Impact of Nutritional Grouping on the Economics of Dairy Production Efficiency

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Abstract

This paper is an adapted excerpt of a published paper. The economic efficiency of nutritional grouping strategies in 5 Wisconsin commercial dairy herds was studied using a daily dynamic stochastic Monte Carlo simulation model. Each month, the clustering method was used to homogeneously regroup cows according to their nutrient concentration requirements. The average net energy for lactation (**NE_L**) and metabolizable protein (**MP**) +1 standard deviation (**SD**) concentration of the group were used to formulate the group diet. The calculated income over feed costs gain (**IOFC**, \$/cow/yr) of having >1 nutritional groups among the herds ranged from \$33 to 58, with an average of \$39 for 2 groups and from \$42 to 58, with an average of \$46 for 3 groups. The improved IOFC was explained by increased milk sales and lower feed costs. Higher milk sales were a result of fewer cows having a milk loss associated with low body condition score (**BCS**) in multi-group scenarios. Lower feed costs were mainly due to less rumen undegradable protein (**RUP**) consumption in multi-group scenarios. The percentage of total NE_L consumed and captured in milk for >1 nutritional group was slightly lower than that for 1 nutritional group due to better distribution of energy throughout the lactation and higher energy retained in body tissue, which resulted in better herd BCS distribution.

Introduction

Grouping lactating cows for nutritional purposes, also referred as nutritional grouping, is a herd management strategy that provides different diets to different groups of lactating cows to better fulfill their nutrient requirements. Hence, nutritional grouping can be beneficial by saving feed costs, improving productivity, improving herd health, and decreasing nutrient emissions to the environment (Cabrera and Kalantari, 2016). Total mixed rations have become an industry standard for feeding management, and many dairy farms are using just 1 total mixed ration (**TMR**) for all lactating cows, despite major differences in nutritional requirements of dairy cows in different lactation stages (Allen, 2008). For example, 58% of Wisconsin and Michigan dairy farms used the same TMR for all lactating cows (Contreras-Govea et al., 2015). The adoption and application of a single TMR as a common practice has resulted in more over-conditioned cows and greater nutrient excretion issues (Allen, 2009). Cows in similar lactation stages could have different nutritional requirements because of their productivity and genetic potential. When feeding only 1 TMR diet, it is usually formulated for high-producing cows to ensure that these cows reach their full milk production potential, which results in overfeeding lower-producing cows (Cabrera and Kalantari, 2016). A strategy to relieve this problem is adopting nutritional groups

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with more precise diets, which will increase profitability and economic efficiency due to the better-tailored diet to the cow requirements in a group, even when it could require more capital management and labor costs (VandeHaar, 2011). Nutritional grouping of lactating cows promotes optimal body condition and health (Allen, 2009), an additional advantage that could translate into economic benefits (Cabrera and Kalantari, 2016). More precise diets would also improve milk productivity (Bach, 2014). Grouping decreases within-group and increases across-group variation of diets' nutrient density, reducing competition at the feed bunk (Grant and Albright, 2001). Within this context, Kalantari et al. (2016) studied by simulation modeling the economic efficiency of nutritional grouping in 5 Wisconsin commercial herds. This paper is an adapted excerpt of that study, highlighting its practical and applicable results.

Materials and Methods

A daily dynamic stochastic Monte Carlo simulation was developed to model individual cows after first parturition in a dairy herd. The next-event scheduling approach (De Vries, 2001) scheduled stochastic events that could happen to cows during each reproductive cycle. First, a data set of all the cows in a herd and their current status were loaded (i.e., lactation number, day postpartum, reproductive status). Then, a list of possible stochastic events was scheduled for each cow at the beginning of the simulation and the list was renewed after starting their next lactation. These events included involuntary culling, death, pregnancy, abortion, dry-off, and parturition. For each event, a 2-step process was followed: 1) determining the binary outcome of the event (it happens or not during the cow's current lactation) and, if it happens, 2) the day of the occurrence (schedule). For each cow, milk, fat, and protein production; body weight (**BW**) and BCS changes, and NE_L and MP requirements were simulated and monitored according to diets. The BCS was restricted to 2.0 and 4.5 in a scale of 1 to 5. If BCS was calculated to go below or above these limits, milk production or dry matter intake (**DMI**) was decreased, respectively, to maintain BCS within these limits. For all specific details of the underlying simulation model algorithms, please refer to Kalantari et al. (2016).

Nutritional grouping

Within the simulation framework portrayed above, nutritional grouping strategies were studied on post-fresh lactating cows (DIM>21) to test their effect in the overall IOFC [IOFC = milk value minus rumen degradable protein (**RDP**), RUP, and NE_L costs]. To be consistent among herds, the sizes of nutritional groups were chosen to be approximately equal among them (total available cows divided by the number of defined nutritional groups). The monthly regrouping process of groups started by ranking the cows based on their NE_L and MP requirements (clustering method; McGilliard et al., 1983). Different strategies have been explored in the literature to determine the NE_L and crude protein (**CP**) concentrations of a diet for a group of cows, but in general, all used average milk production of a group as the basis for calculating lead factors, or the levels at which the diet should be formulated. These methods include, for example, the use of the 83rd percentile in each group (Stallings and McGilliard, 1984) or the use of differentiated levels according to several groups (Stallings, 2011). Kalantari et al. (2016) used individual cow's daily NE_L and MP requirements to formulate more precise diet nutrient concentrations in simulated groups of cows. This method minimized the within-group variability of individual animal nutrient requirements expressed as the concentration of NE_L and MP in the diet. Then, the diet for the group was formulated based on NE_L and

MP requirements of the group. Different levels of NE_L concentrations, average NE_L, average NEL+0.5SD, and average NE_L+1SD, were considered, but it was found that formulating the diet for above the average NE_L concentration changed the body energy contents of the cows in the herd, resulting in an undesirable proportion of obese cows in the herd. For that reason, only average NE_L concentration was used. Regarding MP, the base scenario used MP+1SD.

