Impact of Alfalfa Hay Neutral Detergent Fiber Concentration and Digestibility on Holstein Dairy Cow Performance, Diet Digestibility and Chewing Behavior.

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Dedication

I dedicate this thesis to my family. Thank you for your love, support and encouragement.

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Impact of alfalfa hay neutral detergent fiber concentration and digestibility on Holstein dairy cow performance, diet digestibility and chewing behavior.

Our objectives were to determine the effect of alfalfa hay in vitro neutral detergent fiber digestibility (IVNDFD), compared within relatively low and high neutral detergent fiber (NDF) concentration hay pairs, on Holstein dairy cow performance, apparent digestibility, chewing activity and rumen parameters. Treatments (Lh, Ll, Hh and Hl) included four alfalfa hays selected for low (L) or high (H) NDF concentration and low (l) or high (h) 48-h IVNDFD within NDF concentration pairs. Three studies were conducted. During Study 1 and 2, alfalfa hays were included at 15% of the diet DM. Study 3 was a short-term study (21-d) in which alfalfa hay was fed at 96% of the diet DM. Analysis of alfalfa hay grab samples taken during study 1 confirmed that within the high NDF hays (Hh and Hl) there was no difference in NDF concentration and the Hh hay was 6.8 percentage units higher in IVNDFD compared to Hl. However, within the low NDF hays (Lh and Ll), NDF concentration was 3.8 percentage units higher for the Ll compared to Lh hay and there was no difference in IVNDFD. Therefore, our original study design was not maintained. As a result, we evaluated the impact of alfalfa hay IVNDFD on response variables for the high NDF hay diets and the impact of alfalfa hay NDF concentration on response variables for the low NDF hay diets. When alfalfa hay was fed at 15% of the diet DM, there was no impact of alfalfa hay NDF concentration or IVNDFD on DMI, fat corrected milk (FCM) yield, milk fat, or protein yield among treatments. Within the low NDF hay diets, apparent total tract DM digestibility (DMD) was 6.6 percentage units higher for the Ll compared to the Lh hay

diet and there was a trend for higher apparent total tract NDF digestibility (NDFD) for the Ll compared to Lh hay diet. For the high NDF hay diets, a difference in alfalfa hay IVNDFD of 6.8 percentage units did not affect total tract DM or NDF digestibility. Neither alfalfa hay NDF concentration nor IVNDFD affected rumen pH or VFA concentrations. When alfalfa hay was included at 96% of the diet DM, there was no difference in DMI, 3.5% FCM, milk fat or protein yield among treatments. Within the low NDF hay diets, apparent total tract DM and NDF digestibility were 14.7 and 18.4 percentage units higher for the Lh compared to Ll hay diet. In contrast, within the high NDF hay diets, apparent total tract DMD was 11.1 percentage units higher for the Hl compared to Hh hay and there was no difference in apparent total tract NDFD. Our results suggest that small differences in alfalfa hay IVNDFD or NDF concentration, especially when alfalfa hay is fed at a low dietary inclusion level, should not be expected to have a significant impact on dairy cow lactation performance. Given the challenges associated with forage sampling and IVNDFD repeatability, effectively implementing IVNDFD data in diet formulation for dairy cows is difficult.

INTRODUCTION

Current levels of milk production require dairy cows to consume considerable amounts of concentrates. However, forages are required to maintain rumen function and animal health, and are still considered the foundation of dairy cow diets. In most rations fed to dairy cows, forages comprise at least 40% of the total dry matter (DM) and consequently forage quality has a significant impact on milk production, ration cost and animal health. Two important forage quality components include the concentration and

digestibility of fiber. Fiber, measured as NDF in the feed analysis system developed by Van Soest (1963), constitutes the largest nutritional component of forages and the concentration and digestibility of NDF impact both forage intake potential and available energy across all forage species (Jung and Allen, 1995).

Brown midrib corn and sorghum silages, which have less lignin and higher IVNDFD than their isogenic controls, have been shown to regularly improve milk and or average daily gain of dairy cows (Oba and Allen, 1999, Oba and Allen, 2000, Oliver et al., 2004). However, these silages are generally fed at higher dietary inclusion rates than forage grasses or legumes. A limited number of studies have demonstrated an impact of forage NDF digestibility on lactating dairy cow performance when feeding complex, mixed diets. Dado and Allen (1996) reported increased milk yield and DMI when dairy cows were fed diets containing alfalfa silage with increased 24-h in vitro NDFD (IVNDFD). Results were confounded however, because the alfalfa silages also differed in NDF concentration. Consequently, it is unclear if the production response was caused by decreased alfalfa silage NDF concentration or increased silage IVNDFD. In contrast, Chow et al. (2006) showed that feeding mid-lactation cows barley silage at 59% of dietary DM with high or low 30-h IVNDFD resulted in similar milk yield and DMI. However, average daily gain was higher for cows fed barley silage with increased IVNDFD. As in the study by Dado and Allen (1996), the barley silages also differed in NDF concentration but Chow et al. (2006) reported that the barley with increased IVNDFD was also higher in NDF concentration. Therefore, the improvement in BW gain was likely attributable to increased barley silage IVNDFD.

Kendall et al. (2009) used a different approach to investigate the relative importance of forage NDF and IVNDFD in a mixed diet on lactating cow performance. Cows were fed wheat straw (41% IVNDFD) or ammoniated wheat straw (62% IVNDFD) at 8.5 or 16% of the diet DM resulting in dietary NDF concentrations of 28 or 32%, respectively. Increased wheat straw IVNDFD improved milk yield 1.5 and 2.1 kg/d for the low and high NDF diets, respectively; however, IVNDFD had no affect on DMI. In contrast, decreasing dietary NDF concentration 4 percentage units increased DMI 1.1 kg/d and milk yield 2.5 kg/d. Although the authors of this study successfully differentiated the impact of forage NDFD from NDF concentration, straw is not considered a high quality forage and is typically included at low levels in lactating dairy cow diets; primarily as a source of physically effective fiber. Additionally, the large difference in wheat straw IVNDFD (21 percentage units), obtained by using ammonia, is not likely to occur with typical forages that are generally the major source of fiber in lactating dairy cow diets.

Our objectives were to determine the effect of alfalfa hay IVNDFD, compared within relatively low and high NDF concentration groups, on Holstein dairy cow performance, apparent digestibility of dietary DM and NDF, chewing activity and rumen parameters when high quality alfalfa hay is utilized. Divergent alfalfa hays were fed at typical and forage-only diet inclusion rates (15 and 96% of the diet DM, respectively). In addition because hay quality differed among hay samplings, challenges obtaining accurate hay analysis will be discussed.

MATERIALS AND METHODS

Housing and Treatments

Cows were housed in a tie-stall facility and cared for according to Institutional Animal Care and Usage Committee recommendations (Animal Subjects Code 0309A52001). Three studies were conducted at the University of Minnesota Dairy Research and Teaching Unit. Treatments (Lh, Ll, Hh and Hl) were one of four alfalfa hays selected for low (L) or high (H) NDF concentration and low (l) or high (h) 48-h IVNDFD within NDF concentration groups. Alfalfa hays were included at 15% of the diet DM in Studies 1 and 2 and 96% of the diet DM for Study 3.

Alfalfa Hay Selection

Experimental alfalfa hays were selected in the following manner. Twenty alfalfa hay lots, containing a minimum of 72.6 tonnes of hay per lot, from West and Midwestern portions of the United States were core sampled by commercial hay producers; twenty cores per hay lot were requested. This quantity of hay was required for studies reported here and in a companion study conducted at the US Dairy Forage Research Center (USDFRC) in Madison, WI. Results from the USDFRC study will be presented in a future publication.

Samples were sent to the USDFRC to be analyzed for NDF concentration and 48-h IVNDFD. The initial hay selection criteria were to obtain low and high NDF alfalfa hay concentration groups that differed in 48-h IVNDFD, within each concentration group, by a minimum of 10 percentage units. Once shipped to Minnesota a core sample was taken from each large hay bale (~ 363 to 454 kg) and every 10th small square bale

(~23 kg). Core samples were composited by hay lot and analyzed for NDF and CP concentration and 48-h IVNDFD at the USDRFC (Table 1).

Study 1

Alfalfa hay was included at approximately 15% of the diet DM and diets were formulated to meet or exceed nutrient requirements for 40 kg of milk/d (NRC, 2001). Diets were formulated using pre-study hay core sample analysis (Table 1) and were balanced to be isocaloric, isofibrous and isonitrogenous. As shown in Table 2, the average ingredient composition across all diets was 14.8% alfalfa hay, 35.0% corn silage, 26.5% protein mix, 15.5% ground corn, 5.2% roasted soybeans and 3.0% molasses (DM basis). However, in order to have isofibrous, isocaloric, and isonitrogenous diets the amount of hay and corn silage in the high NDF hay diets (Hh and Hl) was decreased while the amount of corn was increased compared to the low NDF alfalfa hay diets (Lh and Ll); this resulted in a forage (F) to concentrate(C) ratio of 52:48 and 47:53 for the low and high NDF hay diets, respectively. Prior to inclusion in the TMR, alfalfa hay was ground using an AgriMetal tub grinder (DC Atlas Company, Inc., Spencer, WI). Grinding the Ll treatment hay resulted in very fine particles (Table 3); therefore 25% of the Ll hay was included as non-ground long hay. Allowing for 5% feed refusal, the TMR was offered twice daily at 0600 and 1400 h. Corn silage DM was determined weekly and the amount included in the diet (as fed) was adjusted if the silage DM varied by more than 2 percentage units. Cows were milked twice daily at 0500 and 1400 h.

Cows and Diets. In October of 2004, sixty multiparous Holstein cows were blocked by calving date and randomly assigned to one of four alfalfa hay treatment diets (Lh, Ll, Hh, and Hl) immediately following calving. Diets were fed and data collected

for 133 d. Three cows were removed from the study for severe mastitis. Two cows were removed from the Hh treatment and one cow was removed from the Hl treatment.

Data and Sample Collection. Milk yield, feed intake and refusal amounts were recorded daily. Individual milk samples were taken once weekly at the 1400 and 0500 h milking of consecutive d. Ground hays were sampled daily and composited on an equal weight basis by week. Other dietary ingredients, TMR and refusal samples were taken weekly. Body weights were recorded every 28 d. Cow observations were recorded for 2 d in February every 15 min for 24 h on all cows to estimate time spent eating and ruminating. For each observation it was assumed cows continued the noted behavior for 15 min. Individual fecal grab samples were collected during early lactation (67 ± 20 DIM) every 8 h over 3 consecutive d to determine apparent diet DM and NDF digestibility. Fecal samples were collected for 6 d during two collection periods in January and March. Half of the cows were sampled during each collection period. Diet and refusal samples were collected once daily for 6 d, beginning 3 d and 2 d prior to fecal sampling, respectively. Samples were composited by treatment for analysis.

Study 2 – Rumen Characteristics

Cows and Diets. A rumen fermentation study was conducted February to April of 2004. Four rumen cannulated, multiparous cows were utilized in a 4 x 4 Latin square design with 21-d periods; the first 14 d were for dietary adaptation followed by 7 d for data and sample collection. Cows were randomly assigned to one of four alfalfa hay diets (Hh, Hl, Lh, or Ll); the same diets being concurrently fed in study 1 were used in study 2. Initial DIM averaged 39 ± 10 (mean ± SD) and milk yield averaged 43 ± 5 kg/d.

Data and Sample Collection. Rumen fluid was collected d 1 and 3 of each 7-d collection period. Samples were taken just prior to feeding (0 h) and 1-, 2-, 6-, and 12-h post-feeding. The pH of the rumen fluid was determined immediately. Rumen fluid was then strained through 4 layers of cheesecloth, 25% metaphosphoric acid was added at a 1:5 ratio, samples were vortexed and then frozen for subsequent volatile fatty acid (VFA) and lactic acid analysis.

Study 3

Cows and Diets. Study 3 was initiated June of 2004. Twenty Holstein dairy cows that had completed the 133-d lactation study (Study 1) were utilized. Cows remained on their previously assigned alfalfa hay treatment (Hh, Hl, Lh or Ll) but were fed a diet consisting of 95.8% of the appropriate alfalfa hay and 4.2% molasses/vitamin mineral mix (DM basis) rather than the previously described TMR. Cows were transitioned to their respective treatment diets over a 21-d period. After the transition period, cows were adjusted to their new diet for 11 d followed by a 7-d data and sample collection period. Water was added to the diets at 10% of the ration (as-fed basis). Due to excessively fine particle size following grinding, 25% of the Ll alfalfa hay was again fed as non-ground long hay.

Data and Sample Collection. During the 7-d collection period, milk yield, feed intake and refusals were recorded daily. Diet ingredient samples were taken daily and individual milk samples were taken once during consecutive 1400 and 0500 h milking. Time spent chewing, eating and ruminating was recorded on all cows every 15 min, from 0600 to 1500 (9 h/d) d 3 and 4. For each observation it was assumed cows continued the noted behavior for 15 min.

Individual fecal grab samples were collected starting d 5 to determine apparent dietary DM and NDF digestibility. Nine samples were collected over 72 h and composited by cow for analysis. Diet and refusal samples were collected once daily for 6 d starting d 2 and d 3, respectively and analyzed individually.

