Published January 31, 2017

High milk production decreases cow-calf productivity within a highly available feed resource environment

S. R. Edwards,* J. D. Hobbs,* and J. T. Mulliniks*[1]

*Department of Animal Science, University of Tennessee, Knoxville 37996

ABSTRACT: The beef cattle industry tends to focus on selecting production traits with the purpose of maximizing cow-calf performance. One such trait is milking ability, which is considered the primary influence on weaning weight of the calf. Therefore, the objective of this study was to determine the effect of actual milk yield on reproductive performance, circulating blood metabolites, and calf performance in beef cows in the Southeastern US. Over a 2 yr period, data were collected from 237, 3- to 9-yr-old Angus-sired beef cows on 3 research stations in Tennessee. On approximately d 58 and 129 postpartum, 24-hr milk production was measured with a modified weigh-suckle-weigh technique using a milking machine. Subsamples of milk were collected for analysis of milk components. Milk yield data were used to retrospectively classify cows on actual milk yield as High (≥ 10 kg/d), Mod (8 to 9 kg/d), or Low (< 8 kg/d). Cow body weight (BW) and body condition score (BCS) were collected weekly at each location through breeding. Calf BW was recorded at birth, mid-weight at d 58, and weaning. At d 58 and 129 of postpartum, milk yields were different ($P < 0.001$) among the treatment groups. Cow BW during the entire study were not different ($P \geq 0.22$) with increasing milk yield. Timed-AI pregnancy rate were the lowest ($P = 0.02$) in the High milk producing cows with no difference ($P > 0.05$) between Low and Mod milk cows. In addition, overall pregnancy rate continued to be the lowest ($P = 0.04$) in High milk producing cows with the greatest pregnancy rate in Mod milk cows. Calf mid-weight at ~d 58 was increased ($P < 0.001$) in calves from Mod and High milking cows. However, calf BW at weaning was not different ($P = 0.22$) among calves from different milk treatment groups. Results from this study suggest that even in management systems that modify the grazing environments with harvested feedstuffs, high milk production decreases reproductive efficiency. In addition, increasing milk production up to d 129 postpartum did not result in increased calf BW at weaning, indicating that the genetic potential for calf BW at weaning could not be improved with increased genetic potential for milk production.

Key words: beef cattle, calf performance, milk production, reproduction

Transl. Anim. Sci. 2017.1:54–59
doi:10.2527/tas2016.0006

INTRODUCTION

Focus in the beef industry has been to maximize profit by using trait selection. In doing so, cow-calf producers have tended to select for short-term traits such as growth and milk yield to increase weaning weights of calves for the potential to increase profitability (Lewis et al., 1990). These selection traits do play a role in profitability for cow-calf producers; however, calf body weight (BW) at weaning, for instance, only accounts for 5% of profitability for the producer in a profit model (Miller et al., 2001). Therefore, selection and management practices should be more focused on variables that play a large role in profitability.

Selection for increased milk yield results in an increase in cow maintenance energy requirements (Neville and McCullough, 1969; Ferrell and Jenkins, 1985; and Montaño-Bermudez et al., 1990). Therefore, there is a higher input cost of feed to maintain cows with a greater milk yield (van Oijen and Nielsen, 1993). With feed costs accounting for 63% of annual cow cost (Miller et al., 2001), producers may instead focus on decreasing the high-input cost that is associated with high maintenance beef cows

[1]Corresponding author: jmulli@utk.edu
Received October 17, 2016.
Accepted November 10, 2016.

(Lalman et al., 2013; Mulliniks et al., 2015). Although growth and milk selection traits may increase production by increasing calf weight at weaning, the additional cost to maintain production goals with increased milk production may decrease profitability. Therefore, the objective of this study was to evaluate the effects of actual milk yield in mature beefs cows on pregnancy rates, cow BW, cow body condition score (BCS), calf BW and gain. The hypothesis is that cows with high milk yield will not have an increased advantage in productivity in a high feed resource available environment of Tennessee.

