Effects of fat concentration of a high-protein milk replacer on calf performance

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ABSTRACT

The hypothesis was that calves fed high-fat milk replacers (MR) would have reduced starter intake, digestibility, and average daily gain (ADG). Forty-eight Holstein calves (initially 42.4 ± 1.5 kg of body weight, 2 to 3 d of age; 12 calves/treatment) were fed 0.66 kg dry matter (DM) of MR per calf daily that contained 14, 17, 20, or 23% fat. This MR had crude protein (CP) to metabolizable energy (ME) ratios ranging from 51.6 to 56.7 g of CP/Mcal of ME, which were above and below a previously determined optimum. Calves were weaned at 28 d; postweaning measurements were continued to d 56. A 20% CP starter and water were fed ad libitum all 56 d of the trial. Measurements of digestion were made using chromic oxide as a marker in the MR and starter from fecal samples collected on d 19 to 23 from 4 calves/treatment. Selected serum constituents were measured on d 21. Calves were housed individually in pens bedded with straw within a naturally ventilated barn with no added heat. The average barn temperature was 2°C. Data were analyzed as a completely randomized design using polynomial contrasts to separate differences in the means. Preweaning apparent digestibility of DM, organic matter, fat, nonfiber carbohydrates, Ca, and P and serum amylase concentration were linearly reduced as fat increased from 14 to 23%. Preweaning starter intake responded quadratically to fat, being lowest at 14 and 23% fat. A reduction in digestibility and starter intake contributed to less ADG at the higher fat concentrations in the MR. A 27% CP, 17% fat MR with 55 g of CP/Mcal of ME maximized preweaning ADG when fat concentration was varied to obtain various CP to ME ratios in the MR. Additionally, a 27% CP, 20% fat MR with 53 g of CP/Mcal of ME supported overall ADG similar to calves fed the 17% fat MR but preweaning digestion measurements and serum amylase concentrations were less than in calves fed the 17% fat MR.

Key words: fat, protein, digestion, calf

INTRODUCTION

The CP and energy intake from milk replacer (MR) greatly affects calf ADG and carcass protein and fat deposition (Donnelly and Hutton, 1976; Blome et al., 2003; Bartlett et al., 2006). When CP is restricted or limited relative to energy consumed, the extra energy is stored as fat. Similarly, Tikofsky et al. (2001) reported that when MR equal in protein and energy are fed, energy from fat is more likely to result in fat deposition than energy from lactose. Bascom et al. (2007) reported a trend for less ADG when a high-protein MR with 33% fat was fed to calves compared with a high-CP MR with 16% fat; however, fat deposition was considerably greater in the calves fed the 33% fat MR. In the previously mentioned trials, calves were fed MR above their maintenance requirements (i.e., “accelerated” MR programs) and were not fed starter. When calves were fed starter and MR well over their maintenance requirements during cold temperatures in an unheated nursery, Hill et al. (2007b) reported that added energy from MR fat did not improve ADG, but added energy from MR lactose and CP improved ADG. Fat intake is a way to provide energy and reduce body fat loss during sub-thermoneutral temperatures; however, its application in calves fed close to maintenance requirements and housed in hutches during cold weather has yielded mixed results (Davis and Drackley, 1998).

A reason for the mixed results of increasing the nutrients fed via milk or MR is the balance between intake of nutrients from MR or milk and early-life calf growth with the development of the rumen, starter intake, and growth later in the calf’s life. Numerous researchers have reported that feeding too much milk or MR will result in a postweaning reduction in ADG by depressing starter intake (Davis and Drackley, 1998; Hill et al., 2006a, 2007b). Terre et al. (2007) attributed a portion of the lower ADG to a lower digestion of starter in the calves fed the high versus low amount of MR. However, recently, Hill et al. (2009a) fed 27% CP MR that contained either 17 or 31% fat and observed no change in starter intake but less ADG in calves fed the high-fat MR. The fatty acid profiles of these diets were confounded and might have explained the differ-

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ences in ADG because the fatty profile of the 26% fat MR appeared to be deficient in essential fatty acids. However, all of the fat in 31% fat MR and most of the fat in the 17% fat was edible lard, a saturated fat and the predominant source of fat used in MR in the United States.