Sample Analysis

Pre-Purchase and Pre-Study Alfalfa Hay Lot Analysis. Samples were dried for 24 h in a 60°C forced-air oven to determine DM content and ground in a Wiley mill to pass through a 1-mm screen (Thomas Scientific, Swedesboro, NJ). Crude protein was determined via the Dumas method (Elementar Rapid N, Elementar Americas Inc., Mt. Laurel NJ; AOAC, 1995) and NDF using the Gooch crucible technique of Goering and Van Soest (1970) modified to include the addition of sodium sulfite and α-amylase. To determine 48-h IVNDFD, approximately 0.5 g of sample was weighed into 125 ml Erlenmeyer flasks. Flasks were incubated in a water bath (39.5°). Eighty ml of a buffer and reducing solution were added to each flask and continuous CO_2 pressure maintained according to Goering and Van Soest (1970). Rumen fluid collected from three ruminally-cannulated lactating Holstein dairy cows was strained through cheesecloth to remove solids and composited. The solids were blended with a reducing solution, strained through cheesecloth, and added back to the rumen fluid at a concentration of 0.5 g wet solids/ml rumen fluid. Twenty ml of inoculum (rumen fluid with blended solids) was added to each flask. Following 48 h of fermentation, flasks were removed and NDF was determined on the residue as previously described.

Study 1. Milk samples were analyzed for fat, true protein, lactose, and somatic cell count (Minnesota DHIA; Zumbrota, MN). Ingredient, TMR and refusal, samples

were dried for 24 h in a 60°C forced air oven to determine DM content, ground to pass through a 1-mm screen (Wiley mill; Swedesboro, NJ) and composited on an equal weight basis. Weekly ingredient and hay samples were composited on an equal weight basis by month and analyzed for NDF and CP concentration. Using sodium sulfite and α-amylase, the Ankom^{200} fiber system (Ankom Technology Corporation, Fairport, NY) was used for analysis of NDF and CP was determined by the Dumas method (NA2100 Protein Nitrogen Analyzer, ThermoQuest Italia S. P. A., Italy; AOAC, 1995). Monthly alfalfa hay samples were analyzed for 48-h IVNDFD as previously described for hay core samples. The Penn State Particle Separator (PSPS) was used to measure particle size on monthly hay, TMR and refusal samples as described by Kononoff et al. (2003). As an estimate of physically effective NDF, the material on the top and second sieve of the PSPS was analyzed for NDF concentration as described. Weekly refusal samples were composited by month and analyzed for DM and NDF concentration.

Diet, refusal and fecal samples collected to determine apparent total tract digestibility were dried, ground and analyzed for DM content and NDF concentration (using the The Ankom^{200} fiber system) as previously described. Samples were analyzed for acid insoluble ash (AIA) which served as an internal marker to determine apparent total-tract DM and NDF digestibility (Van Keulen and Young, 1977).

Study 2. Rumen fluid VFA and lactic acid concentrations were determined via gas chromatography (Hewlett Packard 6890) according to Erwin et al., (1961). Samples were analyzed using a 4% Carbowax 20M/80/120 Carbopack B-DA column (Supelco, Bellefonte, PA) at 175°C with a flow rate of 24, 40, and 450 ml/min for nitrogen, hydrogen, and air, respectively.

Study 3. A study composite of weekly alfalfa hay samples were analyzed for DM content and NDF concentration as described. Diet, refusal and fecal samples collected to determine apparent total tract digestibility were dried, ground and analyzed for DM content, NDF and AIA concentration as previously described.

Statistical Analysis

All treatment results are reported as least square means. Main effects and interactions were considered significant at $P < 0.05$, and tendencies were declared at $P < 0.10$. Orthogonal contrasts were used to evaluate the effect of alfalfa hay 48-h IVNDFD (Lh versus Ll, Hh versus Hl) and NDF concentration (Hh and Hl versus Lh and Ll) on cow performance.

Study 1. Production data were analyzed as a repeated measures randomized complete block design using the PROC MIXED procedures of SAS© (SAS Institute, 1999). Blocking factor was calving date and the first-order autoregressive covariance structure was used. The model included treatment, wk, and treatment x wk as fixed effects; cow block, treatment x block and wk x block as random effects.

Individual cow activity observations and digestibility data were averaged. Data were analyzed as a randomized complete block design, with calving date as the blocking factor. Treatment was a fixed effect and cow, block and the treatment x block interaction were random effects. Correlations of apparent total tract NDFD and DMD with DMI during the digestibility sampling period were determined using the PROC CORR procedure.

Nutrient composition and particle size of alfalfa hay monthly composited grab samples (10 samples per hay) and the nutrient composition of alfalfa hay diets (calculated

based on analysis of individual feed ingredients on a monthly basis, n =10) were also analyzed using PROC MIXED. The repeated measures, completely randomized design model included treatment and month as fixed effects.

Study 2. Rumen pH, VFA, and lactic acid were analyzed as a 4 x 4 Latin square. Data was averaged within each period to create one observation per time point and analyzed using a repeated measures model. Due to unequally spaced repeated measures, the spatial power law was used as the covariance structure. The model included treatment, period, cow and time as fixed effects. Milk yield and DMI data were analyzed similarly however, data was reduced to a period mean and therefore time was not included in the model.

Study 3. Production and digestibility data from the collection period were reduced to a weekly average for each cow. The complete randomized model included cow as a random effect and treatment as a fixed effect. Average 3.5% FCM yield the week prior to the start of the study was utilized as a covariate for milk yield. Correlations of apparent total tract NDFD and DMD with DMI during the digestibility sampling period were determined.

RESULTS AND DISCUSSION

Alfalfa Hay

Although core sampling was utilized to select the four alfalfa hay treatments, because the hays were ground and blown into storage rooms prior to feeding, the grab samples taken during the course of the studies probably represent the best quality estimate of the hay actually fed. Therefore, the nutrient composition of the alfalfa hay

grab samples was used to calculate the dietary nutrient composition for Studies 1 and 2 and is the basis for the discussion of study results.

The nutrient composition and physical characteristics of alfalfa hay grab samples are shown in Table 3. When selecting our alfalfa hay treatments, we attempted to obtain low and high NDF hay concentration groups that differed in 48-h IVNDFD within each concentration group by a minimum of 10 percentage units. Based on hay grab sample analysis, within the high NDF hays (Hh and Hl), there was no difference in NDF concentration and the Hh hay was 6.8 percentage units higher in IVNDFD compared to Hl ($P < 0.05$). However, within the low NDF hays (Lh and Ll), NDF concentration was 3.8 percentage units higher for the Ll compared to Lh hay and there was no difference in IVNDFD. Therefore, grab sample analysis indicated our original study design was not maintained. As a result, we evaluated the impact of alfalfa hay IVNDFD on response variables for the high NDF hays and the impact of alfalfa hay NDF concentration on response variables for the low NDF hays.

Particle size analysis of ground hays showed differences in the physical characteristics of the hay prior to feeding which supported the decision to include 25% of the Ll hay as non-ground long hay. The Ll and Hh hays had the lowest percentage of long particles, averaging only 12.2% of material on the top screen compared to 25.2% for the Lh and Hl hays. The percentage of small particles was lowest for the Lh and greatest for the Ll hay. It is not clear why the Ll hay ground very finely.

Dietary Nutrient Composition and Physical Characteristics

Studies 1 and 2. Based on analysis of individual feed ingredients sampled during Studies 1 and 2, the nutrient composition of the alfalfa hay diets is shown in Table 4. Dry

matter content was similar across diets averaging 60.4%. Crude protein was 0.7 percentage units lower (17.2% vs. 17.9% CP) and NDF concentration was 1.0 percentage units higher (30.9% vs. 29.9% NDF) for the low as compared to high NDF hay diets (P <0.01). Dietary energy concentration was similar across diets averaging 1.6 Mcal/kg. In order to keep diets isofibrous, the amount of NDF from forage was 1.5 percentage units higher (21.1% vs. 19.6%) and NFC concentration was 1.7 percentage units lower (41.3 vs. 43.0) for the low compared to high NDF hay diets ($P < 0.01$).

Physical characteristics of alfalfa hay diets and refusals in Study 1 are shown in Table 5. Although 25% of Ll hay was included as non-ground long hay the percentage of diet feed particles greater than 19.0 mm and retained on the top screen of the PSPS, was 2.2 percentage units lower for the Ll compared to Lh hay diets ($P < 0.01$). There was no difference in the percentage of feed material on the top screen for the high NDF hay diets or between the low and high NDF hays diets. The percentages of feed material retained on the second and third screens, and in the bottom pan were similar across diets.

The amount of physically effective fiber in the diets, as estimated based on the NDF concentration of the particles retained on the top and second screens, was similar within the low NDF hays. For the high NDF hays, the NDF concentration of the particles contained on the top screen was 3.0 percentage units higher for the Hl compared to the Hh hay diet. This is consistent with the particle size analysis of the high NDF hays which indicated that the proportion of particles on the top screen was 8.9 percentage units greater for the Hl compared to the Hh hay (Table 3). Within the high NDF hay diets there was no difference in the NDF concentration of the particles retained on the second screen of the PSPS averaging 44.5% NDF. When calculated as a proportion of total

dietary NDF, the NDF concentration of particles retained on the top and second screen was 37.3%, 32.7%, 34.9% and 37.5% for the Lh, Ll, Hh and Hl hay diets, respectively. Analysis of refusals indicated a small amount of sorting occurred on all diets. Compared to diets, the NDF concentration of refusals was 2.6 and 4.3 percentage units higher for the low and high NDF hay diets, respectively. Particle size analysis of refusals indicated more sorting occurred when cows were fed the Ll and Hl hay diets compared to the other two diets (Table 5).

Study 3. The nutrient composition of treatment diets when alfalfa hay was included at 96% of the diet DM is shown in Table 6. The concentration of NDF was 1.3 percentage units higher for the Ll compared to the Lh diet and 4.7 percentage units higher for the Hh compared to the Hl diet. As this study was designed to amplify the impact of alfalfa hay IVNDFD on cow performance, diets were essentially forage-only and therefore the energy concentration was low across all diets at 0.7 Mcal/kg for the Lh hay diet and 0.6 Mcal/kg for the other diets.

Lactation Performance, Diet Digestibility and Rumen Characteristics.

As previously discussed, our original study design was not maintained based on analysis of alfalfa hay grab samples. Consequently, although this section will begin by comparing results for the low and high NDF hay diets, a direct comparison of our data with previous studies that have evaluated forage NDF concentration or IVNDFD in lactating dairy cow diets will occur within the low and high NDF hays, respectively.

Low versus High NDF Hays Diets. As shown in Table 7, when alfalfa hay was included at 15% of the diet DM (study 1), there were no difference in DMI or milk yield between the low and high NDF hay diets. Cows consumed 22.3 kg DM/d and produced

39.8 kg of 3.5% FCM/d across treatments. There was also no difference in the concentration of milk components between the low and high NDF hay diets; milk fat averaged 3.6% across treatments with milk protein and lactose concentration averaging 2.9% and 4.8%, respectively. There was no difference in BW change between the low and high NDF hay diets with cows loosing an average of 33.1 kg of BW during the 133 d study. Feed efficiency (FE) was high for all diets averaging 1.9 kg of 3.5% FCM per kg of DMI. In early lactation FE is generally 1.5 to 1.8 kg milk/kg DMI and a FE greater than 1.8 is indicative of excessive weight loss or ketosis (Linn, 2006). As relatively high milk production was maintained across treatments and none of the cows were diagnosed with ketosis, high FE in our study appeared to result from increased BW loss.

In study 1, there was also no difference in NDF intake, apparent total tract DMD or NDFD and digestible DMI (DDMI) between the low and high NDF hay diets (Table 8). This was anticipated because there were no differences in lactation performance or BW loss during the study. Across diets, dietary apparent total tract DM and NDF digestibility averaged 68.0% and 52.4%, respectively. Digestibility results were similar to those previously reported for corn silage based diets (Oelker et al., 2009; Nennich et al., 2003). There was no difference in the amount of time spent eating (218 min/d) or ruminating (468 min/d) for cows on the low compared to high NDF hay diets. Beauchemin et al. (2003) fed ground alfalfa hay to lactating cows at 19.7% of the diet DM. The quality of the alfalfa hay was slightly lower than that fed in our study (52.3% NDF) which may have resulted in cows spending more time eating (258 min/d ± 38.2) and less time ruminating (375 ± 40.6) than in our study. According to Beauchemin et al. (1997), when dietary NDF concentration or forage particle size is increased, chewing

activity (eating and ruminating time) increases. In Study 1 there was relatively little difference in dietary NDF concentration, particle size or the amount of physically effective fiber among the four hay diets; therefore, similar chewing activities were expected.

In study 3 (96% hay diets), there was no difference in DMI between low and high NDF hay diets averaging 18.1 kg/d across all diets ($P = .10$). Our average DMI was similar to those reported by Llano and Peters (1985) for cows fed a ground cubed all hay diet of either early (19.1 kg/d) or normal (18.2 kg/d) cut hay. Within the high NDF hay diets, cows fed Hh consumed 6.5 kg/d more diet than cows fed Hl. As shown in Table 3, the NDF content of these hays were not different, but NDFD was 6.8 percentage units higher for Hh than Hl. For the low NDF hay diets, NDFD was similar between hays, but NDF content was different (Table 3) which apparently had no affect on DMI. If NDF digestibility was a major factor in DMI, then one would have expected DMI of the Ll and Hl diets to be similar as the NDF and NDF digestibility of these two hays was nearly identical. Instead, cows fed the Ll hay diet had the highest numerical DMI (22.2 kg/d) and cows fed the Hl diet the lowest DMI (13.1 kg/d). The reason for the high DMI of cows fed the Ll hay diet is not known however it may be associated with the physical characteristics of the hay. This hay was very fine following grinding and fed at 25% non-ground. It also is unclear why DMI was so much lower for the Hl hay diet however, the Hl hay had 1.6 times the percentage of particles on the top screen of the PSPS compared to the Hh hay and 2.4 times more than the Ll hay (Table 3). The Hl hay was 6.8 percentage units lower in IVNDFD compared to the Hh hay.