MATERIALS AND METHODS

The Institutional Animal Care and Use Committee of University of Tennessee, Knoxville approved all described animal handling and experimental procedures.

In a 2-yr study, 237 spring-calving Angus and Angus crossbred, cows (3- to 9-yr-old; 620.38 ± 9.54 kg) were used to determine the influence of milking potential on reproduction and calf performance at 3 research stations across the state of Tennessee [Plateau Research and Education Center (PREC), Crossville, TN; Middle Tennessee Research and Education Center (MTREC), Spring Hill; Highland Rim Research and Education Center (HRREC), Springfield, TN]. Predominate forage of the pastures were endophyte-infected tall fescue (*Festuca arundinacea* Screb). Tennessee has a moderate climate environment with an average of 1,397 mm annual precipitation and an estimate of 6,734 kg/ha of standing forage (G.E. Bates, University of Tennessee, Knoxville, personal communication).

On approximately d 58 and 129 postpartum, cow milk yield was measured using a modified version of weigh-suckle-weigh method described by Mulliniks et al. (2011). Cows were milked using a portable milking machine (Porta-Milker, Coburn Company Inc., Whitewater, WI). On the day of the milking, cows were gathered from their pasture and calves were removed. Ten minutes before milking, cows were administered an intravenous injection of oxytocin (20 IU; Vedo Inc., St. Joseph, MO) to facilitate milk letdown. Cows were milked until machine pressure could not extract any additional fluid, and milk collected was subsequently discarded. After first milking, cows were kept separate from calves for 3 ± 0.7 h and then milked a second time. Milk weights were recorded to calculate 24-h milk production. An aliquot was collected to analyze for milk protein, butterfat, lactose, and solids non-fat (SNF) by Dairy Herd Lab of Tennessee (DHIA; Knoxville, TN). After milking, cows were retrospectively classified as 1 of 3 milk yield groups: Low (n = 74; 6.57 ± 1.21 kg), Mod (n = 71; 9.02 ± 0.60 kg), or High (n = 92; 11.97 ± 1.46 kg).

Depending on location, management practices varied. At the MTREC and HRREC locations, cows were managed as 1 group in a single pasture. Cows at PREC were managed in 2 groups in 2014 and 3 groups in 2015, in adjacent pastures with treatments evenly distributed. From December to May in each yr, cows were fed ad libitum corn silage [9% CP, 47% neutral detergent fiber (NDF); 65.2% total digestible nutrients (TDN)] at PREC, rye haylage [8% crude protein (CP), 61% NDF; 58.6% TDN] with 5% corn distillers grain (30% CP, 88% TDN) at HRREC, and orchard grass hay (17% CP, 48% NDF; 55.2% TDN) at MTREC. Forage samples were ground with a Wiley mill (Thomas Scientific, Swedesboro, NJ) before analysis was performed. Crude protein analysis was determined by combustion (Leco-NS2000, Leco Corp., St. Joseph, MI). Neutral detergent fiber concentrations were determined using by a fiber analyzer vessel using methods described by ANKOM Technology (ANKOM A200, ANCOM Technology, Macedon, NY).

Calves were born in January and early February (avg. January 26th ± 28 d). Approximately 30-d after calving, cows were weighed weekly until the termination of the breeding season. Body condition scores were assigned to each cow (1 = emaciated, 9 = obese; Wagner et al., 1988) based on visualization and palpation by a trained technician once weekly to the end of the breeding season. Calf BW was determined at birth, adjusted 55-d weight, and adjusted 205-d weight with no adjustment for sex of calf or age of dam.