Sabb et al. (1986) reported that pancreatic lipase activity in rats substantially declines when corn starch replaces fat at dietary fat concentrations below 23%, especially if the fat is saturated. The fat concentration of the complete diet consumed by the calf fed MR and starter is typically declining with age because of increasing starter intake that is low in fat combined with an often fixed MR intake. Thus, lipase production could decline in the later preweaning period of the calf if lipase production in calves is as in rats. Data of this nature could not be found for calves.

In previous research, the optimum CP to energy ratios in MR-fed calves have ranged from 43 to 61 g of CP/Mcal of ME, and the fat concentrations in the optimum MR treatments have ranged from 17.7 to 24.2% (Donnelly and Hutton, 1976; Blome et al., 2003; Bartlett et al., 2006; Hill et al., 2009b). Of these trials, only Hill et al. (2009b) fed starter, weaned the calves, and measured postweaning performance. They fed 17% fat MR ranging from 23 to 29% CP at either 0.545 or 0.654 kg of DM. Calf ADG was maximized with the 27% CP, 17% fat MR fed at 0.654 kg of DM (55 g of CP/Mcal of ME).

With these data in mind, a trial was designed to compare MR containing 27% CP and fed at 0.66 kg of DM daily with fat concentrations of 14, 17, 20, and 23%. These fat concentrations are below and above the range fed in previous trials, and fat concentration was altered using edible lard. The objective was to measure calf performance and digestion of the diets using fat to vary energy intake and the CP to energy ratio of the MR while offering starter and weaning the calves. Calves were fed 0.66 kg DM of a 27% CP MR ranging from 14 to 23% fat. Calves were managed in an unheated nursery (2°C) that was below the thermoneutral zone of calves when additional fat intake might have more benefit to the calves than if in conditions above thermoneutral temperatures. Our hypothesis was that high fat concentrations would depress starter intake, digestibility of starter DM, and ADG.

MATERIALS AND METHODS

This trial compared 4 MR differing in concentrations of fat (14, 17, 20, and 23% fat on a DM basis; Table 1). The MR contained 27% CP. Fat in the MR was increased by adding edible lard from a 7.2% CP, 61.8% fat powder (LOL Milk Products, Black River Falls, WI)

to replace whey (12.8% CP, 0.7% fat) and whey protein concentrate (80.9% CP, 5.4% fat). The MR were fed at 0.681 kg of as-fed (0.660 kg of DM) powder daily. Calves were fed their MR halved into a.m. and p.m. feedings for 25 d, followed by only the a.m. feeding (half their previous MR) on d 26, 27, and 28. The MR were reconstituted at the rate of 134 g of powder into a volume of 1 L with warm water. Calves were fed a pelleted calf starter (formulated for DM basis 20.7% CP, analyzed 22.3% CP; Table 1) and fresh water ad libitum. This trial used 48 Holstein bull calves (12/treatment) <1 wk of age from one dairy farm. (From 20 similar, low variance trials in our research nursery, a power analysis using residual error mean squares and means predicted an 11% difference in means could be separated at $P < 0.05$ with 12 calves per treatment.) Calves were received at approximately 1100 h after a 3.5-h transit. Calves were fed the 21% fat MR at the p.m. feeding and following a.m. feeding. At 1100 h on the day after arrival the calves were weighed (initial BW), blood was sampled from the jugular vein to measure serum protein using an optical refractometer (Atago USA Inc., Bellevue, WA), and calves were randomly assigned to treatment (d 0).

The MR and starter were formulated to contain 0.25% chromic oxide (as-fed basis). The basis was to achieve an intake of approximately 2 g of chromic oxide per calf daily, exceeding the minimum suggested 1 g/calf daily for digestibility estimates (Bouchard et al., 1973). Fecal grab samples were taken from 4 calves randomly selected per treatment on d 19 to 23, frozen daily, combined on an equal wet-weight basis, and subsampled for analysis. Twelve fecal grab samples per calf accounting for the majority of the defecation initiated by palpation were taken to account for 2-h intervals of the 24-h day by rotating sampling times over the 5-d collection period. Approximately 110% of the estimated feeds needed for each treatment were manufactured as single batches. Equal samples of manufactured feeds were collected from every second bag (22.7 kg) of feed at the time of manufacturing and composited. Composites of feed and feeds were analyzed (AOAC, 2000) for DM (oven method 930.15), ash (oven method 942.05), CP (Kjeldahl; method 988.05), and Ca, P, K, Mg (dry ashing, acid digestion, analysis by inductively coupled plasma spectrometry; method 985.01), and Cr (AOAC, 2000; method 993.14). Additionally, the starter was analyzed for NDF with ash by the procedure of Van Soest et al. (1991) without sodium sulfite or α -amylase, and ADF with ash (Robertson and Van Soest, 1981). Measured concentrations of Cr and other nutrients in the feed, feed intake, and Cr and other nutrient concentrations in the feces were used to estimate fecal output and apparent digestibility. On d 21, to correspond with