Economic parameters

Economic parameters for the base scenario were set as 10-yr Wisconsin average prices from 2005 to 2014. Thus, milk price was set to \$0.39/ kg of milk. FeedVal 6.0 decision support tool (http://dairymgt.info/tools.php) was used to calculate the nutrient prices of NE_L, RDP, and RUP. The calculated nutrient prices were: \$0.1/Mcal of NE_L, \$0.18/kg of RDP, and \$1.04/ kg of RUP.

Scenario analyses

Two extreme scenarios were analyzed. The worst-case scenario was designed by coupling the lowest milk price with the highest nutrient costs and vice versa for the best-case scenario. Ten-year annual average of milk price was used to set the highest (\$0.52/kg) and lowest milk (\$0.29/kg) prices. The highest (lowest) nutrient costs were set at \$0.14/ Mcal of NE_L (\$0.05), \$0.26/kg RDP (\$0.09), and \$1.52/ kg RUP (\$0.52).

Considering the large differences among studies regarding milk losses when grouping cows (Smith et al., 1978; Hasegawa et al., 1997; Zwald and Shaver, 2012), possible milk loss due to regrouping lactating cows was explored with a base scenario without any milk loss and another scenario with extreme milk losses of 1.82 kg/ day during 5 days after grouping (Cabrera and Kalantari, 2014). In addition, the effect of having first-lactation cows as a separate nutritional group was studied.

Case study herds and projection timeline

Five Holstein herds from Wisconsin using a TMR feeding management system were studied (Table 1). The model captured current cow and herd profiles (day = 0 of the simulation) and then projected individual cow and herd performance daily for a year (day = 365) with 1,000 replications.

Results and Discussion

Grouping

Post-fresh lactating cows (592) from the 787-cow herd at 300 d in the simulation are shown in Figure 1A, ranked according to their NE_L concentration requirements. It is clear that lactating cow requirements vary substantially on a given day because of differences in lactation stage, pregnancy status, BW, and milk production. In this example, the highest NE_L concentration requirement was from a cow in third lactation, 23 days postpartum, and with milk yield 20% above herd average. The lowest NE_L concentration requirement was from a cow in third lactation, 385 days postpartum, and with 10% below average milk yield. To cope with this high variability, precision feeding according to an individual cow's requirements would be ideal, but unfortunately this is not yet practical, especially in larger herds (Sniffen et al., 1993). On the other hand, preparing a diet of just 1 TMR for all cows could result in large overfeeding or underfeeding problems. A diet is usually formulated for high-producing cows to ensure that milk production is maintained (Weiss, 2014), but that is inefficient. A practical way to overcome this high variability is to group them according to their requirements.

The effect of grouping these 592 post-fresh lactating cows is illustrated in Figure 1B, where the difference between offered and the required NE_L concentrations are depicted for 3 cases of nutritional groupings. Figure 1B shows that when feeding all the cows as one group and formulating the diet based on the average NE_L concentration of the group, approximately half of the cows are overfed and the other half underfed. However, it should be noted that the NE_L concentration of the requirements is not necessarily normally distributed. Thus, formulating based on the average NE_L concentration does not always result in overfeeding half the cows and underfeeding the other half. It was observed that the distribution was strongly affected by herd structure at the point of regrouping the cows. Specifically, it depended on the percentages of fresh animals that were moving into optional groups (>21 days postpartum)—cows with the highest requirements—which caused right skewedness in the distribution. It was also dependent on the percentages of late-lactation cows moving to the dry group, which caused left skewedness in the distribution. Figure 1B shows that increasing the number of groups decreases the variability among the cows within the group, which is especially beneficial in offering the cows a diet closer to individual cow requirements in terms of health, environment, and economics. This benefit is more pronounced in the case of large herds and when the distribution of the requirements is not normal (McGilliard et al., 1983). The difference between offered and required MP for the cows in the group when feeding the group of cows average MP+1SD shows a pattern similar to that for NE_L (data not shown).