There was no difference in the amount of time spent eating or ruminating for cows on the low compared to high NDF hay diets during Study 3. Across treatments cows averaged 284 min/d eating and 502 min/d ruminating. Compared to chewing activity when alfalfa hay was included at 15% of the diet DM, cows spent 66 more min/d eating and 35 more min/d ruminating. This increased chewing activity for the higher forage diets was in agreement with previous research (Kononoff and Heinrichs, 2003; Woodford et al., 1986).

There was no difference in apparent total tract DMD or NDFD between the low and high NDF hays diets in Study 3. Within hay pairs, in vivo NDFD (Table 9) followed in vivo DMD for hays except for the high NDF hay pair (Hh, Hl) where these treatments were not different. This is contradictory to the IVNDFD results (Table 3) where they were different by 6.8 percentage units; HH being higher than Hl. A partial explanation for this may be due to DMI for the Hl diet which was 6.5 kg/d lower than Hh and digestibility of dietary components tend to increase as DMI decreases (NRC, 2001). The trend ($P < 0.10$) towards average DMI being lower on the high NDF hay diet than low NDF hay diets (16.4 vs. 19.8 kg/d) is supported by research of Allen (2000) showing DMI declines as NDF concentration in feeds and forages increases. Studies in which all hay diets were fed to lactating dairy cows are limited. In a study by Llano and DePeters (1985) in which alfalfa hay was fed at 100% of the diet DM, apparent DM and NDF digestibilities averaged approximately 10 percentage units lower than what we found in Study 3; hay quality and DMI was similar between their study and ours. Intake and apparent digestibility data in Study 3 are in agreement as DMI was moderately negatively correlated ($P < 0.05$) to apparent total tract NDFD (r = -0.58) and DMD (r = -0.53).

Digestible DMI was 3.0 kg/d higher ($P = 0.04$) for the low as compared to high NDF hay diets.

The low NDF hays (Lh, Ll) supported a higher milk production and component yield compared to high NDF hay diets (Hh, Hl). Cows on the low NDF hay diets in Study 3 produced 3.7, 0.10, 0.15 and 0.20 kg/d more 3.5% FCM, milk fat, true protein and lactose, respectively, compared to the high NDF hay diets (Table 10). There was no difference in FE between the low and high NDF hay diets with cows averaging 1.2 kg of 3.5% FCM per kg DMI, which is within the normal range expected for cows in late lactation (Linn, 2006).

Rumen pH and VFA concentrations from Study 2, when alfalfa hay was included at 15% of the diet DM, are presented in Table 11. No treatment by time interactions were observed ($P > 0.10$). There was no difference in rumen pH between the low and high NDF hay diets. Just prior to feeding (0 h), pH was highest for all treatments averaging 6.8. Minimum pH was similar across treatments (6.1) but occurred 6-h post feeding for the Lh, Ll and Hl treatments and 12-h post-feeding for the Hh treatment. Rumen pH did not fall below the lower limit (pH < 6.0) that has been shown to significantly reduce fiber digestibility in vitro (Hoover et al., 1984; Mourinõ et al, 2001). Therefore, rumen pH should not have negatively affected alfalfa hay digestibility. There also was no difference in rumen VFA concentrations between the low and high NDF hay diets. Lactic acid was not detected. Rumen pH and VFA concentrations were within the range previously reported for lactating dairy cows fed corn silage based diets (Oelker et al., 2009; Kowsar et al., 2008).

Low NDF Hay Diets. Because the low NDF alfalfa hays (Lh and Ll) were not different in IVNDFD but NDF concentration was higher for the Ll hay, the impact of alfalfa hay NDF concentration on response variables for the low NDF hay diets was evaluated. When alfalfa hay was included at 15% (Table 7) and 96% (Tables 9 and 10) of the diet DM, no differences in DMI or milk yield between the low NDF hay diets was observed (Table 7). However, milk fat percentage was 0.3 percentage units higher for the Ll compared to Lh hay diet ($P < 0.05$) in Study 1 (Table 7) whereas in Study 3 no difference was detected (Table 10). This did not appear to be due to alfalfa hay NDF concentration because when the alfalfa hays were fed at 96% of the diet DM (Study 3) there was no difference in milk fat percentage between the low NDF hays. Instead, the data suggest that the higher milk fat percentage in Study 1 was due to differences in BW loss (Table 7) and apparent total tract NDFD (Table 8) as there was a trend ($P < 0.08$) for increased BW loss and apparent total tract NDFD for the Ll diet. There were no differences in milk protein or lactose concentration for the low NDF hay diets in either Study 1 or 3.

According to Mertens (1994), when physical distension of the reticulo-rumen limits DMI, increasing dietary NDF concentration decreases DMI. However, when alfalfa hay was included at only 15% of the diet DM, the small difference in alfalfa hay NDF concentration between the low NDF hays had little impact on total dietary NDF concentration. Therefore it was not surprising that a 3.8 percentage unit difference in alfalfa hay NDF concentration did not affect animal performance when alfalfa hay was included at only 15% of the diet DM. However, even when alfalfa hay was included at 96% of the diet DM, the difference in NDF concentration between the low NDF hays had

little impact on animal performance. This was however a very short-term study and grab sample analysis of the diets, taken during the 7 d sampling period, indicate the Ll hay diet was only 1.3 percentage units higher in NDF concentration compared to the Lh hay diet (Table 6). Kendall and Combs (2009) reported increased DMI and FCM yield for lactating dairy cows when dietary NDF concentration was different by only 4 percentage units. However, in their study dietary NDF concentration was lowered by reducing the amount of wheat straw in the diet from 16.2 to 8.5 % of the diet DM. Therefore differences in the physical form of their fiber source, which can have a significant impact on the DMI of lactating dairy cows (Allen, 2000) likely contributed to differences in cow performance.

When alfalfa hay was included at 15% of the diet DM, apparent total tract DMD was 6.6 percentage units higher ($P < 0.01$) for the Ll compared to the Lh hay diet (Table 8). However, there was no difference in digestible DM intake (DDMI) between the two low NDF hay diets which partially explains why milk yield for the low NDF hay diets was similar during this study despite differences in apparent total tract DMD. There was no difference in NDF intake between the two low NDF hays; however, there was a trend ($P = 0.07$) for increased apparent total tract NDFD for the Ll compared to Lh hay diet. Greater total tract NDFD for the Ll diet was congruent with the higher milk fat percent reported during this study for cows fed the Ll compared to Lh hay diet. This response was not expected as alfalfa hay IVNDFD was not different between the low NDF hays (Table 3). When alfalfa hay was fed at 96% of the diet DM, apparent total tract DM and NDF digestibility were 14.7 and 18.4 percentage units higher ($P < 0.01$) for the Lh compared to Ll hay diet (Table 9). These results were contrary to diet digestibility data

reported when alfalfa hay was included at 15% of the diet DM. The reason for increased DMI when cows were fed the Ll hay diet is not known; however, this hay was very fine following grinding (Table 3). The differences in PSPS and physical characteristics may have accentuated differences in DMI when hays were fed at 96% of the diet DM compared to 15% of the diet DM.

As shown in Table 11, when alfalfa hay was included at 15% of the diet DM, there was no difference in VFA concentrations between the low NDF hays. Total VFA, acetate and propionate concentrations averaged 92.5 mM, 62.0 mol/100 mol and 20.4 mol/100 mol for the low NDF hays, respectively. There was no difference in the amount of DDMI or digestible NDF intake between the low NDF hay diets and therefore differences in VFA concentration would not be expected.

High NDF Hay Diets. We evaluated the impact of alfalfa hay IVNDFD on response variables for the high NDF hays diets because the high NDF alfalfa hays (Hh and Hl) were not different in NDF concentration but IVNDFD was 6.8 percentage units higher for the Hh hay. When alfalfa hay was included at 15% of the diet DM (study 1), there was no difference in DMI or 3.5% FCM yield within the high NDF hay diets averaging 22.4 kg and 40.5 kg per d, respectively. There were also no differences for milk components. In contrast, when alfalfa hay was fed at 96% of the diet DM, increased alfalfa hay IVNDFD improved DMI but there was no impact on milk or milk component yields (Tables 9 and 10). Milk fat and protein concentration during Study 3 were slightly higher than observed in Study 1; however, lactose concentrations were similar in both studies.

Increased forage NDF digestibility should negate some of the negative impacts of NDF on rumen fill, allow a larger amount of DM to be consumed, and ultimately improve lactation performance. However, our data indicates a relatively small improvement in forage IVNDFD will have little impact on dairy cow performance when forages are included in complex mixed diets. Previous research that has looked at the impact of grass or legume IVNDFD on dairy cow performance is limited but in general is in agreement with our study results. When forages were fed in complex mixed diets, increases of 4.0, 8.4 or 21.0 percentage units in the NDFD of alfalfa hay, sudangrass and wheat straw, respectively, were not observed to improve the DMI of lactating dairy cows (Kendall and Combs, 2009; Ledgerwood et al., 2009; Weakley et al., 2007). In contrast, a number of research studies have reported that feeding brown midrib corn silage with increased IVNDFD increased the DMI of lactating dairy cows compared to isogenic normal corn silage (Oba and Allen, 1999, Oba and Allen, 2000). However, it is difficult to extrapolate NDFD results from corn silage to alfalfa because corn silage is unique due to its combination of grain and forage components and corn silage is generally fed at a higher inclusion rate than alfalfa. An increase of 4.0 or 8.4 percentage units in the NDFD of alfalfa hay or sudangrass, respectively were also not observed to improve the milk yield of dairy cows when forages were fed in mixed diets (Ledgerwood et al., 2009; Weakley et al., 2007). However, Kendall and Combs (2009) reported an increase of 1.8 kg FCM/d when wheat straw IVNDFD was 21 percentage units higher. In our study, alfalfa hay IVNDFD within the high NDF hays differed by 6.8 percentage units. Weakly et al. (2007) observed a possible trend (P = .11) towards improved milk production with only 1.6 percentage units higher IVNDFD than in our study because they included alfalfa

hay at 50% of the diet DM, compared to 15% of the diet DM as in the current study. Therefore, differences in alfalfa hay IVNDFD in their study resulted in larger differences the amount of total dietary digestible NDF ingested compared to our study. In Study 1, the 6.8 percentage unit increase in alfalfa hay IVNDFD only increased total dietary digestible NDF 0.08 kg/d. This would not be expected to alter diet digestibility and similar milk production was understandable.

When alfalfa hay was included at 96% of the diet DM, apparent total tract DMD was 11.1 percentage units higher for the Hl compared to Hh hay, but there was no difference in apparent total tract NDFD between the high NDF hays (Table 9). Increased DM and NDF digestibility for the Hl compared to Hh hay diet was not expected because alfalfa hay IVNDFD was higher for the Hh hay. The most likely explanation for the reversal in NDF digestibility of the Hh and Hl hays in vitro compared to in vivo may be that the lower DMI of the Hl diet resulted in extended rumen retention time of the Hl hay allowing greater NDFD. Despite the difference in digestible DMI between the high NDF hay diets, there was no difference in milk yield during this study.

Alfalfa hay IVNDFD had very little impact on rumen parameters when alfalfa hay was fed at 15% of the diet DM. There was no difference in rumen pH within the high NDF hays, averaging 6.4 across sampling times. There was also no difference in acetate or propionate concentration within the high NDF hays; however, acetate concentration was numerically higher for the Hl compared to Hh diet (6.7 mol/100 mol higher). Consequently, between the high NDF hay diets the acetate-to-propionate ratio was 0.3 mol/100 mol higher ($P < 0.05$) for cows fed the Hl compared to the Hh diet. The higher acetate-to-propionate ratio did not result in any differences in milk fat concentration

between the high NDF hays. Seymour et al. (2005) reported only a weak positive relationship (r^2=0.26) between acetate-to-propionate ratio and milk fat percent, an observation supported by our data.

Alfalfa Hay Analysis

One of the major challenges of this study was sampling large quantities of alfalfa hay (> 70 tonne per hay lot). The hays were sampled three times; prior to purchase, upon delivery, and during the feeding studies. Although we deemed the nutrient analysis of the alfalfa hay grab samples collected during the feeding studies as being most representative of the hay actually fed, differences in analysis results among the three hay samplings occurred. To highlight the challenges of determining quality of large forage lots, hay sampling results and potential reasons for differences between analyses will be discussed.

Analysis of pre-purchase core samples indicated we essentially met our original research criteria of obtaining a low and high NDF concentration group that differed in 48-h IVNDFD, within each concentration group, by a minimum of 10 percentage units (Table 1). Analysis of pre-study core samples appeared to confirm that we had obtained low and high alfalfa hay NDF concentration groups. Unfortunately, the pre-study cores collected upon hay delivery indicated smaller differences in IVNDFD within each hay NDF concentration group; the difference in IVNDFD between hay pairs being approximately 3.5 percentage units, not the 10 percentage units indicated by the pre-purchase core samples. In contrast to the pre-purchase and pre-study alfalfa hay core sample analysis, hay grab sample analysis showed that NDF concentration was unexpectedly higher for the Ll compared to Lh hay, but contrary to expectations no difference in IVNDFD was detected for the low NDF hay pair. Within the high NDF

hays there was no difference in NDF concentration as expected and the Hh hay was 6.8 percentage units higher in IVNDFD compared to Hl; a divergence for IVNDFD that was less than found in the pre-purchase sampling but greater than for the pre-study samples. The reason for the differences between the alfalfa hay core and grab samples is not known. While hays were grab sampled on a daily basis to minimize the error associated with grab sampling, compared to core sampling it is more difficult to obtain a grab sample with a uniform distribution of leaves and stems. Other possible reasons for the differences between hay grab samples and pre-study core samples analysis include leaf loss due to grinding and blowing the hay into storage rooms and analytical variation.