Starting at approximately 35 d postpartum until the end of the breeding season, blood samples (~9 mL) were collected weekly via coccygeal venipuncture into serum separator tube (Corvac, Kendall Health Care, St. Louis, MO). After collection, blood was cooled and centrifuged at 2000 × g at 4 for 30 min. Serum was harvested and stored in plastic vials at -4 for later analysis. To evaluate nutrient status, serum samples were then composited by cow within 2 physiological periods: 1) pre-breeding and 2) artificial insemination (AI) to end of breeding. Composite samples were analyzed using commercial kits for glucose (Infinity, Thermo Fischer Scientific, Waltham, MA), serum urea N (SUN; Infinity, Thermo Fischer Scientific) and nonesterified fatty acids (NEFA; Wako Chemicals, Richmond, VA). Insulin was analyzed by solid-phase radioimmunoassay (RIA; DCP kit, Diagnostic Products Corp., Los Angeles, CA). Inter- and intra-assay CV were < 10% for all serum metabolites.

In April of each yr, cows were synchronized using a controlled internal drug-releasing (CIDR) device (Eazi-Breed CIDR, Zoetis Inc., Kalamazoo, MI) with 7-d CO-Synch + CIDR protocol. Cows were administered a single 2-mL intramuscular (i.m.) injection of GnRH (Cystorelin, Merial LTD., Duluth, GA) and CIDR at the beginning of the synchronization protocol. Seven d later, CIDR was removed and cows were injected with 5-mL i.m. injection of prostaglandin $F_{2\alpha}$ (Lutelyse, Zoetis Inc.). Approximately 66 h after CIDR removal, all cows were given an i.m. injection of 2 mL gonadotropin-releasing hormone (GnRH; Cystorelin, Merial) and artificially inseminated. Fourteen d after timed-AI occurred, cleanup bulls were utilized for natural service with a cow-to-bull ratio of 1:20 at PREC, and 1:30 at MTREC and HRREC. After timed-AI, cows were managed together by location in a 60 ± 5 d breeding season. Pregnancy diagnosis was determined 30 d after timed-AI and an overall pregnancy diagnosis was determined in September. Pregnancy diagnosis was determined at PREC by circulating concentrations of pregnancy-specific protein B (BioPRYN, Golden Standard Labs, Bowling Green, KY) and by transrectal ultrasonography at HRREC and MTREC.

Normality of the data distribution and equality of variances of measurements were evaluated using PROC UNIVARIATE and the Levene test and White's test, respectively. Data were analyzed as a complete randomized design, using a mixed procedure of SAS 9.4 (SAS Inst. Inc., Cary, NC). Cow was used as the experimental unit with the Kenward-Roger degrees of freedom method. The model included fixed effects of milk treatment, location, age of dam, sex of calf, yr and their interactions. Differences in pregnancy rates were analyzed using logistic regression (PROC GLIMMIX) utilizing a model that included the fixed effects of treatment, location, age of dam, yr and their interactions. Serum metabolite concentrations were analyzed with productive period as the repeated factor and cow as the subject with compound symmetry as the covariance structure. The model included treatment, location, period of measurement, age of dam, and their interactions. Significance was determined at $P \leq 0.05$ using least significant difference (**LSD**) mean separation. Milk production level did not interact with cow age, location, or yr and thus will not be presented.

Table 1. Level of milk production × milking date[1] interaction ($P \leq 0.01$) for 24-hr milk production and milk components of beef cows

	Milk production[2]			
Measurement	Low	Mod	High	SEM
24-hr milk production, kg				
d58	6.8^{ax}	8.9^{bx}	12.7^{cx}	0.3
d129	6.0^{ax}	8.8^{bx}	11.0^{cy}	0.3
Milk fat, %				
d58	2.33^{ax}	2.81^{bx}	3.24^{cx}	0.13
d129	2.01^{ay}	2.16^{ay}	2.29^{ay}	0.12
Milk protein, %				
d58	2.71^{ax}	2.70^{ax}	2.82^{bx}	0.04
d129	3.01^{ay}	2.94^{ay}	2.99^{ay}	0.04
Milk lactose, %				
d58	5.13^{ax}	5.21^{ax}	5.24^{ax}	0.04
d129	4.46^{ay}	4.51^{ay}	4.54^{ay}	0.04
Milk solids-non-fat, %				
d58	11.47^{ax}	11.96^{bx}	12.63^{cx}	0.15
d129	10.40^{ay}	10.50^{ay}	10.66^{ay}	0.14

[a–c]Means with different superscripts differ among milk production groups ($P \leq 0.05$).

