Effect of milk replacer program on calf performance and digestion of nutrients with age of the dairy calf

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ABSTRACT

Calves fed large amounts of milk replacer (MR) gain more body weight preweaning than calves fed less-aggressive programs; however, postweaning growth may be reduced. Limited research suggests that less than optimal digestion of the postweaned diet due to large amounts of MR with reduced dry feed intake preweaning may contribute to growth impairment postweaning. Current research was conducted to compare growth and postweaning digestion in 3-d-old male Holstein calves fed various MR programs. The MR programs were a conventional [CON; 0.44 kg of dry matter (DM) 21% crude protein (CP), 21% fat powder fed for 42 d], moderate (MOD; 0.66 kg of DM 27% CP, 17% fat powder fed for 42 d), and aggressive program (AGG; up to 0.87 kg of DM 27% CP, 17% fat powder fed for 49 d). All calves were fed a 20% CP textured starter and water ad libitum for 56 d. The trial used 96 calves (initially 41 ± 1.9 kg of body weight) received 5 wk apart in 2 groups of 48 calves. During d 51 to 56, fecal samples were collected from 5 calves per treatment randomly selected from calves in the first group. Selected nutrients and acid-insoluble ash (used as an internal flow marker) were analyzed in the starter and feces to estimate digestibility. Data were analyzed as a randomized complete block design with starting time of each group of calves as a block. Repeated measure analysis was performed on overall (0 to 56 d) data. Means were separated with a protected least significant difference test. Pen was the experimental unit. Calves fed CON had the least average daily gain [CON = 0.35, MOD = 0.51, and AGG = 0.55 kg/d; standard error of the mean (SEM) = 0.018], feed efficiency (CON = 0.35, MOD = 0.49, and AGG = 0.48 gain/feed, SEM = 0.016), and change in hip width (CON = 3.3, MOD = 4.1, and AGG = 4.1 cm, SEM = 0.20) compared with calves

fed other programs. Calves fed AGG had the greatest change in BCS and least starter intake compared with calves fed the other programs. Digestibility of organic matter was 79, 78, and 68% and neutral detergent fiber was 54, 51, and 26% for calves fed programs CON, MOD, and AGG, respectively, and were least for calves fed AGG. These results indicate that postweaning digestion is lower than optimal and contributes to lower postweaning growth in calves fed aggressive compared with conventional or moderate MR programs.

Key words: calf, milk replacer, digestion

INTRODUCTION

Many have reported that as more milk or milk replacer (MR) is fed preweaning, preweaning ADG increases (Jasper and Weary, 2002; Cowles et al., 2006; Hill et al., 2006a,b, 2007). The amount of increased ADG is a function of nutrients provided. However, when the amount of milk or MR fed is more than approximately 0.7 kg of DM, postweaning ADG may be compromised compared with calves fed conventional amounts of milk (Bar-Peled et al., 1997; Jasper and Weary, 2002), non-acidified MR (Cowles et al., 2006; Hill et al., 2006a,b, 2007), or acidified ad libitum MR (Nocek and Braund, 1986; Hepola et al., 2008; Hill et al., 2013). Additionally, preweaning MR intake did not influence DMI after 56 d (Hill et al. 2007, 2010, 2013; Osorio et al., 2012).

Starter intake and fermentation of starch in the rumen develops the rumen (NRC, 2001). Publications from different laboratories, each using over 900 calves, report that the ADG of the dairy calf between birth and 2 mo of age was positively related to starter intake (Heinrichs and Heinrichs, 2011; Bateman et al., 2012). The meta-analysis of Bateman et al. (2012) was very dynamic across many feeding rates, compositions of MR programs, and a broad range of ambient temperatures. Additionally, Heinrichs and Heinrichs (2011) reported that starter intake in the first 2 mo was significantly associated with more milk, fat, and protein production in the first lactation as well as in lifetime production. Together, these data point to the importance of starter

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intake in driving rumen development, calf growth, and possible future milk production.