Table 1. Nutrient concentrations (DM basis) of the milk replacers (MR) and starter

Item	14% fat MR	17% fat MR	20% fat MR	23% fat MR	Starter
Analyzed, %					
DM	97.12	97.08	97.04	97.01	87.30
CP	26.82	26.84	26.88	26.92	22.34
Fat	14.41	17.49	20.59	23.72	4.48
ADF	—	—	—	—	6.29
NDF	—	—	—	—	10.43
Ash	6.17	6.08	5.99	5.95	6.71
Ca	0.722	0.718	0.714	0.710	1.26
P	0.530	0.516	0.503	0.490	0.581
Calculated					
NFC ¹	52.60	49.59	46.54	43.41	56.08
ME, Mcal/kg ²	4.73	4.89	5.05	5.22	3.67
g of CP/Mcal of ME	56.7	54.9	53.2	51.6	60.9

¹100 – (CP + fat + NDF + ash).²Using NRC (2001) equations.

the fecal collection period, a venous blood sample was taken from each calf in a test tube without preservatives or anticoagulants, separated by centrifugation, and analyzed for albumin, alkaline phosphatase, amylase, creatinine, glucose, total protein, and urea-N, all as described by Hill et al. (2007a), Ca (Michaylova and Ilkova, 1971), and P (Tedokon et al., 1992).

Calves were weighed every 7 d until the end of the trial (d 56). Dry feed offered and feed refusals were weighed daily. Fecal scores were assigned daily based on a 1 to 5 system (1 being normal, thick in consistency; 2 being normal, but less thick; 3 being abnormally thin but not watery; 4 being watery; 5 being watery with abnormal coloring; modified from Kertz and Chester-Jones, 2004) while calves were in individual pens. Hip widths were measured with a caliper and BCS of calves were measured during the initial (d 0) measurement period and every 14-d thereafter. A 1 to 5 system using 0.25-unit increments with 1 being emaciated and 5 being obese was used for BCS (Wildman et al., 1982). Scores were based on changes around the vertical and transverse processes of the spine as palpated by one experienced technician and ranged from 1.5 to 3.5. The trial lasted 56 d and was conducted during the months of January through March. The average ambient temperature inside the barn during the trial was 2°C and ranged from –10 to 20°C based on hourly measurements.

Calves were housed in 1.2- × 2.4-m individual pens within a curtain sidewall barn with no added heat. The pens were bedded with long straw. Calves were cared for by acceptable practices as described in the *Guide for the Care and Use of Agricultural Animals in Agricultural Research and Teaching* (FASS, 1999). Calves received an intranasal tissue sensitive respiratory disease vaccine (TSV-2, Pfizer, Exton, PA) and subcutaneous injections of vitamins A, D, E (Vital E - A + D, Schering-Plough Animal Health, Union, NJ) and Se (MU-SE,

Schering-Plough Animal Health) upon arrival. Calves received an intramuscular respiratory disease vaccine (Bovashield Gold 5, Pfizer) at d 7 and again at d 28. At d 14 they received an intramuscular vaccine for types C and D clostridium (Ultra Choice 7, Pfizer). A pasteurized vaccine (Presponse HM, Fort Dodge, Fort Dodge, IA) was administered intramuscularly on d 28 and 42. Calves were castrated and dehorned at 36 d of age. Animals that required medication for sickness were treated per veterinary recommendation, and treatments were recorded daily. Scouring was the only sickness observed and it was diagnosed based on rectal temperatures >39.5°C, lack of vitality, and fecal scores >2 and treated with subcutaneous ceftiofur sodium (Naxcel, Pharmacia & Upjohn, Kalamazoo, MI).

Data were analyzed using the MIXED procedure in SAS (Version 8, SAS Institute Inc., Cary, NC) as a completely randomized design. Calf within treatment was a random effect used to test the fixed effect of treatment. Day was a repeated measure using an autoregressive type 1 covariance structure within preweaning and postweaning periods. Linear, quadratic, and cubic polynomials were constructed to test for differences among the treatment means. Data reported are least squares means. The experimental unit was calf. Statistical significant differences are discussed at $P < 0.05$, and trends were mentioned when $P < 0.10$.