[x,y]Means with different superscripts differ between timing of milking ($P \leq 0.05$).

[1]Milking dates: d 58 and 129 of lactation.

[2]Milk production groups: Low (6.57 ± 1.21 kg), Mod (9.02 ± 0.60 kg), or High (11.97 ± 1.46 kg).

RESULTS AND DISCUSSION

Milk Yield and Milk Components

Level of milk production did interact ($P < 0.01$; Table 1) with milking date. Due to retrospective-designed treatments, 24-hr milk yield was different ($P < 0.05$) among treatment groups at both milking dates. However, milk production did not decrease ($P \geq 0.10$) from d 58 to d 129 for Low and Mod milking cows, whereas High milk cows decreased ($P < 0.01$) milk production from d 58 to d 129. Similarly, a milk production level × milking date interaction occurred for the milk components (fat, protein, lactose, and solids-non-fat; $P < 0.01$). Milk fat and solids-non-fat increased ($P < 0.05$) with increasing milk production at d 58 milking date. At milk d 58, milk protein percentage was not different ($P = 0.91$) between Low and Mod milking cows; however, High milking cows had an increase ($P < 0.05$) in protein percentage. On the other hand, milk lactose percent was not different ($P > 0.06$) among milk production groups at d 58. From milk d 58 to 129, milk components (fat, lactose, and solids-non-fat) decreased ($P < 0.05$) across all 3 milk production groups; where milk protein increased from d 58 to d 129. Furthermore, all milk components were similar ($P > 0.05$) at d 129 among the milk production groups. Marston et al. (1992) reported that with an increase in milk yield there was an increase in lactose, and a decrease in milk fat. In addition, Rutledge et al. (1971) also reported that fat decreases when milk level increases. With an increase in fat, protein, and solids in High milk cows during early lactation, calves from this study receiving an increase in milk may have an advantage in pre-weaning gain. In agreement, milk with higher fat and protein has been associated with improved pre-weaning weight gain of calves (Brown et al., 2001). In contrast, Rutledge et al. (1971) reported that milk quantity was more in important that milk quality on 205-d BW in calves.

Effects of Milk Yield on Cow Performance

Cow BW during the entire study were not different ($P \geq 0.22$; Table 2) with increasing milk yield. In

Table 2. Effect of milk production level on body weight (BW) and body condition score (BCS) for beef cows

	Milk production[1]				
Measurement	Low	Mod	High	SEM	*P*-value
Cow BW, kg					
Calving	646	622	616	15	0.22
Beginning of Breeding	617	595	592	15	0.36
Nadir	596	573	573	16	0.42
End of Breeding	648	624	620	14	0.25
BCS					
Calving	5.2	5.2	5.2	0.2	0.99
Breeding	5.0	5.0	5.1	0.2	0.96
End of Breeding	5.4	5.3	5.5	0.2	0.23

[1]Milk production groups: Low (6.57 ± 1.21 kg), Mod (9.02 ± 0.60 kg), or High (11.97 ± 1.46 kg).

Table 3. Effect of milk production level on artificial insemination (AI) and final pregnancy rate for beef cows

	Milk production[1]				
Measurement	Low	Mod	High	SEM	*P*-value
AI pregnancy rate, %	57^{a}	55^{a}	44^{b}	3	0.02
Final pregnancy rate[2], %	81^{a}	86^{b}	75^{c}	2	0.03

[a–c]Means with different superscripts differ ($P \leq 0.05$).