Two laboratories have measured digestibility at approximately 1 wk after weaning in calves fed low or high amounts of MR and both reported 6 to 13% lower OM digestibility in calves fed the high level of MR (over 0.7 kg of DM daily) versus lower levels of MR (less than 0.7 kg of DM daily; Terre et al., 2007a,b; Hill et al., 2010). Reduced digestibility in calves fed high levels of MR was likely associated with less development of the rumen (Terre et al., 2007a,b; Suarez-Mena et al., 2011). Digestibility of NDF reported by Terre et al. (2007a,b) was 40% less in calves fed the high (~0.9 kg of DM) versus low (~0.45 kg of DM) level of MR. Feeding large amounts of MR could continue to impair fiber digestion as the calf transitions to higher-fiber diets as they age. More information is needed to understand the effect of MR rates on postweaning digestion. For that reason, we evaluated 3 MR programs involving 3 feeding rates on calf performance and postweaning digestion of several nutrients, including NDF and ADF.

MATERIALS AND METHODS

Holstein bull calves (initially 41 ± 1.9 kg of BW, 2 to 4 d of age) from a single dairy farm were received at midday after a 3.5-h transit. Calves arrived at the research nursery in 2 groups of 48 head, 35 d apart. Calves in each group (block) were randomly assigned to the treatments. The day after arrival, at approximately noon, the calves were weighed (d 0, initial BW). At this time, blood was sampled intravenously, serum was separated by centrifugation at $3,000 \times g$ at 20°C for 15 min (VWR, Batavia, IL), and serum protein concentration was estimated using an optical refractometer (ATAGO U.S.A. Inc., Bellevue, WA).

Three MR programs were compared using 32 male Holstein bull calves per program. The conventional (**CON**) program was 0.44 kg of DM of a 21% CP, 21% fat MR powder (Provimi, Brookville, OH) fed daily for 39 d, divided into 2 equal morning and evening meals. From d 40 to 42, calves were fed 0.22 kg of DM in one morning meal. The moderate (**MOD**) program was 0.66 kg of DM of a 27% CP, 17% fat MR powder (Provimi) fed daily for 39 d, divided into 2 equal morning and evening meals. From d 40 to 42, calves were fed 0.33 kg of DM in one morning meal. The aggressive (**AGG**) program was 0.66 kg of DM for 5 d and 0.87 kg of DM for 37 d (to d 42) divided into 2 equal morning and evening meals. From d 43 to 49, the MR was fed at 0.43 kg of DM/d in one morning meal. The CON and MOD MR were reconstituted to 13% solids and the AGG MR was reconstituted to 15% solids with warm

water (45°C) and fed at 0600 and 1600 h via buckets with nipples. In each program, all calves consumed all of the MR offered. Calves were fed a 20% CP textured starter (Provimi) and water ad libitum for the 56-d trial.

Calves were housed in a curtain-sided, naturally ventilated nursery with no added heat in 1.2×2.4 -m individual pens bedded with straw for 56 d. All animals were cared for as described in the *Guide for the Care and Use of Agricultural Animals in Research and Teaching* (FASS, 2010). The trial was conducted July through October. The average temperature in the nursery was 21°C with a range from 5 to 35°C. The average relative humidity was 77% with a range from 32 to 98%.

Calves were weighed initially and every 7 d. Hip widths of the calves were measured with a caliper and BCS was estimated initially and every 14 d. Calf BCS was based on a 1 to 5 system using 0.25-unit increments, with 1 being emaciated and 5 being obese (Wildman et al., 1982). Scores were based on changes around the vertical and transverse processes of the spine as palpated by an experienced technician. Starter intake offered and refused was measured daily. Feces were scored daily in the first 56 d (1 to 5 scale; 1 = firm, normal, 2 = less firm, normal, 3 = thick, batter-like, 4 = thin, batter-like, 5 = watery; modified from Kertz and Chester-Jones, 2004).