Economic value of nutritional grouping

The economic value of nutritional grouping measured in terms of IOFC is displayed as the difference from 2 to 4 TMR and 1 TMR in Figure 2. It is clear that an economic gain results from nutritional grouping. These gains depended on the number of groups and varied from ($/cow/yr) $39 for 2 groups, to $46 for 3 groups, and to $47 for 4 groups (Figure 2). The gain in IOFC with more nutritional groups was due to higher milk production and lower feed costs. Higher milk production for more than 1 group was due to fewer cows having milk loss for low BCS (BCS <2.0). The lower feed costs with 2 and 3 groups were mainly due to less RUP cost (Figure 2). Compared with RUP cost, other components of IOFC (RDP and NE_L costs and milk revenue) were more stable across different grouping numbers and MP concentrations in the diet. The largest relative IOFC gain was obtained when moving from 1 group to 2 groups. Comparing 1 group and 2 groups, the IOFC gain ranged ($/cow/yr) from $33 (570-cow herd) to $49 (787-cow herd). The overall (average of 5 herds in the study) gain in IOFC ($/cow/yr) from 1 group to 2 groups was $39 ± 6 and from 1 group to 3 groups was $46 ± 7 (Figure 2). Economic gains found in other studies are different because of differences in the model and input values used in those studies. For example, Williams and Oltenacu (1992) reported that the mean annual IOFC ($/cow/yr) of 3 nutritional groups were $21, 33, and 40 higher than that of 2 groups at production levels of 8,000, 9,000, and 10,000 kg/cow/305-d lactation, respectively. St-Pierre and Thraen (1999), using economic optimized lead factors for CP and NE_L for different group numbers, calculated average economic gains ($/cow/yr) of $44 and 77 when comparing 2 and 3 groups with 1 group, respectively. These values are comparable to those found in this study. A study by Østergaard et al. (1996) used a dynamic stochastic simulation model to compare different grouping strategies under different reproductive and culling management, where feeding of the cows was not according to the calculated nutrient requirements but was specified by a feeding regimen of TMR with up to 3 different groups. Although the differences in the feeding systems make it difficult to compare the current study with that of Østergaard et al. (1996), they also showed that, overall, 1 group was inferior to other grouping strategies mainly due to the economic effect of lower milk production and higher amount of concentrate intake in 1 group. They also found that marginal net revenue per cow per year was lower under 1 group compared with 2 or 3 groups under all scenarios of milk production and reproductive and culling management. It should be noted that Kalantari et al. (2016) used the actual requirements of the cows to determine the offered diet concentration of NE_L and MP and included the dynamics of the herd throughout lactation, which might provide a better approximation of the economic gain of nutritional grouping. The other important factor in economic evaluation of grouping lactating cows is the extra labor needed to formulate, prepare, and deliver feeds, and the extra costs of running mixers for preparing the TMR for each group separately. In addition, there is a labor cost related to moving cows among groups. These costs are usually farm specific and vary among herds (Østergaard et al., 1996), and for simplification, they were not included in Kalantari et al. (2016). Overall, profitability and feasibility of nutritional grouping are highly farm and market dependent. Farm size has an effect on the feasibility of nutritional grouping. For example, the extra labor for regrouping and moving cows might be less important in larger herds than in smaller herds (Østergaard et al., 1996). Also, when market conditions determine high feed costs and low milk prices, nutritional grouping could be more economically appealing (Allen, 2008; Hutjens, 2013). Simulation studies (Pecsok et al., 1992; Williams and Oltenacu, 1992) have suggested dividing lactating cows into 3 nutritional groups for optimal efficiency. Results from this study corroborate those previous reports indicating that economic gain and efficiency increase up to 3 nutritional groups. Also, the rate of improvement of IOFC with each additional grouping followed the law of diminishing returns.

Formulated diet

The average NE_L, RDP, and RUP concentrations in DM under 3 levels of offered MP concentrations are summarized in Table 2. The formulated diet for 1 group had a concentration of 1.50 Mcal/kg of DM. Having more groups divides the cows into more homogeneous NE_L concentration groups and hence higher and lower concentrations of NE_L in the diet. A similar pattern was observed in RDP and RUP percentages in the diet. The reported NE_L concentrations by McGilliard et al. (1983) using a clustering method with 2 groups were 1.62 (high) and 1.42 (low) Mcal/kg, which are comparable to those obtained here (1.59 and 1.41 Mcal/kg, respectively). The optimal allocation of NE_L concentration found in the St-Pierre and Thraen (1999) was much less variable and higher than that reported by Kalantari et al. (2016) or in the McGilliard et al. (1983) study. The optimum allocation of NE_L found in St-Pierre and Thraen (1999) study was 1.78 (Mcal/kg) in the 1-group case and remained above 1.70, even in the case of 3 groups. Previous studies have used CP to estimate required protein in the group; whereas, this study used the MP requirement of the cows. The CP percentage (RDP + RUP/0.8) in this study was higher than the reported optimum allocation of CP by St-Pierre and Thraen (1999), which used milk production as the proxy for diet formulations. In 1 group, the estimated range of CP was 18, 18.5, and 19% for average, 0.5SD, and 1SD above average, respectively. In the current study, the difference of CP in different group numbers were approximately 2, 3, and 3.8 percentage points for 2, 3, and 4 groups, respectively. The differences for the optimum allocation of CP reported by St-Pierre and Thraen (1999) were 1 and 2 percentage points for 2 and 3 groups, respectively.

Nutrients captured in milk and BCS

The results of the current study could be explained by studying the detailed charts of the NE_L concentration in the diet (Figure 3) and the distribution of the retained body energy in terms of BCS (Figure 4). A greater proportion of the cows in the herd were underfed in the case of 1 group than with more groups and therefore the total NE_L consumption and milk yield (milk yield depended on the energy in the body as captured in BCS) for just 1 group was less than that with 2 and 3 groups. Utilizing 2 or 3 groups increased the diet NE_L concentration in early lactation (the time that is most needed) until around 150 d postpartum (Figure 3). After this point, 2 and 3 groups had a lower NE_L concentration in the diet than did 1 group. The overall lower NE_L concentration required for late-lactation cows was generally lower than the higher NE_L concentration required for early-lactation cows, and therefore, the total NE_L consumed was higher for multi-groups than for 1 group. Cows in 1 group were then fed close to the average of the group NE_L concentration of their requirements (approximately 1.50 Mcal/kg of DM), which remained almost unchanged until around 300 DIM. At this point, the increasing proportion of low producing, late-lactation cows reduced the average NE_L concentration. On the other hand, in the case of 2 and 3 groups, there was a curvilinear pattern, which is explained by the fact that cows were fed closer to their requirements (and at higher concentrations than in 1 group) when the energy requirements were high. After passing the critical point of early lactation, NE_L concentration decreased for 2 and 3 groups compared with 1 group. Two and 3 groups assure that late-lactation cows have enough energy in the diet but not much more than required. Overall, it is clear that use of 2 or 3 groups distributes NE_L more efficiently based on DIM and productivity, which might increase overall NE_L consumption in the herd.