[1]Milk production groups: Low (6.57 ± 1.21 kg), Mod (9.02 ± 0.60 kg), or High (11.97 ± 1.46 kg).

[2]Final pregnancy rate after a 60 ± 5 d breeding season with cleanup bulls.

Table 4. Effect of milk production level on serum metabolites for beef cows

	Milk production[1]				
Measurement	Low	Mod	High	SEM	*P*-value
Metabolites[2]					
Glucose, mg/dL	65	65	67	8	0.98
Urea N, mg/100 mL	12.2	12.8	12.9	3	0.75

[1]Milk production groups: Low (6.57 ± 1.21 kg), Mod (9.02 ± 0.60 kg), or High (11.97 ± 1.46 kg).

[2]Level of milk production did not interact with physiological period of composite samples, therefore, metabolites were pooled across periods.

Table 5. Level of milk production × physiological period interaction ($P < 0.05$) for serum metabolites of beef cows

	Milk production[1]			
Measurement	Low	Mod	High	SEM
NEFA, μmol/L				
Prebreeding	609^{ax}	710^{bx}	762^{bx}	25
Breeding	436^{ay}	439^{ay}	455^{ay}	21
BHB[2], μmol/L				
Prebreeding	227^{ax}	233^{ax}	225^{ax}	11
Breeding	237^{ax}	256^{ax}	253^{ay}	11
Insulin, ng/mL				
Prebreeding	0.27^{ax}	0.24^{ax}	0.24^{ax}	0.03
Breeding	0.39^{ay}	0.30^{bx}	0.36^{aby}	0.03

[a,b]Means with different superscripts differ among milk production groups ($P \leq 0.05$).

[x,y]Means with different superscripts differ between physiological periods ($P \leq 0.05$).

[1]Milk production groups: Low (6.57 ± 1.21 kg), Mod (9.02 ± 0.60 kg), or High (11.97 ± 1.46 kg).

[2]Beta-hydroxybutyrate.

support, Minick et al. (2001) reported no differences in cow BW between levels of milk production. In addition, cow BCS was similar ($P \geq 0.23$) at the initiation of the study, start of breeding and end of breeding among milk production levels. The similarity in cow BW and BCS during the course of the study was unexpected due to the increase in nutrient demand of lactation (Belcher and Frahm, 1979; Mondragon et al., 1983; Minick et al., 2001; Lake et al., 2005), indicating the level of nutritional plane may have been great enough to buffer nutrient demands of lactation.

Although cow BW and BCS were not different, timed-AI pregnancy rate were the lowest ($P < 0.05$; Table 3) in the High milk producing cows with no difference ($P = 0.82$) between Low and Mod milk cows. In addition, overall pregnancy rate continued to be the lowest ($P < 0.05$) in High milk producing cows with the greatest pregnancy rate in Mod milk cows. In agreement, Butler (2000) reported an inverse relationship between milk yield and fertility in dairy cows. This inverse relationship is due to increased demand of energy competing with nutrient demands for reproduction. Even in environments where energy intake levels are high and met or exceed requirements, increased milk production still may decrease reproductive efficiency in beef cattle.

Cow Metabolite Analysis

Milk yield had no effect on glucose ($P = 0.98$; Table 4) or serum urea N [(SUN); $P = 0.75$]. In contrast, Morbeck et al. (1991) reported low circulating plasma glucose concentrations were positively related to increased milk production during d 30 to d 100 postpartum in dairy cows. In addition, Gustafsson and Palmquist (1993) reported that SUN is positively correlated with milk. However, these authors indicated that the positive relationship could be confounded with sampling time versus time of feeding.