During d 51 to 56, when calves were weaned from MR, fecal samples were collected from 5 calves randomly selected per treatment in the first group of calves received. Calves were rectally palpated by hand to obtain a fecal sample. Fecal samples were systematically collected such that a total of 12 fecal samples were collected from the 5 calves per treatment over 6 d to represent every 2 h in a 24-h period. The starter was sampled daily over 5 d and pooled. Pooled fecal samples by calf were subsampled and analyzed for acid-insoluble ash relative to concentration in the pooled starter feed and feed intake over the 5-d period to estimate digestibility and fecal output.

Composites of feed and fecal samples were dried, ground, stored frozen, and subsequently were analyzed (AOAC International, 2000) for DM (oven method 930.15), CP (Kjeldahl method 988.05), fat (alkaline treatment with Roese-Gottlieb method 932.06 for MR; diethyl ether extraction method 2003.05 for starters and hay), fatty acids (feed only by GC; method 963.22), starch (α -amylase method; Hall, 2009), and sugar (Dubois et al., 1956). The starter and feces were 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). Feeds and fecal samples during the postweaning period were analyzed for acid-insoluble ash (Van Keulen and

Table 1. Analyzed nutrients in milk replacers (MR) and starter

Item	Control MR	Moderate/aggressive MR	Starter ¹
DM, %	96.2	95.9	88.1
CP, % of DM	21.1	27.2	20.4
Fat, % of DM	21.2	18.0	4.6
ADF, % of DM	—	—	8
NDF, % of DM	—	—	15
Sugar, % of DM	—	—	6.1
Starch, % of DM	—	—	40.3
Ash, % of DM	6.7	6.5	6.8
ME, ² Mcal/kg	4.79	4.75	3.23
Fatty acid, %			
C4	0.48	0.44	0.25
C6	<0.01	<0.01	<0.01
C8	0.01	0.01	<0.01
C10	0.08	0.06	<0.01
C12	0.61	0.52	0.33
C14	0.22	0.18	0.17
C16:0	4.44	3.72	0.36
C16:1	0.53	0.49	0.14
C18:0	2.35	1.93	0.21
C18:1	8.61	7.45	1.05
C18:2	1.69	1.39	1.68
C18:3	0.23	0.16	0.15

¹Ingredient composition of starter (as-fed basis): 37% whole corn, 35% supplement pellet, 25% whole oats, 3% molasses; supplement pellet contained 66% soybean meal, 22% wheat middlings, 9% minerals and vitamins, 3% molasses.

²Metabolizable energy calculated using NRC (2001) equations.

Young, 1977) to estimate digestion. Analyzed nutrient content of the diets are in Table 1.

Data were analyzed as a completely randomized block design, with the starting time of each group of calves being the block, using repeated measures over time by Proc Mixed in SAS (version 8, SAS Institute Inc., Cary, NC). Treatment means were separated with a protected LSD test (if the overall F-test for the measurement was significant, $P < 0.05$). Calf was the experimental unit. In the analysis, initial BW differed; thus, initial BW was used a covariate. However, covariate analysis did not change the differences among treatments for the different measurements, so noncovariate-adjusted results are presented.

RESULTS

Initial BW and hip widths of calves were different ($P < 0.05$; Table 2) among treatments. Starter intake by week is reported in Figure 1. Starter intake differed by week ($P < 0.01$) and a week by program interaction ($P < 0.01$) was noted. Weekly ADG differed by week ($P < 0.01$) and we observed a week by program interaction ($P < 0.01$; Figure 2). Hip width change measured every 2 wk differed ($P < 0.01$), but there was no week by program interaction ($P < 0.12$; Figure 3). Calves fed CON had the least ($P < 0.05$) ADG (CON = 0.35, MOD = 0.51, and AGG = 0.55 kg/d, SEM = 0.018),

feed efficiency (CON = 0.35, MOD = 0.49, and AGG = 0.48 gain/feed, SEM = 0.016), and change in hip width (CON = 3.3, MOD = 4.1, and AGG = 4.1 cm, SEM = 0.20) compared with calves fed other programs (Table 2). Calves fed AGG had the greatest ($P < 0.05$) change in BCS and tended to have the greatest ADG compared with calves fed the other programs, suggesting calves fed AGG had the most fat gain. Calves fed AGG consumed the least ($P < 0.05$) amount of starter throughout the 56-d trial compared with calves fed other programs. Fecal scores, days with abnormal fecal scores, and medical treatment days did not differ among treatments.