Excess energy in late-lactation cows is associated with greater BCS and over-conditioned cows that can have complications in the next lactation (Cameron et al., 1998). The effect of several nutritional groups on BW and BCS can be seen in Figure 4, which compares the effect of 1 and 3 nutritional groups on BW and BCS distributions of the 787-cow herd. The left panel of Figure 4 shows that the BW density plot of 2 grouping strategies (1 vs. 3 groups) does not differ considerably; they both have similar distributions. This indicates that use of 1 and 3 groups did not result in overall BW changes of the cows in the herds. The stable BW among different grouping numbers has also been reported in field trials (Smith et al., 1978; Clark et al., 1980; Kroll et al., 1987). The right panel of Figure 4 illustrates the effect of nutritional grouping on the distribution of the cows' body energy content (**BCS**). The 1 group represented by a dark-shaded density plot has a different distribution than 3 groups (light shading). With 1 group, the distribution is thick-tailed, which means the model projects that many cows are either under-conditioned (BCS = 2.0) or over-conditioned (BCS = 4.5), and it has a mode around BCS = 2.75. On the other hand, use of 3 groups shows a rather normal distribution curve with the mode around BCS = 3.25. Similar distribution was observed in the case of 2 groups and in the other studied herds (data not shown). Having 2 or 3 groups appears to ensure that the consumed energy is better-distributed, promoting healthier cows.

The overall MP trend is similar. In the 1 group case, the MP consumption decreased to 11 g/100 g of DM post freshening, and stayed at the same level until about 300 days postpartum, when it decreased consistently through the rest of the lactation (Figure 3). However, in 2 and 3 groups, the provided MP in the diet was closer to the actual requirements. Therefore, with 2 or 3 groups, cows were fed more MP until about 100 days postpartum and thereafter fed lesser MP than the 1-group case. This higher N consumption in late lactation for 1 group compared with more groups is consistent with the literature (VandeHaar, 2014). Having 3 groups and formulating the diet at 1 SD above the MP average improved N efficiency by 2.7%. The main economic gain of having more groups could be attributed to an increased percentage of N captured in milk, which in turn decreases feed cost related to RUP. Having more groups clearly improves the percentage of N captured in milk, which, at the same time, improves environmental stewardship by decreasing the amount of N excreted (VandeHaar, 2014).

Scenario analyses

Results from scenario analyses on the input price, inclusion of milk loss, and separation of the first-lactation cows from older cows are depicted in Table 3. The results show that even in the worst economic conditions (lowest milk price with highest nutrient costs), grouping cows had a similar average IOFC gain compared with the base scenario. Comparing the base and best case scenarios over all herds, the average IOFC gain ($/cow/yr) was $6 higher in 2 groups and $4 in 3 groups. Comparing the IOFC gain ($/cow/yr) of 2 and 3 groups, the relative gain was highest in the worst case scenario ($10) and the lowest relative IOFC gain of having 3 groups instead of 2 groups was under the best case scenario ($6). This emphasizes the importance of grouping lactating cows in tough economic conditions, when the milk price is low compared with feed price. Even though the relative IOFC gain was greater in the worst conditions, the highest IOFC gain in absolute terms was when the milk price was high compared with feed costs (i.e., best case; Table 3). Assumed milk loss (1.82 kg/day for 5 days) due to regrouping decreased the average 5 herds' IOFC of 2 groups by $18 across all the herds and by $20 for 3 groups compared with 1 group (Table 3). The data showed that even under the assumption of milk loss because of regrouping, there is still an overall economic gain. However, considering milk loss for all cows, as was assumed in this study, resulted in the lowest economic gain among all the scenarios, including the worst-case scenario. The amount of IOFC gain ($/cow/yr) ranged from $14 to 32 when comparing 1 and 2 groups and the IOFC gain ranged from $19 to 38 when comparing 1 and 3 groups. The amount of loss depended on the number of times cows were reassigned to a different group, and it was affected by cow characteristics (i.e., milk production and DIM that determine cow requirements) and the nutrient requirement variations among the cows in the groups. The trend when having milk loss because of regrouping was consistent with the base scenario in that the largest gain was observed between 1 and 2 groups. Smith et al. (1978), in a field study, compared lactating cows grouped into 1 and 2 groups. In that study, the average decline in milk production was found to be 2 kg/cow/day for 7 days, and this amount was affected by parity (less milk loss for first-lactation compared with older cows). Even with this amount of milk loss, the IOFC of 2 groups was $30/cow/year greater than that of 1 group, as a result of less concentrate fed (Smith et al., 1978). This amount of gain in IOFC is in the range of values found in this study. In another field study by Zwald and Shaver (2012), the milk loss due to change in groups was reported to be insignificant. Overall, the effects of grouping on the milk production of the cows in inconclusive (Clark et al., 1980), and based on those field studies mentioned above, it seems that the assumed amount of milk loss in this study (total of 9.1 kg in 5 days) could be either underestimated or overestimated. Thus, the true amount of milk loss is unknown, and studies have shown that it could be affected by parity (Smith et al., 1978) and could vary among cows based on their days in milk (**DIM**)