Serum NEFA concentrations exhibited a milk yield and composite sample interaction ($P = 0.02$; Table 5). Serum NEFA concentrations increased ($P < 0.05$) with increasing level of milk production during the prebreeding phase with no difference ($P = 0.95$) between Mod and High milking cows. However, during breeding, serum NEFA concentrations were not different ($P > 0.05$) among milk production groups. Although BW and BCS were similar, the increase in NEFA with an increase in milk yield during early lactation of the pre-breeding phase may be due to the mobilization of fat stores to support a greater amount of milk produced. In agreement, Ospina et al. (2010) also reported that NEFA concentrations increased as milk yield increased in dairy first-calf heifers postpartum. Serum beta-hydroxybutyrate (BHB) concentrations exhibited a milk production level × physiological period interaction ($P < 0.01$; Table 5). During the pre-breeding and breeding periods, serum BHB concentrations were not different ($P \geq 0.73$) across the level of milk production treatments. However, circulating BHB concentrations were similar ($P \geq 0.21$) during pre-breeding and breeding for Low and Mod milk cows; whereas, High milk cows had greater ($P = 0.04$) BHB concentrations during the breeding period. A level of milk production and physiological period interaction ($P < 0.01$) occurred for serum insulin concentration (Table 5). During pre-breeding, circulating insulin concentration were not different ($P \geq 0.59$) among milk production groups. However, during the breeding season, insulin concentrations were lower ($P = 0.02$) in Mod milk cows compared to Low milk, with no difference ($P \geq 0.24$) between Mod and High cows and High and Low milk cows.

Effects of Milk Yield on Calf Performance

Calf BW at birth was not different ($P = 0.63$; Table 6) among milk production groups. Contradictory, Minick et al. (2001) and Jeffery et al. (1971) reported a slight positive correlation between calf BW at birth and milk production. However, calf mid-weight at initial milking (~d 58) was increased ($P < 0.001$) in calves from Mod and High milking cows. In agreement, Ansotegui et al. (1991) reported that milk production influenced calf growth up to 60 d postpartum. However, Ansotegui et al. (1991) reported no differences in ADG of calves from low milk producing cows versus high milk producing cows after d 60, due to forage intake differences, indicating that milk yield may only influence calf growth up to 60 d of age. Calf actual BW at weaning and 205-d adjusted BW was not different ($P \geq 0.22$) among calves from different milk treatment groups. In agreement, Buskirk et al. (1995) also reported that milk production had no influence on calf BW at weaning. Milk yield has been suggested to be responsible for 40% of variance in weaning weights (Robison et al., 1978). Buskirk et al. (1995) indicated that milk consumption was inversely related to forage intake. Likewise, Tedeschi and Fox (2009) indicated that there is an inverse relationship between milk consumption and forage intake, but milk was prioritized over forage intake if both are readily available. Kilograms of calf weaned per cow exposed has been suggested to be a key indicator of efficiency in beef herds (Ramsey et al., 2005). In this study, high milking cows had the least ($P < 0.05$) kilograms of calf weaned per cow exposed with Mod milking cows having the greatest.

Table 6. Effect of milk production level calf body weight (BW) for beef cows

Measurement	Milk production[1] Low	Mod	High	SEM	*P*-value
Calf BW, kg					
Birth	35.7	35.3	36.4	0.7	0.28
Mid-weight[2]	116[a]	125[b]	128[b]	2	< 0.01
Actual weaning	285	294	295	5	0.22
205-d adjusted[3]	270	278	279	6	0.55
Kilograms calf weaned per cow exposed, kg[4]	232[a]	250[b]	222[c]	4	0.02

[a–c] Means with different superscripts differ ($P \leq 0.05$).

[1]Milk production groups: Low (6.57 ± 1.21 kg), Mod (9.02 ± 0.60 kg), or High (11.97 ± 1.46 kg).

[2]Mid-weight taken at ~ d 58 postpartum.

[3]Weaning weight adjusted to 205 d of age using Beef Improvement Federation adjustments without age of dam or calf sex.

[4]Based on the subsequent year's actual (unadjusted) calf weaning BW and percentage of exposed cows to a breeding bull during the year of the study.