Total DMI was least for calves fed CON ($P < 0.05$; Table 3). Intake of fat, CP, and ME was greatest for calves fed AGG ($P < 0.05$). Efficiency of ADG per unit of CP did not differ among treatments. Efficiency of ADG per unit of ME intake was least for calves fed CON ($P < 0.05$). Intake of DM and fat per kilogram of BW did not differ ($P > 0.05$) among treatments.

During the digestion measurement period, BW of calves differed ($P < 0.05$; Table 4), with calves fed CON being lightest, calves MOD being intermediate, and calves fed AGG being greatest. Dry matter intake per kilogram of BW was least ($P < 0.05$) for calves fed AGG. Digestibility percentage of all nutrients measured, except for starch, was least ($P < 0.05$) for calves fed AGG compared with the other programs. Digest-

Table 2. Performance of calves fed 3 milk replacer (MR) programs¹ during the 56-d nursery trial

Item	CON	MOD	AGG	SEM	<i>P</i> -value		
					Treatment	Week	Treatment × week
Initial serum protein, mg/dL	5.0	5.1	4.9	0.12	0.34	—	—
Initial BW, kg	38.6 ^a	40.8 ^a	44.7 ^b	1.86	0.01	—	—
Final BW, kg	58.5 ^a	69.2 ^b	75.6 ^c	1.56	0.01	—	—
Initial hip width, cm	16.9 ^a	17.3 ^b	17.9 ^c	0.19	0.01	—	—
Final hip width, cm	20.2 ^a	21.4 ^b	22.0 ^c	0.26	0.01	—	—
Initial BCS ²	2.1	2.1	2.1	0.05	0.35	—	—
Final BCS	2.1 ^a	2.2 ^a	2.4 ^b	0.03	0.02	—	—
Total MR consumed, kg/calf	17.8	26.5	38.4	—	—	—	—
Starter intake, kg/d	0.573 ^a	0.572 ^a	0.455 ^b	0.0389	0.01	0.01	0.01
ADG, kg/d	0.354 ^a	0.507 ^b	0.553 ^b	0.0184	0.01	0.01	0.01
Gain to feed efficiency ³	0.349 ^a	0.488 ^b	0.475 ^b	0.0156	0.01	0.01	0.26
Fecal score ⁴	2.3	2.4	2.4	0.05	0.27	0.82	0.16
Abnormal fecal days, ⁵ no.	4.0	5.3	5.7	0.76	0.14	0.57	0.17
Medical days, no.	1.1	1.3	1.7	0.27	0.13	0.07	0.15
Hip width change, cm	3.3 ^a	4.1 ^b	4.1 ^b	0.20	0.01	0.01	0.12
BCS change	0.0 ^a	0.1 ^a	0.3 ^b	0.04	0.01	0.01	0.23

^{a-c}Means within a row with different superscripts differ ($P < 0.05$).

¹Control (CON): 0.44 kg of DM of a 21% CP, 21% fat MR powder daily fed for 39 d, then 0.22 kg of DM fed for 3 d; moderate (MOD): 0.66 kg of DM of a 27% CP, 17% fat MR powder daily fed for 39 d, then 0.33 kg of DM fed for 3 d; aggressive (AGG): 0.66 kg of DM of a 27% CP, 17% fat MR powder fed for 5 d, then 0.87 kg of DM for 37 d, then 0.43 kg of DM fed for 7 d.

²1 to 5 point system, with 1 being thin and 5 being obese.

³Feed efficiency was calculated as gain divided by the sum of milk replacer and starter intake.

⁴Feces were scored daily using a 1 to 5 scale, with 1 being normal and 5 being watery.

⁵Days with fecal scores of 3 or greater.

ibility of OM was 79% for CON, 78% for MOD, and 68% for AGG, and digestibility of NDF was 54% for CON, 51% for MOD, and 26% for AGG ($P < 0.05$). The quantity of nutrients digested per unit of BW for all nutrients measured was least ($P < 0.05$) for calves fed AGG compared with the other programs.