(Kroll et al., 1987) and other characteristics. It seems safe to assume that not every cow might experience the same amount of loss and the duration could vary among cows based on their characteristics. However, the amount of saving in the feed cost due to grouping could exceed the loss in the milk production (Smith et al., 1978; Clark et al., 1980). Adding first-lactation cows as a separate group also affected the economics of nutritional groupings and is summarized in Table 3. The average IOFC gain among all the herds was lower than that of the base scenario by $7/cow/year. This smaller gain when separating first-lactation cows was mostly due to the fact that having a separate group of first-lactation animals ensures a diet tailored more closely for those cows and older cows, similar to having a separate nutritional group. Table 2 summarizes the formulated diet when separating first-lactation cows into their own group. Regardless of the number of groups, the formulated diet of first-lactation cows was the same across different group numbers and herds. However, separating the first-lactation cows into a group increased the nutrient concentration of the diet of older cow groups, thus the higher feed costs (higher RUP costs) and smaller IOFC gain in this scenario. It should be mentioned that the model did not consider the possible benefit of separating first-lactation animals due to social hierarchy among the younger cows and older cows, which could result in decreases in feed intake and milk production of first-lactation cows (Botheras, 2007). Considering this issue could increase the reported economic gain of separately grouping first-lactation cows.

Conclusions

Economic gains of nutritional grouping measured as milk income minus NEL and MP costs were $15.2 ± 5.5, 30.5 ± 6.0, and 46.6 ± 6.6 for 2, 3, and 4 nutritional groups compared to 1 group. Economic gains were explained mainly due to higher milk production and lower RUP costs when grouping, and gain was emphasized during tough economic conditions. The effect of a possible constant milk loss when regrouping cows would have a deleterious economic effect but not high enough to overcome the gains.

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Table 1. Studied dairy herds.

Characteristics	Herd Size (Lactating + Dry) 331	570	727	787	1,460
Average Herd ME305[1] (kg/cow/yr)	13,348	16,140	13,897	12,884	14,188
1st Lactation (%)	38	43	39	39	45
Average days in milk[2] (days)	193	169	181	165	174
Average days in pregnancy (days)	134	140	141	133	157
Average lactation number (#)	2.03	1.99	2.29	2.21	2.02
21-days Pregnancy rate[3] (%)	17	18	19	19	18
Conception rate[3] (%)	35	32	36	37	40
Estrus detection[3] (%)	49	57	51	51	45
Culling[3] (%/yr)	35	32	36	37	40
Abortion[3] (%/gestation)	16	7	11	11	7

[1]305-day mature equivalent milk production.
[2]Average days in lactation.
[3]As defined and calculated in DairyComp305 (Valley Agricultural Software, Tulare, CA).

Table 2. Formulated diet components for different nutritional group numbers and scenarios obtained by averaging 5 herds (±SD within herds) throughout the simulation of 12 monthly grouping periods

Group number	Groups	NE_L (Mcal/kg DM)	RDP (% of DM)	RUP (% of DM) 0xSD	0.5xSD	1xSD
Grouping post-fresh lactating cows						
1	G1	1.50±0.004	9.34±0.0002	5.06±0.0004	5.46±0.0004	5.85±0.0005
2	G1	1.59±0.005	9.89±0.0003	5.35±0.0004	5.63±0.0005	5.90±0.0005
	G2	1.41±0.005	8.83±0.0003	4.78±0.0005	5.01±0.0005	5.22±0.0006
3	G1	1.66±0.006	10.27±0.0003	5.42±0.0005	5.68±0.0005	5.95±0.0006
	G2	1.48±0.005	9.25±0.0003	5.15±0.0003	5.27±0.0005	5.36±0.0004
	G3	1.38±0.006	8.67±0.0003	4.67±0.0004	4.85±0.0006	5.02±0.0006
4[1]	G1	1.72	10.60	5.42	5.68	5.95
	G2	1.52	9.49	5.24	5.38	5.50
	G3	1.45	9.07	4.99	5.08	5.18
	G4	1.37	8.59	4.61	4.75	4.93
Separating first lactation cows from older lactating cows						
First lactation[2]		1.50±0.008	9.34±0.0005	4.93±0.0007	5.24±0.0006	5.55±0.0005
1	G1	1.50±0.003	9.35±0.0002	5.15±0.0003	5.57±0.0004	6.00±0.0005
2	G1	1.61±0.005	9.97±0.0002	5.46±0.0004	5.75±0.0005	6.03±0.0005
	G2	1.40±0.002	8.77±0.0002	4.85±0.0002	5.08±0.0002	5.31±0.0002
3	G1	1.67±0.006	10.33±0.0004	5.53±0.0005	5.80±0.0006	6.07±0.0006
	G2	1.48±0.003	9.24±0.0002	5.24±0.0003	5.35±0.0003	5.46±0.0004
	G3	1.37±0.004	8.60±0.0002	4.72±0.0003	4.90±0.0002	5.09±0.0002
4[1]	G1	1.72	10.6	5.54	5.81	6.08
	G2	1.52	9.49	5.28	5.46	5.60
	G3	1.44	9.03	4.95	5.13	5.28
	G4	1.35	8.55	4.62	4.78	4.98

[1]4 groups were studied only on the largest herd (1,460-cow herd).
[2]The average formulated diet for first lactation cows separated from older cows was similar across all the grouping numbers and herds.

Table 3. Average economic gain in IOFC of grouping strategies of 5 studied herds.

Scenario	Difference between grouping strategies and 1 group ($/cow/yr) 2 Groups	3 Groups	4 Groups[1]
Base[2]	38.66	46.24	46.90
Worst[3]	35.48	44.94	47.40
Best[4]	44.34	50.18	48.80
Milk loss[5]	20.46	25.90	23.50
1st lactation[6]	32.64	38.76	38.50

[1]4 groups were studied only on the largest herd (1,460-cow herd).