Implications

Collectively, results from this study suggest that even in management systems that modify the environments with harvested feedstuffs, high milk production decreases reproductive efficiency without increasing calf BW at weaning. Therefore, producers may need to discount high milk producing cows and take into account the requirements for maintaining a greater amount of milk, and the negative influences associated with a greater milk yield.

LITERATURE CITED

Ansotegui, R. P., K. M. Havstad, J. D. Wallace, and D. M. Hallford. 1991. Effects of milk intake on forage intake and performance of suckling range calves. J. Anim. Sci. 69:899–904. doi:10.2527/1991.693899x

Belcher, C. G., and R. R. Frahm. 1979. Productivity of two-year-old crossbred cows producting three-breed cross calves. J. Anim. Sci. 49:1195–1206. doi:10.2527/jas1979.4951195x

Brown, M. A., A. H. Brown, W. G. Jackson, and J. R. Miesner. 2001. Genotype × environment interactions in milk yield and quality in Angus, Brahman, and reciprocal-cross cows on different forage systems. J. Anim. Sci. 79:1643–1649. doi:10.2527/2001.7971643x

Buskirk, D. D., D. B. Faulkner, and F. A. Ireland. 1995. Increased postweaning gain of beef heifers enhances fertility and milk production. J. Anim. Sci. 73:937–946. doi:10.2527/1995.734937x

Butler, W. R. 2000. Nutritional interactions with reproductive performance in dairy cattle. Anim. Reprod. Sci. 60:449–457. doi:10.1016/S0378-4320(00)00076-2

Ferrell, C. L., and T. G. Jenkins. 1985. Cow type and nutritional environment: Nutritional aspects. J. Anim. Sci. 61:725–741. doi:10.2527/jas1985.613725x

Gustafsson, A. H., and D. L. Palmquist. 1993. Diurnal variation of rumen ammonia, serum urea, and milk urea in dairy cows at high and low yields. J. Dairy Sci. 76:475–484. doi:10.3168/jds.S0022-0302(93)77368-3

Jeffery, H., R. Berg, and R. Hardin. 1971. Factors influencing milk yield of beef cattle. Can. J. Anim. Sci. 51:551–560. doi:10.4141/cjas71-076

Lake, S., E. J. Scholljegerdes, R. L. Atkinson, V. Nayigihugu, S. I. Paisley, D. C. Rule, G. E. Moss, T. J. Robinson, and B. W. Hess. 2005. Body condition score at parturition and postpartum supplementation fat effects on cow and calf performance. J. Anim. Sci. 83:2908–2917. doi:10.2527/2005.83122908x

Lalman, D., M. Rolf, R. Kropp, M. Brown, D. Sparks, and S. Linneen. 2013. Addressing cowherd efficiecy in a world of mixed messages for producers: Matching production levels to environmental conditions. In: Proceedings of the 45th Annual Beef Improvement Federation Research Symposium and Annual Meeting, Oklahoma City, OK, June 12-15.

Lewis, J. M., T. J. Klopfenstein, R. A. Stock, and M. K. Nielsen. 1990. Evaluation of intensive vs extensive systems of beef production and effect of level of beef cow milk production on postweaning performance. J. Anim. Sci. 68:2517–2524. doi:10.2527/1990.6882517x

Marston, T. T., D. D. Simms, R. R. Schalles, K. O. Zoellner, L. C. Martin, and G. M. Fink. 1992. Relationship of milk production, milk expected progeny difference, and calf weaning weight in Angus and Simmental cow-calf pairs. J. Anim. Sci. 70:3304–3310. doi:10.2527/1992.70113304x

Miller, A. J., D. B. Faulkner, R. K. Knipe, D. R. Strohbehm, D. F. Parrett, and L. L. Berger. 2001. Critical control points for profitability in the cow-calf enterprise. Prof. Anim. Sci. 17:295–302.