RESULTS

The starter was intended to be 20.7% CP, DM basis, but analyzed slightly higher (22.3% CP, DM basis). Initial calf measurements did not differ ($P > 0.05$). No cubic contrasts were significant for any measurement.

During the digestion phase (d 19 to 23) using 4 of the 12 calves per treatment, intake of fat increased and intake of NFC decreased linearly ($P < 0.05$) as

Table 2. Intake and apparent total-tract digestibility of nutrients in the 16 calves fed 27% CP milk replacer (MR) with 4 concentrations of fat as determined on d 19 to 23 (DM basis)

Item	14% fat	17% fat	20% fat	23% fat	SEM	Linear <i>P</i> -value ¹	Quadratic <i>P</i> -value ¹
Intake, g/d							
Starter DM	237	239	243	231	29	0.63	0.78
MR DM	661	661	661	661	—	—	—
Total DM	898	900	904	892	29	0.74	0.69
OM	842	845	849	891	27	0.83	0.94
CP	230	231	231	229	6	0.94	0.96
Fat	106	127	147	167	1	0.01	0.79
Ca	7.8	7.8	7.8	7.6	0.36	0.94	0.67
P	4.9	4.8	4.8	4.6	0.20	0.81	0.59
NFC	388	368	349	327	13	0.01	0.98
Digestibility, g/g							
DM	0.830	0.827	0.809	0.800	0.006	0.01	0.37
OM	0.835	0.833	0.819	0.809	0.006	0.01	0.45
CP	0.767	0.772	0.743	0.739	0.024	0.15	0.81
Fat	0.938	0.930	0.916	0.901	0.010	0.01	0.60
Ca	0.720	0.727	0.625	0.628	0.043	0.01	0.96
P	0.842	0.815	0.782	0.773	0.027	0.06	0.64
NFC	0.797	0.783	0.766	0.742	0.016	0.07	0.21
Digested, g/d							
DM	745	744	731	713	21	0.12	0.54
OM	703	704	695	678	20	0.18	0.49
CP	176	178	172	169	8	0.31	0.71
Fat	100	118	135	151	2	0.01	0.31
Ca	5.6	5.6	4.9	4.8	0.43	0.07	0.18
P	4.1	3.9	3.7	3.6	0.17	0.01	0.99
NFC	309	288	267	242	10	0.01	0.60

¹Cubic contrasts were not significant ($P > 0.20$).

fat concentration in the MR increased (Table 2). The apparent digestibility of DM, OM, fat, and Ca decreased linearly ($P < 0.05$) as the concentration of fat increased in the MR. The apparent digestibility of P and NFC tended ($P < 0.10$) to decrease linearly as the concentration of fat increased in the MR. The amount of fat digested increased and the amounts of P and NFC digested decreased linearly ($P < 0.05$) as the concentration of fat increased in the MR. The amount of Ca digested tended ($P < 0.10$) to decrease linearly as the concentration of fat increased in the MR. Serum amylase concentrations (taken on d 21) decreased linearly ($P < 0.05$) as fat concentration increased in the

MR (Table 3). Serum Ca and P concentrations tended ($P < 0.10$) to decrease linearly as the concentration of fat increased in the MR.

Calf ADG responded in a quadratic manner ($P < 0.05$) to fat concentration in the MR (Table 4). Prewaning (d 0 to 28) and overall (d 0 to 56) ADG were greatest in calves fed the 17 to 20% fat MR and lowest in calves fed the 23% fat MR. Postweaning (d 28 to 56) and overall ADG were unchanged between 14 and 20% fat and lowest for calves fed the MR with 23% fat. Prewaning starter intake responded quadratically ($P < 0.05$) to fat concentration in the MR increasing from 14 to 20% fat, but decreasing to 23% fat.

Table 3. Selected serum constituents in 48 calves fed 27% CP milk replacer with 4 concentrations of fat as determined on d 21

Item	14% fat	17% fat	20% fat	23% fat	SEM	Linear <i>P</i> -value ¹	Quadratic <i>P</i> -value ¹
Alkaline phosphatase, U/L	215	217	208	183	41	0.17	0.28
Amylase, U/L	63	61	46	25	6.9	0.01	0.32
Albumin, g/L	17.8	17.3	17.5	17.8	0.68	0.73	0.64
Urea nitrogen, mmol/L	3.0	3.0	3.3	3.5	0.27	0.19	0.18
Total protein, g/L	57	57	57	58	2.6	0.90	0.99
Creatinine, μ mol/L	80	76	71	66	6.8	0.14	0.63
Glucose, mmol/L	5.88	5.68	5.50	5.40	0.335	0.08	0.57
Calcium, mmol/L	2.78	2.73	2.72	2.67	0.047	0.08	0.26
Phosphorus, mmol/L	3.03	2.97	2.94	2.90	0.057	0.09	0.34

¹Cubic contrasts were not significant ($P > 0.20$).