DISCUSSION

Digestibility measurements in our trial were consistent with measurements reported in a similar trial by Terre et al. (2007a,b) and 2 similar trials by Hill et al. (2010). Consistent with Terre et al. (2007a,b), the magnitude of reduction in NDF digestion was much larger than the magnitude of reduction in OM digestion

Figure 1. Weekly starter intake of calves fed 3 milk replacer (MR) programs (SEM = 0.048 kg/d, $P < 0.01$ for both week and week by program interaction; in wk 5, 6, and 7, AGG was less than CON and MOD, $P < 0.05$). Control (CON) = 0.44 kg of DM of a 21% CP, 21% fat MR powder daily fed for 39 d, then 0.22 kg of DM fed for 3 d; moderate (MOD) = 0.66 kg of DM of a 27% CP, 17% fat MR powder daily fed for 39 d, then 0.33 kg of DM fed for 3 d; aggressive (AGG) = 0.66 kg of DM of a 27% CP, 17% fat MR powder fed for 5 d, then 0.87 kg of DM for 37 d, then 0.43 kg of DM fed for 7 d.

Figure 2. Weekly ADG of calves fed 3 milk replacer (MR) programs (SEM = 0.049 kg/d, $P < 0.01$ for both week and week by program interaction; in wk 1, 2, and 3, CON was less than MOD and AGG, $P < 0.01$). Control (CON) = 0.44 kg of DM of a 21% CP, 21% fat MR powder daily fed for 39 d, then 0.22 kg of DM fed for 3 d; moderate (MOD) = 0.66 kg of DM of a 27% CP, 17% fat MR powder daily fed for 39 d, then 0.33 kg of DM fed for 3 d; aggressive (AGG) = 0.66 kg of DM of a 27% CP, 17% fat MR powder fed for 5 d, then 0.87 kg of DM for 37 d, then 0.43 kg of DM fed for 7 d.

Table 3. Intakes of total DM, CP, fat, and ME and efficiency of CP and ME use for ADG over the 56-d nursery trial when 3 milk replacer (MR) programs¹ were fed

Item	CON	MOD	AGG	SEM	P-value		
					Treatment	Week	Treatment × week
DMI, kg/d	0.891 ^a	1.045 ^b	1.141 ^b	0.0551	0.01	0.01	0.07
CP intake, kg/d	0.184 ^a	0.245 ^b	0.279 ^c	0.0137	0.01	0.01	0.06
Fat intake, kg/d	0.094 ^a	0.111 ^a	0.144 ^b	0.0073	0.01	0.01	0.07
ME intake, Mcal/d	3.37 ^a	4.09 ^b	4.73 ^c	0.259	0.01	0.01	0.10
g of ADG/g of CP intake	1.92	2.07	1.98	0.075	0.21	0.01	0.14
g of ADG/Mcal of ME intake	0.105 ^a	0.124 ^b	0.117 ^b	0.0041	0.01	0.01	0.17
DMI, g/kg of BW	18.4	19.0	19.0	1.322	0.08	0.01	0.19
CP intake, g/kg of BW	3.79 ^a	4.45 ^b	4.60 ^b	0.293	0.01	0.01	0.06
Fat intake, g/kg of BW	1.94	2.02	2.40	0.146	0.01	0.01	0.07
ME intake, kcal/kg of BW	69.5 ^a	74.5 ^{ab}	78.6 ^b	3.37	0.01	0.01	0.06

^{a-c}Means within a row with different superscripts differ ($P < 0.05$).

¹Control (CON): 0.44 kg of DM of a 21% CP, 21% fat MR powder daily fed for 39 d, then 0.22 kg of DM fed for 3 d; moderate (MOD): 0.66 kg of DM of a 27% CP, 17% fat MR powder daily fed for 39 d, then 0.33 kg of DM fed for 3 d; aggressive (AGG): 0.66 kg of DM of a 27% CP, 17% fat MR powder fed for 5 d, then 0.87 kg of DM for 37 d, then 0.43 kg of DM fed for 7 d.

when large amounts of MR were fed. As NDF and ADF are predominately digested in the rumen of calves, the lower digestibility of NDF and ADF postweaning with high MR feeding rates points to issues with rumen fermentation, which may be due to impaired rumen development. This is also consistent with reports of less rumen development in calves fed large amounts of MR (Terre et al., 2007a,b; Suarez-Mena et al., 2011). This reduction in rumen development may negatively affect future rumen fermentation and milk production (Heinrichs and Heinrichs, 2011).