Pre-purchase core sampling analysis indicated our hays were less divergent in IVNDFD than we had anticipated based on pre-purchase core samples. When sampling a hay lot, an accurate forage analysis is dependent on sampling intensity, methodology and equipment, lot uniformity and analytical accuracy (Martin et al. 1992). Therefore, one likely explanation for these differences is hay sampling error. Core sampling intensity was much greater pre-study than pre-purchase. Pre-study, one core sample was taken from every large bale and every 10^{th} small bale. In contrast, for pre-purchase core sampling, commercial hay producers were requested to take twenty core samples per hay lot. According to Sheaffer et al. (2000), sampling 12 large (~400 kg) alfalfa hay bales per lot will adequately capture the variation in nutrient composition within a lot. At this sampling intensity, NDF, ADF and CP were determined with a standard error of 1.0, 0.8 and 0.5%, respectively. Therefore, pre-purchase core sampling intensity should have resulted in a representative sample. However, the actual number of core samples taken pre-purchase was not known and alfalfa hay sampling intensity recommendations by

Sheaffer et al. (2000) were made based on smaller hay lots than were sampled in our study (~ 20 tonne versus 70 tonne). In addition, more intensive sampling decreases the variation among the individual core samples and results in a more representative core sample composite (Undersander et al., 2005). Sampling methodology, equipment and sample handling during pre-purchase core sampling were also unknown; however, as the CP concentration of pre-purchase and pre-study alfalfa core samples were similar it does not appear these factors resulted in core samples with a disproportionate amount of leaves compared to stems.

Analytical variation was also a likely a contributor to discrepancies in quality assessment among of the hays. Crude protein and NDF concentration were analyzed pre-purchase by the USDFRC while pre-study and study grab samples were analyzed by the University of Minnesota (U of MN). Although some inter-laboratory variation is likely this should have been minimal. According to the Forage Testing Association in 2004, analytical variability for CP and NDF analysis among laboratories using referenced analytical methods for forage analysis was 0.2 (SD) for CP (n=22) and 0.6 (SD) for NDF (n=11) (Undersander et al., 2005). Crude protein analysis was conducted using the Dumas method in both laboratories. Neutral detergent fiber was determined using the ANKOM fiber bag method at the U of MN and the Gooch crucible method at the USDFRC; however, these methods have been shown to produce comparable analyses for forages (Vogel et al., 1999). All 48-h IVNDFD analysis was conducted at the USDRFC; however, pre-purchase and pre-study samples were run, by necessity, using different rumen fluid collections. Wakker (2007) reported rumen fluid collection significantly affects 48-h IVNDFD results for forages. When comparing IVNDFD for five legume

and four grass hay samples, using 3 different rumen fluid collections, the ranking of IVNDFD for each collection differed within legume and grass hay samples.

Due to differences in core sampling intensity of the alfalfa hays pre-purchase compared to pre-study, unknown sampling methodology and sample handling during pre-purchase core sampling, analytical variation associated with IVNDFD, NDF and CP analysis, potential leaf loss of the hay actually fed and the error associated with grab sampling, it is not surprising that differences exist between the pre-purchase and pre-study core sample analysis and grab sample analysis. Declining divergence of the hays for NDF and IVNDFD from pre-purchase core to grab samples from the feeding period indicate that in order to obtain large differences in alfalfa hay 48-h IVNDFD and similar NDF concentration, larger difference in IVNDNFD pre-purchase would be necessary.

Currently there is increased interest in measuring forage fiber digestibility. One reason is that a 48-h IVNDFD measurement is required in order to calculate the new hay quality index, Relative Forage Quality (RFQ) proposed by Moore and Undersander (2002). However in our study, the difference in alfalfa hay IVNDFD within each NDF concentration group was reduced by more than half for the pre-study core samples compared to pre-purchase core samples which were taken by commercial hay producers. This indicates sampling intensity that is typical for commercial hay producers is not great enough to capture actual differences in hay IVNDFD. Therefore, IVNDFD may not be an appropriate criterion for setting the economic value of alfalfa.

CONCLUSIONS

Obtaining large differences in high quality, alfalfa hay 48-h IVNDFD when hays are similar in NDF concentration is very challenging. Our study suggests small differences in alfalfa hay IVNDFD or NDF concentration, especially when alfalfa hay is fed at a low dietary inclusion levels and diets are formulated to be similar in NDF concentration, should not be expected to have a significant impact on dairy cow lactation performance.

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Table 1. Nutrient composition of alfalfa hay core samples.

	Hay[1]			
Item	Lh	Ll	Hh	Hl
		Pre-Purchase[2]		
CP, % DM	20.8	21.5	20.1	20.9
NDF, % DM	34.2	34.8	38.0	39.2
IVNDFD[3], % NDF	52.4	41.7	51.6	42.8
		Pre-Study[4]		
CP, % DM	21.4	22.5	20.1	20.8
NDF, % DM	37.2	36.4	41.7	40.8
IVNDFD, % NDF	41.3	37.9	44.6	41.1
NFC[5]	28.8	24.0	24.0	25.9

[1]Alfalfa hay with low (L) or high (H) neutral detergent fiber concentration (NDF) and low (l) or high (h) 48-h in vitro NDF digestibility within NDF concentration groups.

[2]Core samples from alfalfa hay lots collected by commercial hay producers in MN, ID, IL and KS sent to the US Dairy Forage Research Center (Madison, WI) for nutrient analysis prior to purchasing hays.

[3]IVNDFD = 48-h in vitro neutral detergent fiber analysis.

[4]A core sample was taken from each large hay bale (~ 363 to 454 kg) and every 10th small square bale (~23 kg) at the University of Minnesota. Core samples were composited by treatment for analysis.

[5]NFC = (100-((NDF-NDICP) + CP + Ash + EE)).

Table 2. Ingredient composition of alfalfa hay diets fed during Studies 1 and 2.[1]

Item	Diet[2]			
	Lh	Ll	Hh	Hl
	----------% of DM ----------			
Corn Silage[3]	36.3	36.3	33.7	33.7
Alfalfa hay[4]	16.0	16.0	13.7	13.7
Protein Mix	26.4	26.4	26.5	26.5
Corn	13.1	13.1	17.8	17.8
Roasted Soybeans	5.2	5.2	5.3	5.3
Molasses	3.0	3.0	3.0	3.0
	% of protein mix			
Soybean meal	34.3	34.3	34.3	34.3
Soybean hulls	26.7	26.7	26.7	26.7
DDGS[5]	22.9	22.9	22.9	22.9
Blood meal	3.8	3.8	3.8	3.8
Sodium bicarbonate	3.8	3.8	3.8	3.8
Calcium carbonate	2.9	2.9	2.9	2.9
Salt	1.9	1.9	1.9	1.9
Di-calcium phosphate	1.3	1.3	1.3	1.3
Magnesium oxide	0.9	0.9	0.9	0.9
Vitamin and minerals	0.8	0.8	0.8	0.8
Yeast	0.7	0.7	0.7	0.7

[1]Diets balanced to be isofibrous, isocaloric, and isonitrogenous.

[2]Diets (Lh, Ll, Hl and Hh) contained one of four alfalfa hays selected for low (L) or high (H) neutral detergent fiber concentration (NDF) and low (l) or high (h) 48-h in vitro NDF digestibility within NDF levels.

[3]Nutrient composition of corn silage (DM basis): 40.6% NDF, 7.4% CP, 44.9% NFC.

[4]Alfalfa hay was ground using an AgriMetal tub grinder prior to inclusion in the total mixed ration. Grinding the Ll treatment hay resulted in very fine particles; therefore, 25% of this hay was included in the ration as non-ground long hay.

[5]DDGS = dried distillers grains with solubles.

Table 3. Nutrient composition and physical characteristics of alfalfa hay grab samples collected during Study 1.[1]

	Hay[2]					Contrasts[3]		
Item	Lh	Ll	Hh	Hl	SEM	1	2	3
n =	10	10	10	10				
DM, %	93.8	93.0	87.4	91.5	1.1	0.01	0.03	<0.01
CP, % DM	19.0	16.7	22.1	19.9	0.4	<0.01	<0.01	<0.01
NDF, % DM	37.7	41.5	43.1	43.0	0.7	<0.01	0.89	<0.01
IVNDFD[4], % NDF	41.4	43.2	50.0	43.2	0.9	0.16	<0.01	<0.01
Particle Size[5], % retained (as is)								
Top	26.9	9.7	14.6	23.5	1.9	<0.01	<0.01	0.68
Second	16.6	22.8	23.1	21.5	1.0	<0.01	0.25	0.01
Third	33.3	34.0	32.8	30.2	1.0	0.61	0.09	0.06
Bottom	23.2	33.5	29.5	24.8	2.1	<0.01	0.12	0.56

[1]Samples were taken on a weekly basis and composited by month for analysis.

[2]Alfalfa hay with low (L) or high (H) neutral detergent fiber concentration (NDF) and low (l) or high (h) 48-h in vitro NDF digestibility within NDF levels.

[3]Contrasts: 1= Lh vs. Ll, 2 = Hh vs. Hl, 3 = Lh and Ll vs. Hh and Hl.

[4]48-hour in vitro NDF digestibility (% of NDF).

[5]Determined using Penn State Particle Separator.

Table 4. Nutrient composition of alfalfa hay diets fed during Studies 1 and 2[1].

	Hay[2]				
Item	Lh	Ll	Hh	Hl	SEM
	---------- % DM ----------				
DM[3]	60.1	59.8	61.3	60.5	0.22
CP	17.1	17.3	18.0	17.7	0.06
NDF	30.6	31.2	29.9	29.9	0.11
Forage NDF	20.8	21.4	19.6	19.6	0.11
EE	3.4	3.3	3.5	3.4	0.005
NFC[4]	41.2	41.4	43.0	43.0	0.08
NE_L[5] (Mcal/kg)	1.61	1.61	1.63	1.61	

[1]Calculated based on nutrient analysis of individual dietary ingredients sampled during the study.

[2]Diets (Lh, Ll, Hl and Hh) contained one of four alfalfa hays selected for low (L) or high (H) neutral detergent fiber concentration (NDF) and low (l) or high (h) 48-h in vitro NDF digestibility within NDF levels.

[3]Oven dried at 60°C.

[4]NFC = (100-((NDF-NDICP) + CP + Ash + EE)).

[5]Determined using the Dairy NRC model (2001).

Table 5. Physical characteristics of alfalfa hay diets fed and refusals when alfalfa hays were included at approximately 15% of the diet DM during Study 1.

	Diet[1]					Contrasts[2]		
Item	Lh	Ll	Hh	Hl	SEM	1	2	3
				Diet				
Particle Size[3], % retained (as-fed)								
Top	5.5	3.3	3.5	4.1	0.3	<0.01	0.12	0.05
Second	19.0	19.1	19.1	19.1	0.8	0.99	0.95	0.95
Third	56.6	57.4	57.8	57.1	0.7	0.37	0.47	0.51
Bottom	18.9	20.2	19.7	19.6	0.6	0.14	0.96	0.87
NDF in retained fraction of PSPS[4], % of DM								
Top	56.8	57.5	59.0	62.0	1.0	0.68	0.03	<0.01
Second	44.8	43.6	43.8	45.2	0.9	0.39	0.30	0.74
				Refusals				
DM[5]	62.3	61.2	62.7	59.8	0.9	0.39	0.03	0.58
NDF, % DM	32.8	34.1	32.2	36.1	0.5	0.07	<0.01	0.18
Particle Size[3], % retained (as-fed)								
Top	7.3	6.9	4.3	9.1	0.9	0.72	<0.01	0.62
Second	20.5	23.5	19.3	23.7	0.9	0.02	<0.01	0.55
Third	54.1	51.7	56.5	51.7	0.9	0.07	<0.01	0.22
Bottom	18.1	17.8	20.0	15.6	0.8	0.81	<0.01	0.80

[1]Diets (Lh, Ll, Hl and Hh) contained one of four alfalfa hays selected for low (L) or high (H) neutral detergent fiber concentration (NDF) and low (l) or high (h) 48-h in vitro NDF digestibility within NDF levels.

[2]Contrasts: 1= Lh vs. Ll, 2 = Hh vs. Hl, 3 = Lh and Ll vs. Hh and Hl.

[3]Determined with Penn State Particle Separator (PSPS) on monthly as-fed samples.

[4]As an estimate of physically effective NDF, the material on the top and second sieve of the Penn State Particle Separator (PSPS) was analyzed for NDF concentration using the Ankom[200] fiber system.

[5]Oven dried at 60°C.

Table 6. Nutrient composition of alfalfa hay diets fed during Study 3.

	Diet[1,2]			
Item	Lh	Ll	Hh	Hl
	---------- % of DM ----------			
DM	83.2	82.5	77.7	81.2
CP	19.1	17.0	19.7	18.9
NDF	37.7	39.0	44.7	40.0
EE	1.1	1.3	1.4	1.2
Ash	9.5	13.5	10.7	10.2
NFC[3]	33.1	31.8	30.2	31.3
NE_L[4] (Mcal/kg)	0.7	0.6	0.6	0.6

[1]Diets consisted of 95.8% alfalfa hay and 4.2% molasses/vitamin mineral mix (DM basis). Water was added at 10% of diets (as-fed). Results based on analysis conducted on a composite of TMR samples taken daily during the sampling and data collection period.

[2]Diets (Lh, Ll, Hl and Hh) contained one of four alfalfa hays selected for low (L) or high (H) neutral detergent fiber concentration (NDF) and low (l) or high (h) 48-h in vitro NDF digestibility within NDF levels.

[3]NFC = (100-((NDF-NDICP) + CP + Ash + EE)).

[4]Determined using the Dairy NRC model (2001).

Table 7. Dairy cow performance when alfalfa hays were fed at approximately 15% of the diet DM during Study 1.