Table 4. Performance of 48 calves fed 27% CP milk replacers with 4 different concentrations of fat

Item	14% fat	17% fat	20% fat	23% fat	SEM	Linear <i>P</i> -value ¹	Quadratic <i>P</i> -value ¹
Initial serum protein, mg/dL	4.6	4.4	4.5	4.7	0.15	0.29	0.31
Initial BW, kg	42.3	42.7	42.3	42.4	1.49	0.34	0.64
ADG, kg/d							
0 to 28 d	0.334	0.364	0.353	0.315	0.020	0.22	0.04
28 to 56 d	0.728	0.715	0.719	0.658	0.032	0.09	0.05
0 to 56 d	0.531	0.540	0.536	0.486	0.022	0.12	0.04
Starter intake, kg/d							
0 to 28 d	0.151	0.186	0.193	0.158	0.018	0.30	0.04
28 to 56 d	1.547	1.489	1.529	1.381	0.107	0.28	0.13
0 to 56 d	0.849	0.837	0.861	0.769	0.059	0.31	0.19
Milk replacer intake, kg/d							
0 to 28 d	0.626	0.626	0.626	0.626	—	—	—
28 to 56 d	—	—	—	—	—	—	—
0 to 56 d	0.313	0.313	0.312	0.312	—	—	—
Feed efficiency							
0 to 28 d	0.430	0.448	0.431	0.402	0.024	0.35	0.11
28 to 56 d	0.471	0.480	0.470	0.476	0.016	0.57	0.64
0 to 56 d	0.457	0.470	0.457	0.449	0.013	0.28	0.19
Fecal score ²							
0 to 28 d	2.1	2.0	2.2	2.1	0.13	0.78	0.84
28 to 56 d	1.5	1.5	1.5	1.6	0.09	0.82	0.94
0 to 56 d	1.8	1.8	1.8	1.8	0.08	0.61	0.68
Abnormal fecal days, ² n							
0 to 28 d	0.6	0.7	0.5	0.7	0.31	0.22	0.26
28 to 56 d	0	0	0	0	—	—	—
0 to 56 d	0.6	0.7	0.5	0.7	0.31	0.36	0.39
BCS ³							
Initial	2.3	2.2	2.3	2.2	0.04	0.74	0.69
0 to 28 d change	0.1	0.2	0.1	0.2	0.04	0.69	0.55
28 to 56 d change	0.2	0.1	0.2	0.1	0.07	0.73	0.78
0 to 56 d change	0.3	0.3	0.3	0.3	0.06	0.99	0.98
Hip width, cm							
Initial	17.3	17.6	18.1	17.6	0.32	0.25	0.21
0 to 28 d change	0.9	1.1	0.9	0.9	0.17	0.34	0.15
28 to 56 d change	2.8	2.8	2.7	2.5	0.24	0.39	0.91
0 to 56 d change	3.7	3.9	3.7	3.3	0.25	0.19	0.13

¹Cubic contrasts were not significant ($P > 0.10$).

²Fecal score system: 1 = normal, thick in consistency; 2 = normal, but less thick; 3 = abnormally thin but not watery; 4 = watery; 5 = watery with abnormal coloring. Abnormal fecal days were days with fecal scores >2 .

³1 to 5 system based on Wildman et al. (1982).

DISCUSSION

In each period (pre- and postweaning and overall) the calves fed the 23% fat MR had the lowest ADG. Both starter intake and digestion of nutrients were involved because calves fed the 23% fat MR had the lowest intake and lowest digestion of several major nutrients. The reduction in Ca digestibility and amount of P digested as fat increased in the MR is consistent with results in other species (French and Elliot, 1943; Calverley and Kennedy, 1947) and calves (Toullec et al., 1980), especially when saturated fats were fed (Yacowitz et al., 1967).