Digestibility of starch was high and did not differ among treatments (94 to 96.7%, Table 4). Starch can

be digested in the both the rumen and large intestine by microbial fermentation and in the intestine from pancreatic enzymes (NRC, 2001). Thus, the high digestibility of starch with similar coefficients among treatments is logical.

It is difficult to explain why the digestion of sugar, CP, and fat was less in calves fed AGG versus other programs (Table 4). Sugar should be easy to ferment in the rumen and its concentration in the diet was low. Sucrase production is nonexistent to low in neonates (Huber et al., 1961) and possibly was slower to develop in calves fed the AGG versus other programs. Another possibility is that the rate at which starter intake increased for AGG on wk 8 increased the rate of passage of feed through the rumen, not giving enough time for bacteria to ferment the sugar. Another possibility is that lower fermentation of NDF in the rumen reduced the release of intracellular sugars and fat, reducing their overall digestibility. Endogenous losses of N can be greater with soybean proteins compared with milk proteins. The soybean proteins in the starter consumed in limited amounts by the neonate but more aggressively by the older calves fed AGG could have stimulated more endogenous N loss during the last week of the trial in calves fed AGG versus CON or MOD (Montagne et al., 2001). If so, more endogenous losses of N could have reduced the apparent digestion of CP in calves fed AGG. Also, lower fiber digestibility is an indicator of lower microbial activity in the rumen; therefore, rumen-digestible protein may not have been used as efficiently by calves on AGG versus other programs. Greater carbohydrate fermentation in the intestines may have also contributed to decreased N digestibility by increasing bacterial protein in the feces. In lactating cows, increasing intestinal carbohydrate fermentation resulted in lower N output in the urine

Figure 3. Hip width change in 2-wk increments measured of calves fed 3 milk replacer (MR) programs (SEM = 0.01 cm/d, $P < 0.01$ for both week, $P < 0.12$ for week by program interaction; in wk 2, 4, and 6, CON was less than MOD and AGG, $P < 0.01$). Control (CON) = 0.44 kg of DM of a 21% CP, 21% fat MR powder daily fed for 39 d, then 0.22 kg of DM fed for 3 d; moderate (MOD) = 0.66 kg of DM of a 27% CP, 17% fat MR powder daily fed for 39 d, then 0.33 kg of DM fed for 3 d; aggressive (AGG) = 0.66 kg of DM of a 27% CP, 17% fat MR powder fed for 5 d, then 0.87 kg of DM for 37 d, then 0.43 kg of DM fed for 7 d.

and higher output in the feces (Gressley and Armeniano, 2005). Additionally, calves on the AGG program could have had a faster rate of passage than calves on the other programs resulting from less rumen development (Vazquez-Anon et al., 1993).

Despite similar to greater DM, CP, and ME intakes (kg/d and kg/kg of BW) over the 56-d trial (Table 3 and Figure 1), the lower DMI per kilogram of BW and lower digestibility coefficients for all nutrient measures except starch in the last week of the trial resulted in less nutrients digested (g/kg of BW) during the last week of the trial for calves fed AGG versus the other programs. This reduced supply of all digested nutrients measured is an important consideration when feeding MR programs similar to AGG. Some of the greater BW gain in the neonatal calves fed the AGG program was lost during the postweaning period, likely due to the lower supply of digested nutrients.