	Diet[1]					Contrasts[2]		
Item	Lh	Ll	Hh	Hl	SEM	1	2	3
n =	15	15	13	14				
DMI, kg/d	22.7	21.7	22.1	22.7	0.8	0.37	0.61	0.83
FCM[3], kg/d	38.3	40.0	40.5	40.4	1.5	0.45	0.94	0.22
Fat, %	3.4	3.7	3.7	3.7	0.1	0.03	0.83	0.18
Protein, %	2.7	2.9	2.9	3.0	0.1	0.09	0.16	0.06
Lactose, %	4.8	4.8	4.8	4.8	0.04	0.77	0.55	0.73
Fat, kg/d	1.3	1.4	1.5	1.4	0.1	0.25	0.82	0.25
Protein, kg/d	1.1	1.1	1.1	1.2	0.03	0.36	0.56	0.05
FE[4]	1.7	1.9	1.9	1.9	0.1	0.16	0.82	0.66
BW change, kg[5]	-20.8	-49.1	-37.8	-24.5	15.3	0.08	0.47	0.75

[1]Diets (Lh, Ll, Hl and Hh) contained one of four alfalfa hays selected for low (L) or high (H) neutral detergent fiber concentration and low (l) or high (h) 48-h IVNDFD within NDF levels. Diets fed for 133 d.
[2]Contrasts: 1= Lh vs. Ll, 2 = Hh vs. Hl, 3 = Lh and Ll vs. Hh and Hl.
[3]FCM = 3.5% fat corrected milk.
[4]Feed efficiency (FE) = kg of 3.5% fat corrected milk/kg DM intake.
[5]Body weight (BW) change = final BW – initial BW.

Table 8. Apparent total tract dry matter and NDF digestibility of diets when alfalfa hays were fed at approximately 15% of the diet DM during Study 1.

	Treatment[1]					Contrasts[2]		
Item	Lh	Ll	Hh	Hl	SEM	1	2	3
n =	15	15	13	14				
DIM	72	65	66	65	5.0	0.08	0.67	0.30
FCM[3], kg/d	38.3	40.0	40.5	41.0	1.9	0.47	0.90	0.38
DMI, kg/d	20.6	19.2	20.3	20.6	1.5	0.53	0.58	0.75
NDFI[4], kg/d	6.5	5.7	5.9	6.1	0.5	0.17	0.53	0.87
DDMI[5], kg/d	13.4	13.5	12.9	13.9	1.0	0.94	0.55	0.95
DMD[6], %	65.5	72.1	68.6	65.9	2.1	<0.01	0.70	0.75
NDFD[7], %	49.3	56.3	52.0	51.9	2.5	0.07	0.68	0.99

[1]Diets (Lh, Ll, Hl and Hh) contained one of four alfalfa hays selected for low (L) or high (H) neutral detergent fiber concentration and low (l) or high (h) 48-h IVNDFD within NDF levels. Diets fed for 133 d.

[2]Contrasts: 1= Lh vs. Ll, 2 = Hh vs. Hl, 3 = Lh and Ll vs. Hh and Hl.

[3]FCM = 3.5% fat corrected milk.

[4]NDFI = NDF intake.

[5]DDMI = digestible dry matter intake (DMI x apparent total tract DM digestibility)

[6]DMD (apparent total tract DM digestibility) determined using acid insoluble ash as an internal marker. Fecal sample collected during early lactation (67 ± 20 DIM) every 8 h over three consecutive days.

[7]NDFD (total tract NDF digestibility) determined using acid insoluble ash as an internal marker. Fecal sample collected during early lactation (67 ± 20 DIM) every 8 h over three consecutive days.

Table 9. Apparent total tract dry matter and NDF digestibility of diets when alfalfa hays were fed at approximately 96% of the diet DM during Study 3.[1]

	Diet[2]					Contrasts[3]		
Item	Lh	Ll	Hh	Hl	SEM	1	2	3
n =	5	5	5	5				
DIM	230	220	224	234	8	0.42	0.38	0.63
DMI, kg/d	17.4	22.2	19.6	13.1	2.0	0.11	0.04	0.10
NDFI, kg/d	6.6	8.8	9.7	5.7	0.9	0.10	<0.01	0.99
DDMI[4], kg/d	14.1	14.6	12.8	9.9	1.3	0.76	0.13	0.04
DMD[5], %	80.8	66.1	65.8	76.9	2.4	<0.01	<0.01	0.40
NDFD[6], %	74.2	55.8	65.0	71.1	2.7	<0.01	0.13	0.27

[1]Cows transitioned to treatment diets over a 21 d period. Treatment diets fed for 18 days with the last 7 days for data collection.

[2]Diets (Lh, Ll, Hl and Hh) contained one of four alfalfa hays selected for low (L) or high (H) neutral detergent fiber concentration and low (l) or high (h) 48-h IVNDFD within NDF levels.

[3]Contrasts: 1= Lh vs. Ll, 2 = Hh vs. Hl, 3 = Lh and Ll vs. Hh and Hl.

[4]DDMI = digestible dry matter intake (DMI x apparent total tract DM digestibility)

[5]DMD = apparent total tract DM digestibility (determined using acid insoluble ash as an internal marker).

[6]NDFD = total tract NDF digestibility (determined using acid insoluble ash as an internal marker).

Table 10. Dairy cow performance when alfalfa hays were fed at approximately 96% of the diet DM during Study 3.[1]

	Diet[2]					Contrasts[3]		
Item	Lh	Ll	Hh	Hl	SEM	1	2	3
n =	5	5	5	5				
FCM[4], kg/d	22.7	22.2	18.0	19.6	1.0	0.78	0.30	<0.01
Fat, kg/d	0.8	0.8	0.7	0.7	0.05	0.97	0.46	0.03
True Protein, kg/d	0.7	0.7	0.5	0.6	0.04	0.66	0.47	<0.01
Lactose, kg/d	1.0	1.0	0.8	0.8	0.1	0.87	0.72	0.01
FE[5]	1.3	1.0	0.9	1.6	0.2	0.26	0.02	0.49

[1]Cows transitioned to treatment diets over a 21 d period. Treatment diets fed for 18 days with the last 7 days for data collection.

[2]Diets (Lh, Ll, Hl and Hh) contained one of four alfalfa hays selected for low (L) or high (H) neutral detergent fiber concentration and low (l) or high (h) 48-h IVNDFD within NDF levels.

[3]Contrasts: 1= Lh vs. Ll, 2 = Hh vs. Hl, 3 = Lh and Ll vs. Hh and Hl.

[4]FCM = 3.5% fat corrected milk.

[5]Feed efficiency (FE) = kg of 3.5% fat corrected milk/kg DM intake.

Table 11. Average rumen pH and volatile fatty acid (VFA) concentration when alfalfa hays were fed at approximately 15% of the diet DM during Study 2.[1]

	Diet[2]					Contrasts[3]		
Item	Lh	Ll	Hh	Hl	SEM	1	2	3
n =	4	4	4	4				
pH	6.4	6.4	6.4	6.4	0.1	0.98	0.99	0.90
Total VFA, mM	93.6	91.3	94.8	100.8	4.4	0.72	0.39	0.27
---------- mol/100 mol ----------								
Acetate	62.4	61.5	62.0	68.7	2.8	0.64	0.15	0.22
Propionate	20.5	20.0	20.2	20.9	1.1	0.73	0.65	0.85
Butyrate	8.3	7.9	10.2	8.4	1.5	0.87	0.42	0.43
A:P[4]	3.1	3.1	3.1	3.4	0.1	0.84	0.03	0.26

[1]Rumen fluid collected during the last week of each 21 d period.

[2]Diets (Lh, Ll, Hl and Hh) contained one of four alfalfa hays selected for low (L) or high (H) neutral detergent fiber concentration and low (l) or high (h) 48-h in vitro NDF digestibility within NDF levels.

[3]Contrasts: 1= Lh vs. Ll, 2 = Hh vs. Hl, 3 = Lh and Ll vs. Hh and Hl.

[4]Acetate to propionate ratio.

Impact of conventional or intensive milk replacer programs on Holstein heifer performance through six months of age and during first lactation.

The objectives were to evaluate the impact of conventional or intensive milk replacer (MR) feeding programs on heifer calf performance through six months of age, age at first calving and first lactation performance. At 3 (± 1 d) d of age, one-hundred thirty-three Holstein heifer calves from 3 commercial dairy farms were randomly assigned, within calf source, to a conventional (20% CP, 20% fat) or intensive MR (28% CP, 18% fat). Milk replacer treatments and percent solids were: 1) conventional non-acidified (CNA) – 13.9%, 2) conventional acidified (CA) – 13.9%, 3) modified intensive high solids (IHS) – 16.7%, 4) modified intensive low solids (ILS) – 12.5% and 5) intensive high solids, high feeding (IHSHF) – 16.7%. Calves were individually housed and remained on trial 56 d.

At 2 months of age, heifers were grouped in pens by treatment with 6 heifers per pen (4 pens per treatment). An 18.1% CP grower concentrate mix (DM basis) was fed to heifers that received a conventional MR and a 21.2% CP grower concentrate mix was fed to heifers that received the intensive MR pre-weaning. Heifers were offered 2.45 kg/d (DM basis) of their respective grower concentrate mix for 112 d plus hay and water free choice. At approximately 24 wk of age, heifers were transported to a second stage grower before returning to their respective farms approximately 1 month prior to calving. First lactation performance was determined using Dairy Herd Improvement Association records.

The IHSHF treatment resulted in increased calf body weight and hip height during the pre-weaning and early post-weaning (PEP) period and the post-weaning heifer grower (PHG) period as compared to the conventional (CNA and CA) or modified intensive MR treatments (IHS and ILS). Calves receiving the IHS treatment were heavier at d 56 of the PEP period compared to the conventional or ILS treatments however this growth advantage was not maintained in the PHG period. Feed cost per kg of gain during the PEP period was lowest for CNA and CA, intermediate for IHS and ILS and highest for the IHSHF treatment.

There was no affect of MR feeding program on first lactation performance however heifers that received the IHSHF MR pre-weaning calved 27.5 d earlier than those fed a conventional MR.

INTRODUCTION

With 69% of dairy calves fed milk replacer (MR) during the pre-weaning period, MR is the predominant liquid diet fed to calves prior to weaning on dairy operations in the United States (USDA, 2007). The two most common MR feeding programs fed by dairy producers today are intensive and conventional. Conventional programs include feeding a MR containing 20 to 22% CP and 15 to 20% fat and were traditionally reconstituted to approximately 12.5% solids. Intensive calf feeding programs feed more DM per d from MR generally containing greater than 25% CP with fat content similar to conventional. Solids content of intensive MR at feeding ranges from 12.5 to 17.5% (Cowles, et al., 2006).

Reported benefits of intensive calf feeding programs are increased weight gain without increased fat deposition (Bascom et al., 2007) along with improved feed efficiency (FE) and increased stature during the pre-weaning period (Cowles et al., 2006; Brown et al., 2005). Enhanced immune status has been suggested as a potential benefit of intensive calf feeding programs, although supporting research is limited (Foote et al., 2007). Challenges associated with increased nutrient intake from MR are decreased calf starter intake and increased feed cost during the pre-weaning period along with decreased calf performance during weaning (Brown et al., 2005; Drackley, 2005; Cowles et al., 2006).

Research comparing intensive and conventional MR programs has focused on the pre-weaning and early post-weaning period. However, to understand the impact of early calf nutrition programs on economics of rearing replacement heifers additional growth and production measures such as differences in post-weaning heifer performance, age at first calving, first lactation performance and cow longevity are needed (Sejrsen and Purup, 1997; Drackley, 2005). To date, very limited research comparing lactation performance of conventional and intensive MR fed calves is available.

The objectives of this study were to determine the impact of conventional or intensive MR feeding programs on heifer calf performance through six months of age, age at first calving and first lactation performance.

MATERIALS AND METHODS

Animals, Housing and Diets

One-hundred thirty-three Holstein heifer calves from 3 commercial dairy farms in Minnesota were utilized. Heifers were housed at the Southern Research and Outreach Center (SROC) Calf and Heifer Research Facility from approximately 2 to 180 d of age (June 24, 2004 to March 8, 2005). After 180 d, heifers were moved to a second stage grower and then returned to their respective farms approximately 1 month prior to calving. While housed at the SROC Calf and Heifer Research Facility, calves were cared for according to the University of Minnesota Institutional Animal Care and Usage Committee recommendations (Animal Subjects Code 0212A38841).

Pre-weaning and early post-weaning period. Upon arrival at the SROC Calf and Heifer Research Facility calves were randomly assigned, within calf source, to 1 of 5 MR treatments. During the pre-weaning and early weaning period calves were in individual pens (2.3 x 1.2 m) in two curtain side-wall naturally ventilated 30' x 200' barns. Each barn was divided into two rooms with approximately 40 calves per room. As shown in Table 1, calves were fed a conventional (C) milk replacer (20% CP, 20% fat) or an intensive (I) milk replacer (28% CP, 16% fat). Milk replacer treatments were: 1) conventional non-acidified (CNA), 2) conventional acidified (CA), 3) modified intensive high solids (IHS), 4) modified intensive low solids (ILS) and 5) intensive high solids, high feeding (IHSHF). All milk replacers were manufactured by Milk Products of Chilton, WI.