Guilloteau et al. (1985) reported that lipase was greatest in the milk fed calf and decreased as starter consumption increased during weaning and postweaning. Because digestion measures were made on d 19 to 23 in the current trial, before weaning at d 28, lipase

production could have been declining and have contributed to the reductions in fat digestion that were measured. Sabb et al. (1986) reported that rat pancreatic lipase activity was not linearly related to lipid intake and lipase activity differs relative to the lipid content and type in the diet. They reported no difference in lipase activity from diets with 5 to 20% fat but large increases in activity with diets containing 23 and 29% fat. Additionally, rats fed diets with saturated fat had much lower lipase activities than unsaturated fat diets at 17% fat. In the current trial, during d 19 to 23 when the digestion measures were made, the total dietary fat (predominantly saturated fat from lard) ranged from 11 to 18%, diluted by starter intake, from MR treatments that ranged from 14 to 23% fat.

The decrease in serum amylase concentrations, starter intake, and digestion of NFC with increasing fat intake is consistent with measures of amylase activities in the

intestine of calves and rats. Amylase was lowest in the milk-fed calf and increased as starter consumption increased during weaning and postweaning (Guilloteau et al., 1985). In rats, amylase activity was directly related to carbohydrate intake (Thornburg et al., 1987; Sankaran et al., 1992) and declined with the intake of fat (Forman and Schneeman, 1980).

The quadratic response of starter intake to MR fat concentration preweaning could have attributed to some of the differences in ADG. Consumption of concentrates by calves stimulates the microbial population of the rumen and their end-products that initiate rumen epithelial development (Hibbs et al., 1956; Warner et al., 1956), which could have contributed to the increased digestion measurements observed at lower fat intakes.

Maximal ADG at 17 to 20% fat is consistent with results from previous studies that tested the concentration of fat in MR fed at the same rate and fed to calves weaned at 42 d and reported maximal ADG and starter intake with 17% fat (Hill et al., 2006b). Postweaning performance did not differ ($P > 0.05$) and differed little numerically among calves fed the 14, 17, and 20% fat MR, but ADG was the lowest for calves fed the 23% fat MR.

A MR with 27% CP, 17% fat, and 55 g of CP/Mcal of ME maximized preweaning ADG in this trial, where fat level was varied, and in a previous trial (Hill et al., 2009b), where CP was varied; however, the MR with 27% CP, 20% fat, and 53 g of CP/Mcal of ME supported overall ADG similar to the 17% fat MR. In each trial, starter was fed and the calves were weaned, and postweaning ADG and starter intake were lowest in calves fed the 23% fat MR. The 53 to 55 g of CP/Mcal of ME in the MR is less than 61.2 g of CP/Mcal of ME in the MR to maximize ADG as reported by Donnelly and Hutton (1976). However, 95% of their ADG response occurred between 35.7 (their low) and 49.4 g of CP/Mcal of ME MR and only 5% of the ADG response between 49.4 and 61.2 (their high) g of CP/Mcal of ME MR. Bartlett et al. (2006) reported 48.6 g of CP/Mcal of ME and Blome et al. (2003) reported 51.7 g of CP/Mcal of ME per unit of BW to maximize ADG per unit BW. Calves in the trials of Donnelly and Hutton (1976), Blome et al. (2003), and Bartlett et al. (2006) were more than 14 d of age at the start of the trials, were on trial for 35 to 49 d, and were fed only MR (no starter). Calves in the current trial and Hill et al. (2009b) were 2 to 3 d old initially and fed MR for 28 d and starter for the entire trial. A younger calf age and feeding starter might account for an apparent greater CP to ME ratio to maximize ADG.

CONCLUSIONS

Prewaning digestion of DM, OM, fat, NFC, Ca, and P and serum amylase concentration were linearly reduced as fat increased from 14 to 23% in a 27% CP milk replacer powder fed at 0.660 kg of DM/calf daily. Prewaning starter intake responded quadratically to fat, being lowest at 14 and 23% fat. A reduction in digestion and starter intake contributed to less ADG at the higher fat concentrations of the MR. A 27% CP, 17% fat MR with 55 g of CP/Mcal of ME maximized preweaning ADG when fat concentration was varied, consistent with previous results when CP was varied to obtain various CP to ME ratios in the MR. Additionally, a 27% CP, 20% fat MR with 53 g of CP/Mcal of ME supported overall ADG similar to calves fed the 17% fat MR, but preweaning digestion measurements and serum amylase concentrations were less than in calves fed the 17% fat MR.

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