In Figure 2, note that the pattern of ADG from wk 2 to 8 was increasing for calves fed CON and MOD programs. The ADG for calves fed AGG appear to slow at wk 6 or plateau around wk 4, but then increase during wk 8. The increase during wk 8 (despite lower digestibility) could be a function of more digesta filling of the gut from the rapid increase in starter intake in wk 7 and 8 combined with the lower digestibility coefficients of most nutrients. If true, then carcass or empty BW gain would be less reflected in the ADG for calves fed AGG. Changes in hip widths over the 56-d trial did not

differ between calves fed MOD and AGG programs (4.1 cm), whereas ADG were numerically but not statistically greater for calves fed AGG versus MOD (0.553 vs. 0.507 kg/d). Similar hip width changes might indicate that digesta fill was elevating ADG for calves fed AGG.

Calves fed AGG had greater BCS change over the 56-d trial than calves fed the other programs. Fat intake was greater as grams of fat daily but not as grams of fat per kilograms of BW (yet appeared numerically greater, 2.40 vs. 1.94 to 2.02 g of fat/kg of BW for AGG, CON, and MOD respectively; Table 3). Early growth in calves fed AGG could have contained more fat than calves fed the other treatments (Bascom et al., 2007). Recently, deuterium oxide dilution methods have been used for assessment of body composition for cows and heifers (Rius et al., 2005). This may be a valid method for determining the composition of growth in calves fed these aggressive MR feeding programs. More body fat with a similar change in hip width might not be the type of growth preferred. High fat concentrations and intakes from MR have reduced pre- and postweaning starter intake and pre- and postweaning ADG (Hill et al., 2009a,b, 2010, 2012) while increasing carcass fat gain and decreasing carcass protein gain and structural growth (Bascom et al., 2007).

As shown in Figure 1, starter intake of calves fed AGG substantially increased during wk 7 when MR was reduced and wk 8 when MR was removed. This is common in all the trials previously cited that evalu-

Table 4. Body weights, intake, and apparent digestibility of calves (5/treatment) fed the 3 milk replacer (MR) programs¹ during d 51 to 56 when digestibility was estimated

Item	CON	MOD	AGG	SEM	P-value
BW, kg	62.7 ^a	72.3 ^b	82.8 ^c	4.05	0.01
DMI, kg/d	2.04	2.30	2.28	0.2583	0.08
DMI, g/kg of BW	32.5 ^a	31.8 ^a	27.5 ^b	2.31	0.02
Digestibility, %					
DM	77.6 ^a	76.9 ^a	66.0 ^b	1.67	0.01
OM	79.2 ^a	78.2 ^a	67.9 ^b	1.65	0.01
ADF	56.3 ^a	53.2 ^a	26.7 ^b	3.89	0.01
NDF	54.1 ^a	50.7 ^a	26.2 ^b	2.86	0.01
Starch	96.7	94.5	94.0	1.33	0.36
CP	71.9 ^a	74.1 ^a	56.3 ^b	2.72	0.02
Sugar	93.1 ^a	91.5 ^a	86.2 ^b	1.68	0.02
Fat	81.4 ^a	83.2 ^a	74.1 ^b	1.84	0.01
Digested, g/kg of BW					
OM	24.0 ^a	22.5 ^a	17.2 ^b	1.79	0.02
ADF	1.8 ^a	1.6 ^a	0.7 ^b	0.16	0.01
NDF	3.1 ^a	2.7 ^a	1.3 ^b	0.16	0.01
Starch	12.2 ^a	11.3 ^a	9.9 ^b	0.23	0.01
CP	4.7 ^a	4.5 ^a	3.0 ^b	0.93	0.01
Sugar	1.9 ^a	1.8 ^a	1.5 ^b	0.33	0.04
Fat	1.2 ^a	1.2 ^a	0.9 ^b	0.13	0.03

^{a-c}Means within a row with different superscripts differ ($P < 0.05$).

¹Control (CON): 0.44 kg of DM of a 21% CP, 21% fat MR powder daily fed for 39 d, then 0.22 kg of DM fed for 3 d; moderate (MOD): 0.66 kg of DM of a 27% CP, 17% fat MR powder daily fed for 39 d, then 0.33 kg of DM fed for 3 d; aggressive (AGG): 0.66 kg of DM of a 27% CP, 17% fat MR powder fed for 5 d, then 0.87 kg of DM for 37 d, then 0.43 kg of DM fed for 7 d.

ated high feeding rates of MR. However, when DMI was expressed per kilogram of BW in the first 1 to 2 wk postweaning, intake was lower in calves fed programs such as AGG, as we observed (Table 4).