The CNA and CA MR were mixed to contain 13.9 % solids with calves offered 0.57 kg MR (as fed) in 3.51 kg water per d, provided in 2 equal feedings from d 1 to 35

of the treatment period. The amount of MR offered was reduced by half on d 36 and fed once daily until weaning at d 42. Calves assigned to the IHS and ILS treatments received MR mixed to contain 16.7% solids (0.68 kg MR in 3.40 kg water) and 12.5% solids (0.68 kg MR in 4.76 kg water), respectively. Calves were fed MR in 2 equal feedings per d from d 1 to 35. The amount of MR fed was reduced by half starting d 36 and fed once daily until weaning at d 42. Milk replacer fed to calves on the IHSHF treatment was mixed to contain 16.7% solids. Calves were fed 0.68 kg MR in 3.40 kg water per d from d 1 to 10 and 1.02 kg DM in 5.10 kg water per d from d 11 to 42. Starting on day 43, the amount of MR fed was reduced by half until weaning on d 49. The MR for all treatments contained all-milk protein and calf starter (CS) was offered ad-libitum beginning on d 2 of the MR feeding period (Table 1). Calves assigned to treatments CNA and CA received a 20.2% CP (DM basis) CS while a 25.0% CP (DM basis) CS was offered to calves on the IHS, ILS, and IHSHF treatment. All CS were manufactured by Hubbard Feeds Inc. (Mankato, MN). Water was provided free choice starting d 1.

Post-weaning heifer grower period. At approximately 2 months of age, heifers were grouped in 6.4 m x 2.7 m pens by treatment with 6 heifers per pen for 112 d (4 pens per treatment). Fifteen heifers that had completed the pre-weaning and early post-weaning period were not utilized because of the inability to completely fill a treatment pen. Across treatments, pen age averaged 79.0 ± 3.8 d and BW averaged 96.3 ± 6.1 kg per heifer (mean ± SD).

As shown in Table 2, a commercial whole shelled corn and pellet concentrate mixture (Hubbard Feeds Inc., Mankato, MN) containing 18.1% CP (DM basis) was offered to heifers that were previously fed the conventional MR (CNA and CA) while

those fed intensive MR (IHS, ILS and IHSHF) received a similar mix with slightly higher CP concentration (21.2%, DM basis). Monensin (Elanco Products Co., Indianapolis, IN) was included in the concentrate mixture at a concentration of 49.0 ppm (DM basis). Heifers were fed up to 2.45 kg of the concentrate mixture (DM basis) per head per d. Hay and water were offered free choice. Heifers were fed for 112 d.

Data Collection and Analysis

Pre-weaning and early post-weaning period. On d 1, blood samples were taken via jugular venipuncture and collected in 10-ml serum Vacutainer tubes. Samples were allowed to clot, centrifuged to separate the serum, and immediately analyzed for total serum protein concentration using a handheld refractometer (Spartan Refractometer, Model A 300 CL; Spartan, Tokyo, Japan). Intake of MR and CS were recorded daily. Body weights were taken d 1, 14, 28, 42, 49 and 56 and hip heights (HH) d 1 and 56. Fecal consistency was evaluated and scored daily scores on a scale from 1 to 4 (1= normal, 2=loose, pudding, 3= very loose, no watery separation, and 4 = very watery) according to Larson et al. (1977). Health incidents and treatment costs were recorded through d 56.

Milk replacer and CS samples were taken weekly and composited by treatment for analysis. Samples were dried for 24 h in a 60°C forced air oven to determine DM content and ground to pass through a 1-mm screen (Wiley mill; Swedesboro, NJ). Organic matter was determined by ashing samples in a muffle furnace at 500°C (AOAC, 1995). Samples were analyzed for crude protein (CP) (NA2100 Protein Nitrogen Analyzer, ThermoQuest Italia S. P. A., Italy; AOAC, 1995). Crude fat was analyzed as ether extract (AOAC, 1995); milk replacer samples under went ether extraction after acid

hydrolysis (AOAC, 1995). Calf starter samples were sequentially analyzed for NDF and ADF (Hintz and Mertens, 1996) via the Ankom^{200} fiber system (Ankom Technology Corporation, Fairport, NY). Samples were also analyzed for NDF using sodium sulfite and α-amylase (Sigma no. A3306; Sigma Chemical Co., St. Louis, MO). Neutral detergent insoluble crude protein (NDICP) and acid detergent insoluble crude protein (ADICP) were determined by Kjeldahl analysis (AOAC, 1995) using the NDF or sequential ADF residue, respectively. Minerals were analyzed using the Applied Research Laboratories (ARL) model 3560 AES inductively coupled plasma (ICP) spectrometer system (Sunland, CA).

Post-weaning heifer grower period. Grower concentrate mix and hay intake were recorded daily. Body weights were measured d 1, 28, 56, 84 and 112 of the study. Body condition score (Wildman et al., 1982) and HH were recorded d 1, 56 and 112 of the study. Grower concentrate samples were collected weekly and composited by treatment for analysis. Hay was core sampled and analysis was conducted on a study composite. Samples were analyzed for DM, NDF, ADF, NDICP, ADICP, crude fat, CP and minerals as described previously.

Lactation performance. First lactation performance of heifers that were utilized in the 112 d post-weaning grower data set (n=114) was determined using Dairy Herd Improvement Association (DHIA) records (Minnesota DHIA, Buffalo, MN). Data collected included age at calving, 305-d standardized mature equivalent milk (305 SME) reported on the last test d, average fat and protein percent during the lactation and first test day somatic cell count (SCC).

Statistical Analysis

Data were analyzed using the PROC MIXED procedures of SAS© (SAS Institute, 1999). Non-orthogonal contrasts were used to compare 1) CNA versus CA, 2) CNA versus IHS and ILS, IHS + ILS versus IHSHF and 4) CNA versus IHSHF. Contrasts (non-orthogonal) for first lactation performance were: 1) Control (CNA and CA) versus IHS and ILS, 2) IHS and ILS versus IHSHF, and Control versus IHSHF. All treatment results are reported as least square means, significance was declared at $P < 0.05$ and a trend was declared at $P < 0.10$.

Pre-weaning and early post-weaning period. Data were analyzed as a completely randomized design. Treatment and calf location (calves were housed in 1 of 4 rooms by age) was included in the model as a fixed effect and calf was included as a random effect. Initial BW was utilized as a covariate for intake, weight gain and FE. Initial HH was used as a covariate for the 56-d HH measurement. Intake, growth and fecal score measurements taken over time were analyzed as a repeated measures using the spatial power law covariance structure due to unequally spaced measurements.

Post-weaning period. For all analyses, pen was considered the experimental unit and was included in the model as a random effect. Data were averaged within each pen to create one observation per pen for statistical analysis. Intake and growth measurements taken over time were analyzed as repeated measures.

Lactation performance. Data were analyzed as a completely randomized design. Commercial dairy farm source was included in the model as a fixed effect and heifer was included as a random effect. Data from treatments CNA and CA were pooled. These treatments were identical with the exception of mild acidification with citric acid for the CA treatment. There were no differences in calf performance between the CNA and CA

treatments during the pre-weaning and early post-weaning period or post-weaning heifer performance.

RESULTS AND DISCUSSION

Pre-weaning and Early Post-Weaning Period:

Intake. As expected based on the study protocol, calves on the conventional MR programs (CNA and CA) consumed less ($P < 0.05$) MR DM per d from d 1 to 42 than those fed intensive MR programs (IHS, ILS, and IHSHF) (Table 3). Average MR DM intake per d during the pre-weaning period for the CNA and CA treatments was 1.3% of initial BW as compared to 1.5% for the IHS and ILS treatments and 1.9% for the IHSHF treatment. There were no differences in CS intake d 1 to 14 (Table 3). Calves that received the IHSHF treatment had the lowest ($P < 0.05$) CS intake through d 49 consuming 19.0 kg compared to an average of 31.3 kg for the CNA, CA, IHS, and ILS treatments. This was not unexpected however as this treatment received the highest liquid feeding rate and was weaned 1 week later than the other treatments. Decreased CS intake due to increased liquid consumption of milk or MR generally results in decreased CS intake (Quigley et al., 2006). Studies have shown a 36 to 55% reduction in CS intake during the pre-weaning to early post-weaning period for calves fed an intensive as compared to a conventional MR program (Pollard et al., 2003; Cowles et al., 2006).

Total DMI (Table 3) was greater ($P < 0.05$) for the IHS and IHSHF treatments as compared to the CNA, CA and ILS treatments d 1 to 42 (45.9 vs. 39.8 kg DM) and d 1 to 56 (74.9 vs. 67.6 kg DM). Calves receiving the IHS and IHSHF treatment consumed 9.3% more DM than calves receiving the CNA, CA and ILS treatments. Cowles et al.

(2006) found calves fed conventional MR (20% CP, 20% fat) at 0.4 kg DM/d consumed 11% less DM than calves receiving 1.1 kg DM/d over a 63 d pre-weaning, post-weaning period. In contrast to our study, their calves were weaned on d 49 and remained on study one week longer.

Decreased CS intake for calves on the ILS treatment resulted in a reduction in total DMI d 0 to 56 of 0.13 kg/d compared to the IHS treatment (Table 3). There were no differences in MR, CS or total DM intake between the CNA and CA treatments. Similarly, Jaster et al. (1990) did not report a difference in MR, CS or total DM intake when calves were fed an acidifed or non-acidified MR at 10% of BW. Erickson et al. (1989) fed a MR containing 15% soy protein and reported no difference in MR intake when feeding an acidified MR at 1.25% of BW but decreased intake when acidified MR was fed at 2.5% of BW.

Growth. Calf growth is presented in Table 4. There was no difference in initial BW across treatments. Body weights of calves fed conventional MR (CA, CNA) was lower ($P < 0.05$) on d 14, 28 and 42 (44.5, 52.8, and 63.4 kg, respectively) compared to the intensive (IHS, ILS, and IHSHF) fed calves (47.8, 58.2, and 69.8 kg, respectively). Calves fed the IHSHF treatment gained the most BW from d 1 to 56. Calves receiving the IHSHF treatment had gained 17.6% more BW than calves fed IHS or ILS treatments and 30.0% more BW than calves on the CNA or CA treatment at the time of their weaning on d 42. By d 56, calves on the IHSHF treatment were 5.8 kg heavier than calves fed the IHS or ILS treatments and 9.7 kg heavier than calves fed the CNA or CA treatment. There were no differences in initial HH averaging 80.8 cm across treatments. Final HH was 1.8 cm greater ($P < 0.05$) for the IHSHF treatment compared to the CNA,

CA, IHS or ILS treatments. Brown et al. (2005) reported increased BW (12.1 kg) and calf height (2.4 cm) at d 56 for calves fed an intensive (30.3% CP, 15.9% fat) as compared to a conventional (21.3% CP, 21.3 % fat) MR feeding program. However, they utilized a higher CP MR for the intensive treatment, fed a larger quantity of intensive MR (2.0% of BW, DM basis) and less conventional MR (1.1 % of BW, DM basis) as compared to our study. Cowles et al. (2006) reported increased ADG during the pre-weaning period, increased HH the week of weaning and two weeks post-weaning and increased heart girth over-all for calves fed an intensive as compared to a conventional MR. In two trials Pollard et al. (2003) found calves fed an intensive MR feeding program had greater BW and heart girth through wk four pre-weaning. Differences in calf growth were not maintained however at two wk post-weaning.

Feed efficiency. Gain per DMI was lower ($P < 0.05$) for the conventional MR fed calves from d 1 to 42 (0.6 kg gain/kg DM intake) compared to intensified MR fed calves (0.7 kg gain/kg DMI). Calves on the IHSHF treatment gained 0.12 kg more BW/kg DM intake daily than calves fed conventional MR treatments and 0.07 kg more BW/ kg DM intake daily than calves fed IHS treatment. Feed efficiency for calves fed the ILS treatment was intermediate and not statistically different from calves fed the IHSHF, CNA or IHS treatments. Quigley et al. (2006) reported similar improvements in 56 d FE with calves offered intensive MR (28% CP, 17% fat) at 1.0 to 2.0% of initial BW (DM basis) gaining 0.1 kg more BW/kg DM intake as compared to conventionally fed calves (20% CP: 20% fat fed at 1.0% of initial BW on a DM basis). Cowles et al. (2006) reported intensive fed calves gained 0.1 kg more BW per kg DM intake per d compared to conventionally fed calves during the pre-weaning period. There were no differences in

over-all FE in this study and FE the week of weaning was significantly lower for the calves fed an intensive MR. In our study, FE during the wk of weaning cannot be directly compared across all treatments as calves on the IHSHF treatment were weaned 1 wk later than the other treatments. Performance during the wk of weaning was therefore confounded by calf age. Feed efficiency for conventional and intensive fed calves in our study was greater than FE reported by Quigley et al. (2006) or Cowles et al. (2006). The use of sale barn calves that were under a significant amount of environmental and immunological stress could explain reduced FE reported by Quigley et al. (2006). An explanation for the lower FE reported by Cowles et al. (2006) is less clear.

Health. Serum protein concentrations of calves at the time of arrival at SROC were similar across treatments with an average of 4.96 g/dl. This value is slightly lower than recommended (≥ 5.0 g/dl) for adequate passive immunoglobulin transfer (Donovan et al., 1998) however calves were in good health and mortality was 0.0% for all treatments.

Fecal scores from d 1 to 42 were significantly higher for calves fed the largest volume of liquid (ILS and IHSHF treatments) compared to calves fed conventional MR and amounts of liquid (Table 5). Higher fecal scores due to increased MR feeding has been reported by a number of authors, although increased fecal scores in these studies did not result in differences in calf health (Diaz et al., 2001; Nonnecke et al., 2003). Through 56 d, fecal scores were not different across treatments. Days scouring (fecal score ≥ 3) was greater from d 1 to 42 for calves on the IHSHF treatment (2.8 d) compared to the CNA, CA, and IHS (1.4 d). Fecal scores and number of days scouring were intermediate for calves on the ILS treatment at 1.6 and 2.2 d respectively but were not significantly

different from the other 4 treatments. There were no differences in the number of d calves scoured the last wk of the study and in general the incidence and severity of diarrhea during this study were very low across treatments. Treatment costs, which reflects the cost of administering medication to calves, were not significantly different across treatments ($P > 0.10$) averaging \$1.51/calf. Acidification of the conventional MR (CA) did not result in any difference in average fecal score, scouring d or treatment cost compared to the CNA treatment. One of the proposed benefits of MR acidification is the inhibition of pathogenic organism growth in the gut due to decreased gastrointestinal tract pH (Erickson et al., 1989). Jaster et al. (1990) reported a significant reduction in fecal score for calves receiving acidified compared to non-acidified conventional MR at 1.25% of BW. They reported fecal scores of 1.6 vs. 1.4, a difference which is not likely to have biological significance.

