ME/day ⁱ	-2.0	3.1	0.0	0.0	0.0
Second parity cows ^b					
Dry matter intake (DMI), kg/day					
High quality harvested forage ^d	4.4	4.7	0.6	7.7	7.8
Supplement ^e	3.4	2.5	3.4		
Legume ^f	1.6	0.8	0.8		
Sorghum ^f				0.4	1.4
Total DMI, kg/day	11.4	14.2	13.3	8.1	9.2
ME allowable growth, kg/day ^g		0.78	0.33		
ME allowable milk production, kg/day ^h	18.5	13.7	10.4		
Feed energy balance, Mcal ME/day ⁱ	-2.0	5.4	0.0	0.0	0.0
Third parity cows ^a					
Dry matter intake (DMI), kg/day					
High quality harvested forage ^d	4.4	4.7	0.6	7.6	8.5
Supplement ^e	4.4	3.5	5.2		
Sorghum ^f					0.5
Total DMI, kg/day	12.6	12.9	11.0	7.6	9.0
ME allowable milk production, kg/day ^h	18.3	14.8	10.5		
Feed energy balance, Mcal ME/day ⁱ	-1.9	0.0	0.4	0.0	0.0
Third parity cows ^b					
Dry matter intake (DMI), kg/day					
High quality harvested forage ^d	4.4	4.7	0.6	8.1	8.2
Supplement ^e	3.6	2.7	3.6		
Legume ^f	1.6	0.8	0.8		
Sorghum ^f					1.0
Total DMI, kg/day	12.3	14.1	12.0	8.1	9.2
ME allowable milk production, kg/day ^h	19.9	16.1	11.4		
Feed energy balance, Mcal ME/day ⁱ	-2.1	2.4	1.8	0.0	0.0

^a Cows calving in the early dry season (October 1) receiving supplemental higher quality harvested forage and sorghum grain without legumes since first calving interval

^b Cows calving in the early dry season (October 1) receiving supplemental higher quality harvested forage and sorghum grain with legumes since first calving interval

^c The Genesis farmer organization is part of a larger association called Grupo Ganadero para la Validación y Transferencia de Tecnología (Cattlemen's Validation and Technology Transfer Group)

^d Harvested forage was assumed to have the same chemical composition as *Andropogon gayanus* of season two; it could be fed as hay or silage

^e Forage-based diets supplemented with poultry manure, molasses and commercial concentrate (amounts shown in Table 8 in Absalón-Medina 2008)

^f Average value of *Glyricidia sepium* and *Leucaena leucocephala*. This legume substituted the poultry bedding supplementation. Sorghum chemical information is from CNCPS v. 6.0 Tropical feed library

^g Growth was assumed to be enabled (could occur) after recovery of initial BW and BCS at calving

^h Predicted 270-day lactation milk production for second (high-quality grass=3,536 kg; high-quality grass + legume=3,834 kg) and third parity (high-quality grass=3,929 kg; high-quality grass + legume=4,260 kg)

ⁱ Feed energy balance = feed energy supply (intake) minus total energy requirements for maintenance, lactation, pregnancy and growth (if enabled). A negative value during lactation represents the expected amount of ME supplied from catabolized body tissues to support milk synthesis. Positive feed energy balance signifies the amount of dietary ME available for tissue repletion (and growth). During late gestation (dry period), a negative value signifies a dietary energy deficit, which means diverting maternal tissue energy to the fetal unit

productivity by about 80% (i.e., from group management with CNCPS monitoring and properly supplemented diets with good forage quality). Based on the available information, Genesis farmers, and probably many other dual purpose herd owners in coastal Veracruz, apparently have large incentives to increase milk sales by implementing nutritional management strategies like those considered in this study.

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