Minick, J. A., D. S. Buchanan, and S. D. Rupert. 2001. Milk production of crossbred daughters of high- and low-milk EPD Angus and Hereford bulls. J. Anim. Sci. 79:1386–1393. doi:10.2527/2001.7961386x

Mondragon, I., J. W. Wilton, O. B. Allen, and H. Song. 1983. Stage of lactation effects, repatabilities and influences on weaning weights of yield and composition of milk in beef cattle. Can. J. Anim. Sci. 63:751–761. doi:10.4141/cjas83-090

Montaño-Bermudez, M., M. K. Nielsen, and G. H. Deutscher. 1990. Energy requirements for maintenance of crossbred beef cattle with different genetic potential for milk. J. Anim. Sci. 68:2279–2288. doi:10.2527/1990.6882279x

Morbeck, D. E., J. H. Britt, and B. T. McDaniel. 1991. Relationship among milk yield, metabolism, and reproductive performance of primiparous Holstein cows treated with somatotropin. J. Dairy Sci. 74:2153–2164. doi:10.3168/jds.S0022-0302(91)78388-4

Mulliniks, J. T., A. G. Rius, M. A. Edwards, S. R. Edwards, J. D. Hobbs, and R. L. G. Nave. 2015. FORAGES AND PASTURES SYMPOSIUM: Improving efficiency of production in pasture- and range-based beef and dairy systems. J. Anim. Sci. 93:2609–2615. doi:10.2527/jas.2014-8595

Mulliniks, J. T., M. E. Kemp, S. H. Cox, D. E. Hawkins, A. F. Cibils, D. M. VanLeeuwen, and M. K. Petersen. 2011. The effect of increasing amount of glucogenic percursors on reproductive performance in young postpartum range cows. J. Anim. Sci. 89:2932–2943. doi:10.2527/jas.2010-3198

Neville, W. E., and M. E. McCullough. 1969. Calculated energy requirements of lactating and non-lactating Hereford cows. J. Anim. Sci. 29:823–829. doi:10.2527/jas1969.295823x

Ospina, P. A., D. V. Nydam, T. Stokol, and T. R. Overton. 2010. Associations of elevated nonesterified fatty acids and β-hydroxybutyrate concentrations with early lactation reproductive performance and milk production in transition dairy cattle in the northeastern United States. J. Dairy Sci. 93:1596–1603. doi:10.3168/jds.2009-2852

Ramsey, R., D. Doye, C. Ward, J. McGrann, L. Falconer, and S. Bevers. 2005. Factors affecting beef cow-herd costs, production, and profits. J. Agric. Appl. Econ. 37:91–99. doi:10.1017/S1074070800007124

Robison, O. W., M. K. M. Yusuff, and E. U. Dillard. 1978. Milk production in Hereford cows I. means and correlations. J. Anim. Sci. 47:131–136. doi:10.2527/jas1978.471131x

Rutledge, J. J., O. W. Robison, W. T. Ahlschwede, and J. E. Legates. 1971. Milk yield and its influence on 205-day weight of beef calves. J. Anim. Sci. 33:563–567. doi:10.2527/jas1971.333563x

Tedeschi, L. O., and D. G. Fox. 2009. Predicting milk and forage intake of nursing calves. J. Anim. Sci. 87:3380–3391. doi:10.2527/jas.2009-2014

van Oijen, M. M.-B., and M. K. Nielsen. 1993. Economical and biological efficiencies of beef cattle differing in level of milk production. J. Anim. Sci. 71:44–50.

Wagner, J. J., K. S. Lusby, J. W. Oltjen, J. Rakestraw, R. P. Wettemann, and L. E. Walters. 1988. Body condition at parturition and postpartum weight gain influences luteal activity and concentrations of glucose, insulin, and nonesterified fatty acids in plasma of primiparous beef cows. J. Anim. Sci. 76:927–936.