[2]Base scenario running on the average NE_L concentration and average MP+1xSD with 10 years average annual milk price ($0.39/kg) and nutrient costs (NE_L=$0.10/Mcal, RDP=$0.18/kg, and RUP = $1.04/kg).

[3]Worst case scenario couples the lowest milk price with the highest feed price from historical 10 years annual average (Milk price=$0.29/kg, NE_L=$0.14/Mcal, RDP=$0.26/kg, and RUP=$1.52/kg).

[4]Best case scenario couples the highest milk price with the lowest feed price from historical 10 years annual average (Milk price=$0.52/kg, NE_L=$0.05/Mcal, RDP=$0.09/kg, and RUP=$0.52/kg).

[5]Adding 5 days of 1.82 kg/day milk loss for cows changing to another group under base scenario.

[6]Including 1st lactation cows as a separate obligatory group under base scenario. In this scenario, the 1 group itself has 2 groups: 1st lactating cows and ≥ 2nd lactating cows. Thus, in addition to the number of groups for older cows, one group is just for first lactation cows.

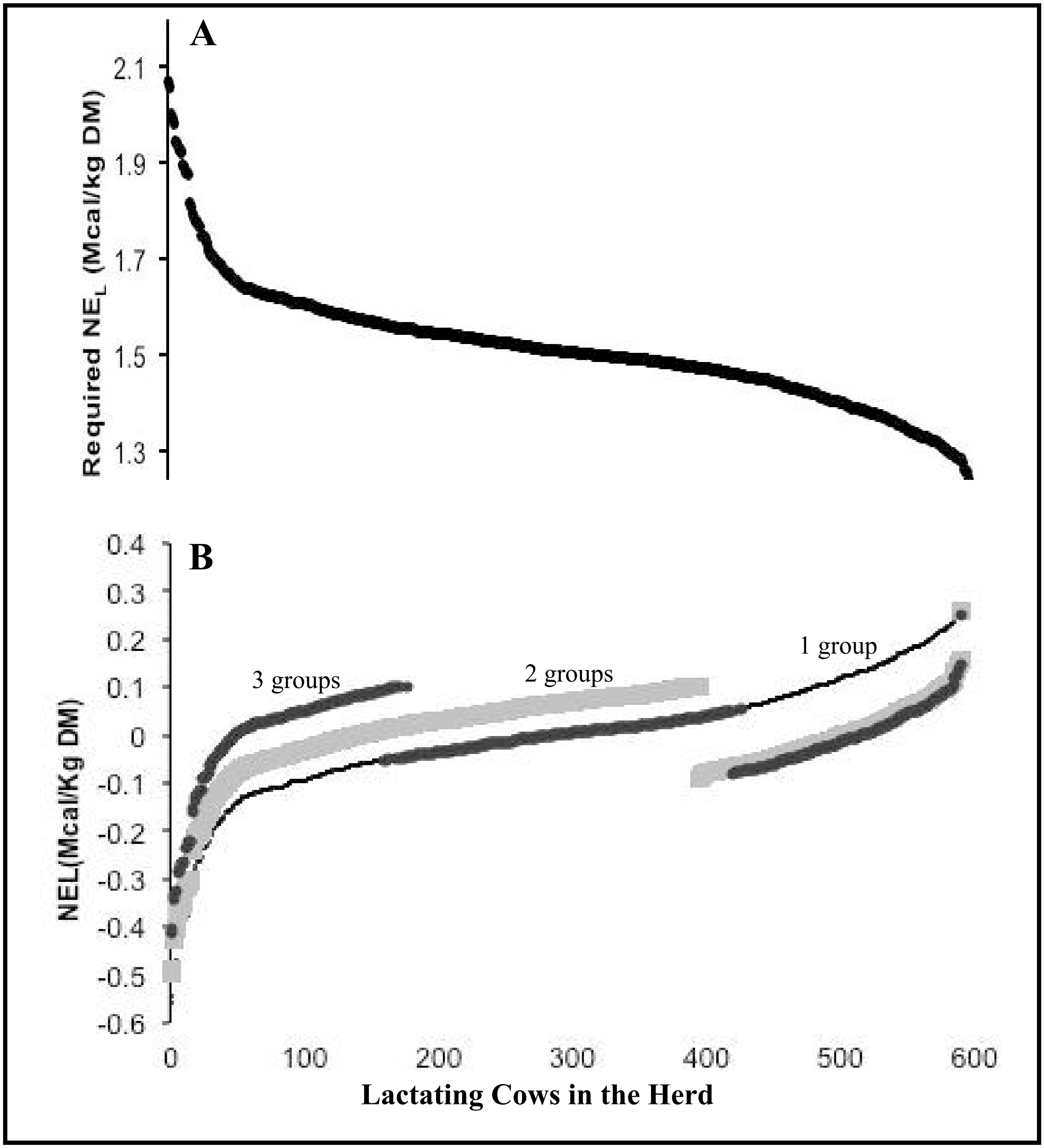

Figure 1. Nutrient NE_L required and provided to 592 post-fresh lactating cows from the 787-cow herd at d=300 in simulation. A) NE_L concentration of the requirements. B) Difference between provided and required NE_L concentration (offered NE_L – required NE_L, Mcal/kg) under 1, 2, and 3 nutritional groups based on the diet offered at the average NE_L concentration of the group.