In the current research, ADG per ME intake and ADG per CP intake did not differ between calves fed AGG and MOD programs (Table 3). This is true in the previous literature cited. In the current research, ADG per ME intake was greater and ADG per CP intake did not differ between calves fed AGG and CON programs. This is also consistent with most of the literature, except in research where ADG did not differ with the amount of MR fed. When considering these results, note that total MR intake per calf is typically >2 times greater for programs such as AGG versus CON. Nutrients in MR are more digestible than starter feeds, contain 4 to 5 times more fat, and are typically 5 to 8 times more expensive.

Longer periods to gradually wean calves from the maximum amount of MR fed are recommended to overcome the poor postweaning digestibility in calves fed large amounts of MR. At least 4 studies from 3 laboratories have addressed this (Khan et al., 2007a,b; Hill et al., 2007, 2013; Sweeney et al., 2010). From these studies it appears that a 3-wk period where MR is fed at 0.7 kg of DM or less is needed to avoid slumps in postweaning ADG. Calves fed AGG in the current study only had a 7-d period where the MR was halved from the maximum of 0.87 kg of DM/d.

We found no differences in fecal scores or days with abnormal fecal scores or medical treatments in the current trial. In some studies it is frequently reported that calves fed AGG-like programs have looser feces than calves fed CON-like programs (Quigley et al., 2006; Hill et al., 2006a, Osorio et al., 2012, Ballou et al., 2015). This health-related measurement is likely a function of the pathogen involved and when the pathogen infects the calf.

The ADG of individual calves during the first 7 d of the trial is shown in Figure 4. Whereas mean growth rates were positive for all 3 treatments, over one-third of the calves fed the CON program lost BW. Few calves fed the MOD or AGG programs lost BW in the first 7 d; although not shown, the results for the second week were similar. During the first 1 or 2 wk of life, the calf experiences significant stresses (health and environmental) and does not digest or metabolize nutrients as well as later in life (NRC, 2001). Additionally, maintenance may be a threshold where gross nutrients fed could affect health or immunity (Griebel et al., 1987; Pollock et al., 1994). Feeding more than this conventional minimum amount of solids delivered by the CON program would be preferred for health and growth. Feeding programs such as MOD provide a nutrient intake well above calf

Figure 4. Individual calf and program mean ADG during wk 1 for calves fed 3 milk replacer (MR) programs. Control (CON) = 0.44 kg of DM of a 21% CP, 21% fat MR powder daily fed for 39 d, then 0.22 kg of DM fed for 3 d; moderate (MOD) = 0.66 kg of DM of a 27% CP, 17% fat MR powder daily fed for 39 d, then 0.33 kg of DM fed for 3 d; aggressive (AGG) = 0.66 kg of DM of a 27% CP, 17% fat MR powder fed for 5 d, then 0.87 kg of DM for 37 d, then 0.43 kg of DM fed for 7 d.

maintenance requirements and promote good overall growth (both pre- and postweaning), as observed in this trial and others (Hill et al., 2006a,b, 2007, 2010, 2012, 2013; Raeth-Knight et al., 2009).

CONCLUSIONS

In MR programs that feed more than approximately 0.7 kg of DM daily, preweaning starter intake was decreased and ADG was increased compared with MR programs that fed less DM. Also, postweaning intake of DM typically increased, quickly approaching amounts similar to calves fed less MR; however, postweaning intake of DM per kilogram of BW and digestibility coefficients and digested amounts of nutrients per kilogram of BW were considerably less than calves fed less MR, which was consistent with the results of several other published trials. Data from our study indicated that less digestion postweaning in calves fed amounts of MR over approximately 0.7 kg of DM results in less than optimum postweaning ADG and structural growth while increasing body fat and BCS of calves by approximately 2 mo of age.

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