Feed costs. Feed costs are presented in Table 6. Milk replacer cost was determine using a price of \$2.89/kg DM for CNA, \$2.90/kg DM for CA and \$3.60 for IHS, ILS, and IHSHF. Calf starter costs were \$0.55/kg DM for calves on conventional MR treatments and \$0.60/kg DM for calves fed intensive MR treatments. Due to the highest total MR intake and lowest CS intake, the IHSHF treatment was most costly at \$169.02. This treatment cost \$82.50, \$54.40, and \$49.70 more than the conventional MR (CA or CAN), the ILS and the IHS treatments, respectively. Feed cost per kg of gain was lowest ($P < 0.05$) for the conventional MR (\$2.50/kg BW gain), intermediate for IHS and ILS (\$3.00/kg BW gain) and highest for IHSHF (\$3.80/kg BW gain). Total feed cost for all treatments was within 1 SD of the average feed cost of raising one calf as reported by

Zwald et al. (2007) for 61 ± 17.3 (avg ± SD) d of age in Wisconsin (MR = $87.8 ± 43.6 and CS = $23.4 ± 14.1).

Post-weaning heifer grower period. One pen was removed from treatment CA because they were not fed the correct concentrate mix. Intake and growth performance are presented in Table 7 and 8, respectively. As heifers were limit fed the grower concentrate, there were no differences in concentrate intake across treatments. Heifers across all treatments consumed as much as they were offered per d (2.45 kg DM/d). Hay intake and feed efficiency were also similar across treatment. From d 1 to 112 of the post-weaning grower period, heifers consumed 2.3 kg hay daily and gained 0.2 kg of BW per kg of DM intake.

Growth parameters (BW and HH) were maintained for calves on the IHSHF MR treatment during the post-weaning heifer grower period. Heifers that received the IHSHF MR pre-weaning were heavier and taller during the post-weaning grower period than heifers fed the other 4 treatments ($P < 0.06$). On d 112, heifers on the IHSHF treatment averaged 6.7 kg heavier and 1.1 cm taller than heifers on the IHS and ILS treatment and 8.8 kg heavier and 1.8 cm taller than heifers on the CNA and CA treatments. There were no differences in BCS across treatments averaging 3.8 at d 112. A limited number of studies have determined the impact of early calf nutrition programs on post-weaning heifer performance. Nocek and Braund (1986) reported increased BW at weaning for calves fed a conventional MR ad libitum as compared to 0.96% of BW. Growth performance was not maintained during the post-weaning grower period (~ 94 d). However, calves were abruptly weaned and those fed MR ad libitum were only consuming 0.11 kg CS/d prior to weaning as compared to 0.48 kg/d for calves fed MR at

0.96% of BW. To our knowledge, studies specifically comparing conventional and intensive MR programs on post-weaning heifer performance have not been reported.

Feed costs during the heifer grower period are provided in Table 6. The grower concentrate fed to heifers that received an intensive MR as calves (IHS, ILS, IHSHF) was more expensive ($0.34/kg DM vs. $0.32/kg DM) than the grower concentrate fed to heifers that received a conventional MR as calves (CNA, CA). The increased cost of $6.90 to feed heifers for 112 d on a higher cost intensified grower concentrate mix reflects the cost of concentrate mix as amounts of concentrate mix and hay DM consumed were similar across all treatments. There was no difference in feed cost/kg of gain across treatments which averaged $1.18/kg BW gain.

Lactation performance. Nineteen heifers were excluded from the data set. Five heifers did not have a data record on DHIA or on their respective farms. One heifer died from hardware disease and nine heifers were sold prior to calving. Four heifers were sold shortly after calving (7 to 60 DIM). They were removed from the data set as only 1 DHIA test d was available and their total milk yield was less than 3 SD from the mean.

Heifers freshened from April to December of 2006 and averaged 348 ± 64.5 (avg ± SD) d of lactation across treatments. The lactation performances of 95 heifers were analyzed (Table 9). There was no treatment by dairy farm source interaction for any response variable. Calves that received the IHSHF treatment pre-weaning calved 27.5 d earlier ($P = 0.05$) than those fed a conventional MR program. Calving age was intermediate for the modified intensive MR treatments (IHS and ILS) at 734.3 d and not statistically different from the IHSHF or the conventional MR treatments (CNA and CA).

Tozer and Heinrichs (2001) reported small changes in calving age can have a significant impact on the cost of a heifer replacement program; a 1 mo reduction in calving age decreased cost 4.3%. As stated by Ettema and Santos (2004), this is assuming the reduction in calving age does not negatively impact reproduction, lactation or survivability. Similarly to our study, Rincker et al. (2006) reported calves fed an intensive (30.6% CP, 16.1% fat) compared to a moderate (21.5% CP, 21.5% fat) milk replacer program pre-weaning calved 17 d earlier ($P < 0.05$). In contrast, Drackley et al. (2007) pooled lactation data from two similar trials and reported no difference in age to first calving when heifers were fed a conventional (22% CP, 20% fat) or intensive (28% CP, 20% fat) MR as calves. Average age at calving was 25.9 and 24.1 mo across treatments for trial 1 and 2, respectively.

In the current study, there were no differences in 305 SME milk yield between heifers that were fed a conventional or modified intensive MR pre-weaning. Numerically, there was approximately a 6% increase ($P = 0.17$) in 305 SME when heifers received the IHSHF treatment pre-weaning compared to those fed a conventional MR or a modified intensive MR. The 305 SME for heifers on the IHSHF treatment were 718.0 kg and 734.0 kg greater than heifers on the conventional or modified intensive treatments, respectively. There were no difference in average milk fat or protein or first test d SCC across treatments averaging 3.6%, 3.0% and 4.7 $\log_{10}$ SCC/ml, respectively. Drackley et al. (2007) reported a response of a similar magnitude. In their study, the average increase in actual 305-d milk yield across trial 1 and 2 was 837.0 kg ($P < 0.05$) for heifers fed an intensive as compared to a conventional MR program as calves. They further noted that yield of 305-d milk protein was also increased ($P < 0.05$) while 305-d

milk fat yield was not different across treatments. Rincker et al. (2006) found no difference in first lactation performance between heifers fed an intensive or moderate milk replacer program however only the first 60 DIM was reported.

CONCLUSIONS

Under the conditions of this study, feeding calves an intensive MR with high solids at a high feeding rate pre-weaning resulted in increased BW and HH during the pre-weaning and early post-weaning period which was maintained over a 112-d post-weaning grower period as compared to a conventional or a modified intensive MR. Calves receiving the IHS treatment were heavier d 56 of the pre-weaning and early post-weaning period compared to the conventional or ILS treatments however this growth advantage was not maintained in the post-weaning heifer grower period.

Feed cost per kg of gain during the pre-weaning and early post-weaning period was lowest for CNA and CA, intermediate for IHS and ILS and highest for the IHSHF treatment; there was no difference in feed cost per kg of gain during the post-weaning grower period.

Heifers that received the IHSHF MR pre-weaning calved 27.5 d earlier than those fed a conventional MR. There was no difference in first lactation performance across treatments. All treatments resulted in healthy calves, acceptable growth rates, age to first calving and lactation performance.

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Table 1. Nutrient composition of conventional (C) and intensive (I) milk replacer and calf starter fed with each milk replacer during the pre-weaning and early post-weaning period.

Item	C[1]	I[1]
Milk replacer[2]		
DM, %	95.9	96.3
CP, %	20.6	28.2
Crude fat, %	20.2	18.0
Ash, %	10.6	10.0
Lactose[3], %	47.8	43.8
Vitamin A[4], IU/kg	66,150.0	33,075.0
Vitamin D[4], IU/kg	22,050.0	11,025.0
Vitamin E[4], IU/kg	220.5	110.3
Gross energy (GE)[5], Mcal/kg	5.0	5.0
Calf starter[6]		
DM, %	86.6	86.4
CP, %	20.2	25.0
Crude fat, %	2.5	2.8
NDF, %	14.8	16.0
ADF, %	6.2	6.7
NFC, %	69.2	65.0
Ca, %	1.1	0.6
P, %	1.1	0.6
Gross energy (GE)[7], Mcal/kg	4.3	4.4

[1]C = Conventional milk replacer (13.9% DM) was fed to calves on treatments CNA and CA. I = Intensive milk replacer was fed to calves on treatment IHS, ILS, and IHSHF. CNA = Conventional milk replacer (20% CP, 20% fat) non-acidified; CA = Conventional milk replacer (20% CP, 20% fat) acidified; IHS = Intensive milk replacer (28% CP, 16% fat) high solids (16.7% DM); ILS = Intensive milk replacer (28%CP, 16% fat) low solids (12.5% DM); IHSHF = Intensive milk replacer (28% CP, 16% fat) high solids, high feeding rate (16.7% DM).

[2]Milk replacer was fed d 1 to 42 for treatments CNA, CA, IHS, and ILS and d 1 to 49 for treatment IHSHF.

[3]Lactose estimated as 100-CP-fat-ash.

[4]Vitamin A, D and E concentration as reported on milk replacer feed tags.

[5]Gross energy (GE) for milk replacer = 0.057CP% + 0.092fat%, + 0.0395lactose% (NRC, 2001)

[6]Calf starter offered ad-libitum starting d 2. Treatments CNA and CA received Calf Krunch Formula (Hubbard Feeds, Inc.). Treatments IHS, ILS and IHSHF received Super Krunch Formula (Hubbard Feeds, Inc.).

[7]GE for starter = 0.057CP% + .094EE% + 0.0415NFC% (NRC, 2001).

Table 2. Nutrient composition of grower concentrate mixes and hay offered to group housed heifers during the 112 d post-weaning heifer grower period.

Item	C[1]	I[2]	Alfalfa/Grass Hay[3]
DM, %	90.1	90.2	90.0
CP, %	18.1	21.2	19.6
Crude fat, %	0.4	0.4	0.4
NDF, %	16.1	14.9	47.4
NFC[4], %	58.8	56.6	22.0
Ash, %	8.1	8.5	12.8
Ca, %	1.1	1.1	1.3
P, %	0.7	0.7	0.4

[1]C = concentrate mix fed during the grower period to heifers that had received a conventional milk replacer during the pre-weaning period. Concentrate mix was offered up to 2.45 kg (DM basis per head per day). Ingredient composition = 63.1% corn, 35.8% pellets and 1.1% molasses (DM basis). Monensin was added to concentrate mix at a concentration of 49.0 ppm.

[2]I = concentrate mix fed during the grower period to heifers that had received an intensive milk replacer during the pre-weaning period. Concentrate mix was offered up to 2.45 kg (DM basis) per head per day. Ingredient composition = 40.1% corn, 58.9% pellets and 1.0% molasses (DM basis). Monensin was added to concentrate mix at a concentration of 49.0 ppm.

[3]Hay fed free ad-libitum to all heifers.

[4]NFC = [100 – (NDF-NDICP) + CP + ash + EE], where EE = ether extract and NDICP = neutral detergent insoluble CP.

Table 3. Pre-weaning and early post-weaning milk replacer (MR), starter, dry matter (DM), nutrient and energy intake of calves fed a conventional or intensive milk replacer.

	Treatment[1]					
Intake	CNA	CA	IHS	ILS	IHSHF	SEM
No of calves=	26	28	26	29	24	
MR DM, kg/d						
d 1 to 14	0.53[a]	0.52[a]	0.65[b]	0.58[c]	0.73[d]	0.08
d 15 to 28	0.54[a]	0.54[a]	0.66[b]	0.65[b]	0.99[c]	0.01
d 29 to 42	0.41[a]	0.41[a]	0.49[b]	0.49[b]	0.99[c]	0.01
d 43 to 49	0.00[a]	0.00[a]	0.00[a]	0.00[a]	0.50[b]	0.02
Calf starter DM[2,3], kg/d						
d 1 to 14	0.04	0.04	0.05	0.06	0.03	0.007
d 15 to 28	0.35[a]	0.34[a]	0.35[a]	0.32[a]	0.17[b]	0.03
d 29 to 42	0.93[a]	0.88[a]	0.95[a]	0.87[a]	0.52[b]	0.05
d 43 to 49	1.87[ab]	1.81[a]	1.95[b]	1.88[ab]	1.26[c]	0.07
d 49 to 56	2.19[ab]	2.14[a]	2.30[b]	2.17[ab]	2.13[a]	0.07
Total DM[2], kg/d						
d 1 to d 42	0.95[a]	0.94[a]	1.06[b]	0.95[a]	1.13[b]	0.03
d 1 to d 56	1.23[a]	1.20[a]	1.33[b]	1.20[a]	1.34[b]	0.04
Crude protein[4], kg						
MR	4.32[a]	4.29[a]	7.08[b]	6.83[c]	11.70[d]	0.03
Starter	9.61[a]	9.34[a]	12.19[b]	11.19[b]	8.58[a]	0.45
Crude fat[4], kg						
MR	4.32[ac]	4.29[a]	4.52[b]	4.36[c]	7.50[d]	0.02
Starter	1.19[a]	1.16[a]	1.37[b]	1.25[b]	0.96[c]	0.05
Gross energy[5], Mcal						
MR	103.9[a]	103.0[a]	125.6[b]	121.0[c]	207.3[d]	0.45
Starter	204.5[a]	198.8[a]	214.6[a]	196.9[a]	151.0[b]	8.3

[1] Treatments: CNA = Conventional milk replacer (20% CP, 20% fat) non-acidified (13.9% DM); CA = Conventional milk replacer (20% CP, 20% fat) acidified (13.9% DM); IHS = Intensive milk replacer (28%CP, 16% fat) high solids (16.7% DM); ILS = Intensive milk replacer (28% CP, 16% fat) low solids (12.5% DM); IHSHF = Intensive milk replacer (28% CP, 16% fat) high solids, high feeding rate (16.7% DM). Treatment CNA, CA, IHS, and ILS weaned at 42 d while IHSHF weaned at 49 d.