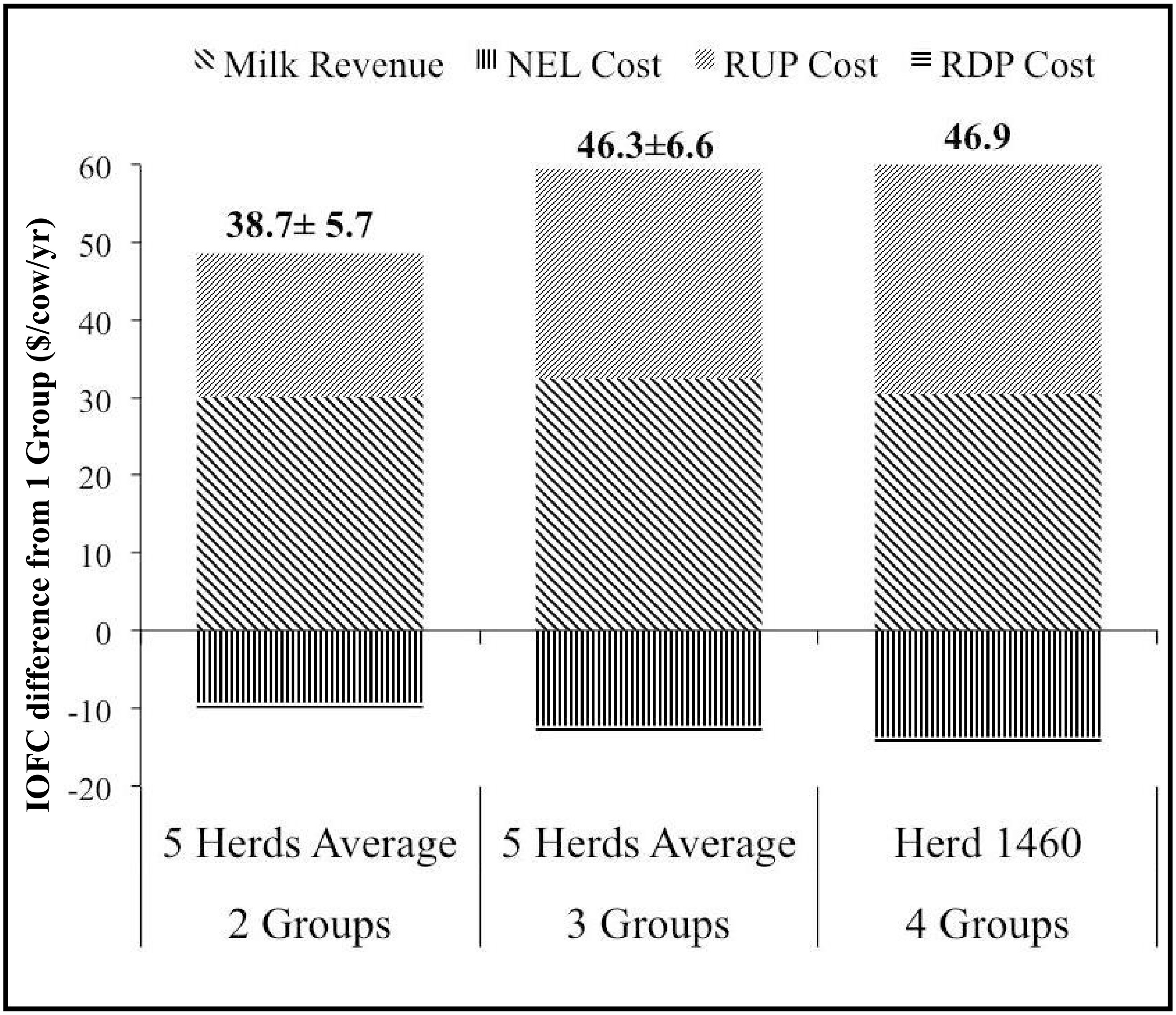

Figure 2. Difference in income over feed cost (IOFC) of 2, 3, and 4 nutritional groups and 1 nutritional group disaggregated in its components: cost of rumen degradable protein (RDP), cost of rumen undegradable protein (RUP), cost of NEL, and milk revenue. The zero line is the average IOFC obtained by 1 group was equal to $2,822 for diet formulated at average MP+1xSD. The labels on top of the bars are the additional IOFC (± SD among the herds) above 1 group. Four nutritional groups were applied only to the largest herd (1,460-cow herd).