[2]Initial BW included in the model as a covariate; Significant ($P < 0.05$) trt x period interaction.

[3]Calf starter offered ad-libitum starting d 2. Treatments CNA and CA were fed a 20.3% CP starter and treatments IHS, ILS and IHSHF received a 25.0% CP starter.

[4]Total intake d 0 to 42 for treatments CNA, CA, IHS, and ILS and d 0 to 49 d for treatment IHSHF.

[5]Gross energy for milk replacer = 0.057CP% + 0.092fat%, + 0.0395lactose% (NRC, 2001). Total gross energy intake during d 0 to 42 for treatments CNA, CA, IHS, and ILS and d 0 to 49 d for treatment IHSHF.

[a,b]Means within a row without common superscripts are different at $P < 0.05$.

Table 4. Pre-weaning and early post-weaning growth and feed efficiency (kg gain/kg DMI) of calves fed a conventional or intensive milk replacer.

	Treatment[1]					
Item	CNA	CA	IHS	ILS	IHSHF	SEM
No of calves=	26	28	26	29	24	
BW, kg						
d 1	41.22	41.44	40.72	39.51	40.31	0.75
d 14	44.47^{a}	44.48^{a}	47.46^{b}	46.85^{b}	48.97^{b}	0.84
d 28	52.86^{a}	52.57^{a}	57.22^{b}	56.44^{b}	61.05^{c}	0.93
d 42	64.04^{a}	62.94^{a}	68.51^{b}	67.20^{b}	73.70^{c}	1.08
d 49	70.19^{a}	68.56^{a}	74.26^{b}	73.06^{b}	80.35^{c}	1.12
d 56	77.15^{ab}	74.96^{b}	81.45^{c}	78.47^{a}	85.80^{d}	1.33
ADG, kg/d[2]						
d 1 to d 42	0.56^{a}	0.53^{a}	0.66^{b}	0.63^{b}	0.79^{c}	0.02
d 1 to d 56	0.65^{ab}	0.61^{b}	0.73^{c}	0.68^{ac}	0.80^{d}	0.02
HH, cm[3]						
d 56	91.19^{a}	91.09^{a}	91.25^{a}	90.59^{a}	93.09^{b}	0.34
Gain/DMI						
d 1 to d 42	0.59^{a}	0.57^{a}	0.63^{b}	0.67^{bc}	0.70^{c}	0.02
d 1 to d 56	0.54^{ab}	0.51^{a}	0.55^{b}	0.57^{bc}	0.60^{c}	0.01

[1]Treatments: CNA = Conventional milk replacer (20% CP, 20% fat) non-acidified (13.9% DM); CA = Conventional milk replacer (20% CP, 20% fat) acidified(13.9% DM); IHS = Intensive milk replacer (28% CP, 16% fat) high solids (16.7% DM); ILS = Intensive milk replacer (28% CP, 16% fat) low solids (12.5% DM); IHSHF = Intensive milk replacer (28% CP, 16% fat) high solids, high feeding rate (16.7% DM). Treatment CNA, CA, IHS, and ILS weaned at 42 d while IHSHF weaned at 49 d.

[2]Initial BW included in the model as a covariate; Significant ($P < 0.05$) trt x period interaction.

[3]Initial HH included in the model as a covariate.

[a,b]Means within a row without common superscripts are different at $P < 0.05$.

Table 5. Pre-weaning and early post-weaning fecal scores, scouring days and treatment cost of calves fed a conventional or intensive milk replacer.

	Treatment[1]					
Item	CNA	CA	IHS	ILS	IHSHF	SEM
No of calves=	26	28	26	29	24	
Fecal Score[2]						
1 to 42	1.49[a]	1.50[a]	1.53[ab]	1.64[b]	1.65[b]	0.05
1 to 56	1.58	1.58	1.62	1.70	1.67	0.05
Scouring days[3]						
1 to 42	1.42[a]	1.39[a]	1.38[a]	2.17[ab]	2.75[b]	0.29
43 to 56	0.19	0.04	0.15	0.55	0.21	0.29
Days fecal score of 4						
1 to 42	0.00	0.00	0.04	0.07	0.00	0.04
Treatment cost, $						
1 to 42	0.80	0.50	0.84	1.14	0.77	0.30
43 to 56	0.73	0.65	0.56	1.19	0.35	0.30
1 to 56	1.54	1.15	1.41	2.33	1.11	0.44

[1] Treatments: CNA = Conventional milk replacer (20% CP, 20% fat) non-acidified (13.9% DM); CA = Conventional milk replacer (20% CP, 20% fat) acidified (13.9% DM); IHS = Intensive milk replacer (28% CP, 16% fat) high solids (16.7% DM); ILS = Intensive milk replacer (28% CP, 16% fat) low solids (12.5% DM); IHSHF = Intensive milk replacer (28% CP, 16% fat) high solids, high feeding rate (16.7% DM). Treatment CNA, CA, IHS, and ILS weaned at 42 d while IHSHF weaned at 49 d. Starter was offered free choice starting d 2; treatments CNA and CA were fed a 20.3% CP starter and treatments IHS, ILS and IHSHF received a 25.0% CP starter.

[2]Fecal score = 1 to 4; 1 = normal, ≥ 3 = scours.

[3]Scouring day = any day with a fecal score ≥ 3.

[a,b]Means within a row without common superscripts are different at $P < 0.05$.

Table 6. Cost of DM intake and gain during the 56-d pre-weaning and early post-weaning period and the 112-d post-weaning heifer grower period.

	Treatment					
Item	CNA	CA	IHS	ILS	IHSHF	SEM
Pre-weaning and early post-weaning period[1] (d 0 to 56)						
No of calves=	26	28	26	29	24	
MR[2], $	60.01[a]	61.82[b]	90.29[d]	87.03[c]	148.89[e]	0.3
Starter[3], $	26.18[ab]	25.29[a]	28.99[b]	26.59[ab]	20.13[c]	1.2
Total, $	86.19[a]	87.11[a]	119.27[c]	113.62[b]	169.02[d]	1.3
Cost ($)/gain (kg)	2.42[a]	2.59[a]	2.98[b]	3.04[b]	3.81[c]	0.1
Post-weaning[4] (d 0 to 112)						
No of pens[4]	4	3	4	4	4	
Grower concentrate[5], $	90.81[a]	90.82[a]	97.00[b]	97.00[b]	96.91[b]	0.04
Hay[6], $	33.18	34.24	33.94	34.35	35.17	1.2
Total, $	123.99[a]	125.06[a]	130.95[b]	131.35[b]	132.08[b]	1.2
Cost ($)/gain (kg)[7]	1.14	1.16	1.18	1.20	1.23	0.02

[1] Calves housed individually. Treatments: CNA = Conventional milk replacer (20% CP, 20% fat) non-acidified (13.9% DM); CA = Conventional milk replacer (20% CP, 20% fat) acidified (13.9% DM); IHS = Intensive milk replacer (28%CP, 16% fat) high solids (16.7% DM); ILS = Intensive milk replacer (28%CP, 16% fat) low solids (12.5% DM); IHSHF = Intensive milk replacer (28%CP, 16% fat) high solids, high feeding rate (16.7% DM). Treatment CNA, CA, IHS, and ILS weaned at 42 d while IHSHF weaned at 49 d. Starter was offered free choice starting d 2; treatments CNA and CA were fed a 20.3% CP starter and treatments IHS, ILS and IHSHF received a 25.0% CP starter.

[2]Milk replacer cost: CAN = $2.89/kg DM; CA = $2.90/kg DM; IHS, ILS, and IHSHF = $3.60/kg DM.

[3]Starter cost: CNA and CA = $0.55/kg DM; IHS, ILS, and IHSHF = $0.60/kg DM.

[4]Calves housed in pens with 6 heifers per pen. Treatments CNA and CA received a 18.1% CP (DM basis) grower concentrate and treatments IHS, ILS and IHSHF received a 21.2 % CP grower concentrate (DM basis) up to 2.5 kg/d (as-fed). Hay offered free choice.

[5]Grower concentrate = $0.33/kg DM for all treatments.

[6]Hay = $0.13/kg DM for all treatments.

[7]Significant ($P < 0.05$) contrast = CNA + CA versus IHSHF.

[a,b]Means within a row without common superscripts are different at $P < 0.05$.

Table 7. Pen average post-weaning intake and feed efficiency (kg gain/kg DMI) during the post-weaning heifer grower period (112 d) of group housed heifers that received a conventional or intensive milk replacer as calves pre-weaning.

	Treatment[1]					
Item	CNA	CA	IHS	ILS	IHSHF	SEM
No of pens[1]=	4	3	4	4	4	
Grower DMI, kg/d						
d 1 to d 112	2.45	2.45	2.46	2.46	2.45	0.001
Hay DMI, kg/d						
d 1 to d 112	2.24	2.31	2.29	2.32	2.37	0.08
Total DMI, kg/d						
d 1 to d 112	4.69	4.76	4.75	4.77	4.83	0.08
Gain/DMI						
d 1 to d 112	0.21	0.20	0.21	0.21	0.20	0.01

[1]Calves housed in pens with 6 heifers per pen. Calves that received a conventional milk replacer pre-weaning (CNA = conventional non-acidified, CA = conventional acidified) received an 18.1% CP (DM basis) grower concentrate. Calves that received an intensive milk replacer pre-weaning (IHS = intensive high solids, ILS = intensive low solids, IHSHF = intensive high solids high feeding rate) received a 21.2 % CP grower concentrate (DM basis) up to 2.5 kg/d (as-fed). Hay offered free choice.

[a,b]Means within a row without common superscripts are different at $P < 0.05$.

Table 8. Pen average body weight (BW), body condition score (BCS) and hip height (HH) during the post-weaning heifer grower period of group housed heifers that received a conventional or intensive milk replacer as calves pre-weaning.

	Treatments[1]						Contrasts[2]			
Item	CNA	CA	IHS	ILS	IHSHF	SEM	1	2	3	4
No of pens[1]=	4	3	4	4	4					
BW, kg							0.97	0.72	0.03	0.02
d 1	93.92	94.86	95.25	93.33	103.98	2.8				
d 112	202.49	202.53	205.90	203.50	211.41	2.7				
BCS[3]							0.13	0.73	0.36	0.25
d 1	2.98	3.05	3.05	2.99	3.10	0.04				
d 112	3.77	3.83	3.77	3.78	3.80	0.1				
HH, cm							0.86	0.23	0.06	0.01
d 1	95.52	94.72	94.85	94.91	97.21	0.7				
d 112	113.80	113.57	114.09	114.67	115.44	0.5				

[1]Calves housed in pens with 6 heifers per pen. Calves that received a conventional milk replacer pre-weaning (CNA = conventional non-acidified, CA = conventional acidified) received an 18.1% CP (DM basis) grower concentrate. Calves that received an intensive milk replacer pre-weaning (IHS = intensive high solids, ILS = intensive low solids, IHSHF = intensive high solids high feeding rate) received a 21.2 % CP grower concentrate (DM basis) up to 2.5 kg/d (as-fed). Hay offered free choice.

[2]Contrast: 1 = CNA versus CA, 2 = CNA + CA versus IHS + ILS, 3 = IHS + ILS versus IHSHF, 4 = CNA + CA versus IHSHF.

[3]BCS = Body condition score (1 to 5; 1 = thin and 5 = fat).

[a,b]Means within a row without common superscripts are different at $P < 0.05$.

Table 9. First lactation performance of heifers fed a conventional (C) or intensive (I) milk replacer program as calves pre-weaning using Dairy Herd Improvement Association (DHIA) records.

	Treatment[1]					Contrasts[2]		
Item	Control [3] (CNA + CA)	IHS	ILS	IHSHF	SEM	1	2	3
No of heifers=	34	18	21	22				
Age at calving, d	744.5	731.1	737.5	717.0	10.6	0.38	0.20	0.05
305 SME[4] milk, kg	12962	13123	12769	13680	393.1	0.97	0.15	0.17
Fat[5], %	3.5	3.6	3.7	3.6	0.1	0.12	0.39	0.64
Protein[5], %	3.0	3.1	3.0	3.0	0.03	0.90	0.51	0.59
Log SCC[6]	4.7	4.8	4.7	4.7	0.2	0.82	0.98	0.83

[1]Treatments CNA and CA received a conventional milk replacer as calves and treatment IHS, ILS and IHSHF received an intensive milk replacer. CNA = Conventional milk replacer (20% CP, 20% fat) non-acidified (13.9% DM); CA = Conventional milk replacer (20% CP, 20% fat) acidified (13.9% DM); IHS = Intensive milk replacer (28%CP, 16% fat) high solids (16.7% DM); ILS = Intensive milk replacer (28%CP, 16% fat) low solids (12.5% DM); IHSHF = Intensive milk replacer (28%CP, 16% fat) high solids, high feeding rate (16.7% DM). Treatment CNA, CA, IHS, and ILS weaned at 42 d while IHSHF weaned at 49 d.

[2]Contrast: 1 = Control versus IHS and ILS, 2 = IHS and ILS versus IHSHF, 3 = Control versus IHSHF.

[3]CNA and CA treatments were pooled and referred to as the control treatment.

[4]305 SME = standardized mature equivalent (projected 305 day mature equivalent milk yield).

[5]Lactation average.

[6]First test day SCC following calving.

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