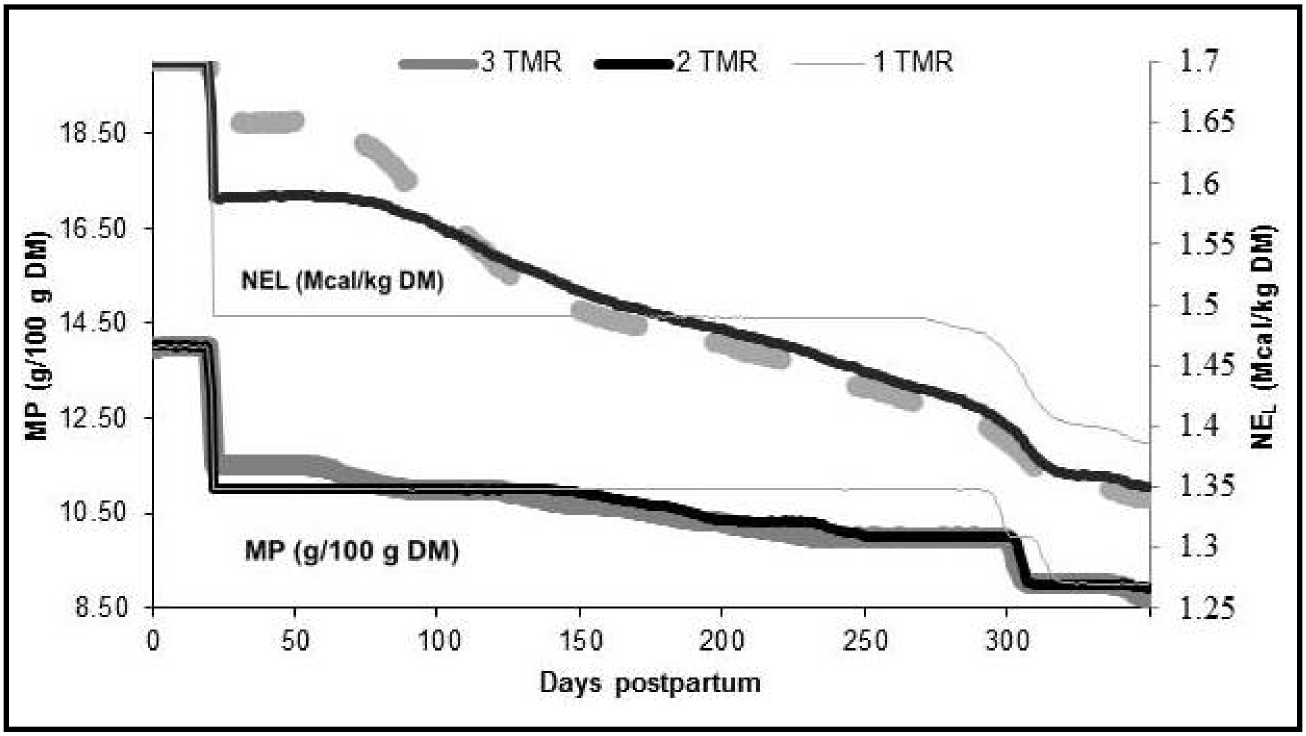

Figure 3. Offered diet average NE_L and metabolizable protein (MP) after calving for the 727-cow herd under different number of nutritional groups.

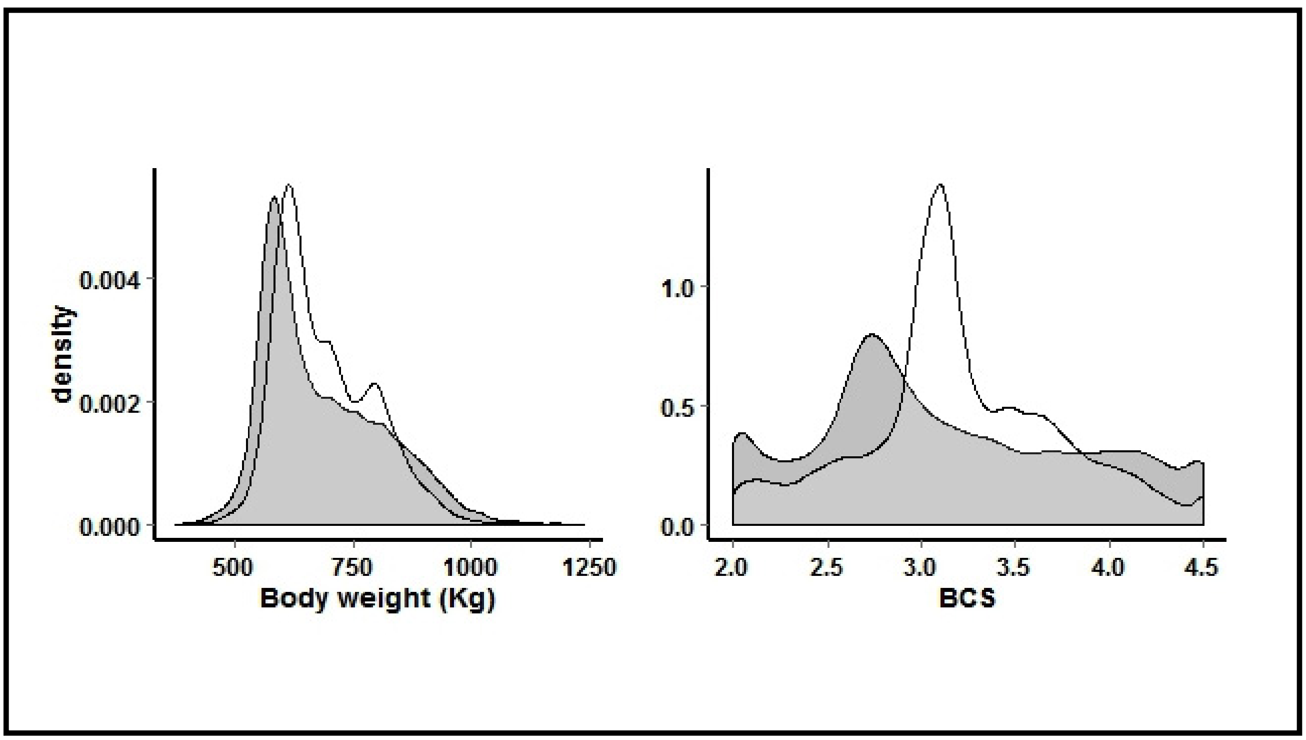

Figure 4. Body weight (left) and BCS (right) density plot from the 787-cow herd for 1 (dark shade) and 3 (light shade) nutritional groups. The BCS average ± SD for 1 and 3 nutritional groups are 3.0±0.7 and 3.25±0.5, respectively. Total area under the curves adds to 1.