Feeding for Success: What Cows Need in Their Feeding Environment

Rick Grant and Mac Campbell
William H. Miner Agricultural Research Institute
Chazy, NY 12921
Email: grant@whminer.com

Introduction

Providing a well-designed feeding environment enhances the cow's response to her diet. Ensuring feed availability is particularly critical - herds that routinely feed for refusals and practice consistent feed push-up average about 1.4 to 4.1 kg/d more milk than herds that do not (Bach et al., 2008). Few management factors elicit that magnitude of milk response; consequently, any assessment of feeding management should begin with feed availability.

When cattle are grouped, competition at the feed bunk is inevitable. Even with unlimited access to feed, cows interact in ways that give some an advantage over others (Olofsson, 1999). Therefore, the goal of feeding management is not to eliminate competition at the feed bunk, but rather to control it. Key factors that must be optimized to encourage desirable feeding behavior and optimal intake of a well-formulated ration include:

- Adequate feed availability and accessibility,
- Competition that doesn't hinder access to feed, and
- No restrictions on resting or ruminating activity.

Feeding, resting, and ruminating behavior are interconnected. A comfortable cow will lie down, on average, 11 to 14 h/d and greater than 90% of rumination will occur while she is lying down. Greater recumbent rumination promotes more saliva production. Cows sacrifice feeding in an effort to recoup lost resting time (Metz, 1985), and a review of published studies found that cows give up approximately one minute of eating time for each 3.5 minutes of lost rest (Grant, 2015). The bottom line is that cows require adequate access to comfortable resting areas in order to optimize their feeding behavior and feed intake.

Based on research and practical on-farm observations, recommended feeding management practices for lactating dairy cows include (Grant, 2016):

- providing consistent feed quality and quantity along the entire length of the feed bunk,
- keeping feed bunk stocking density ≤100% (≥60 cm/cow),
- feeding freshly mixed total mixed ration (TMR) 2x/day,
- ensuring that feed is pushed-up during the 2 hours after feed delivery,
- targeting approximately 3% feed refusals for lactating cow groups except for fresh pen, which should be closer to 7%, and
- making certain that the feed bunk is empty no more than 3 h/d (ideally never empty).

This paper focuses on: 1) recent research conducted at Miner Institute on the influence of stocking density and its interactions with key components of the diet and feeding environment such as fiber and feed restriction; and 2) re-assessing industry norms for design of a feeding environment and management that promotes natural feeding behavior and optimizes dry matter intake. A primary focus will be how overcrowding influences the behavioral, health, and performance responses of lactating dairy cows.

Overstocking and Cow Responses

A primary factor that influences dairy cow feeding behavior and feed intake is stocking density of the feeding and resting resources. Overstocking has become a common occurrence in the US dairy industry. A USDA-NAHMS survey of free-stall dairy farms reported that 58% of farms provided less than 0.60 m/cow of bunk space (i.e., current dairy industry recommendations for feeding space; NFACC, 2009) and 43% provided less than one stall per cow (USDA, 2010). In a survey of the northeastern US, feed bunk stocking density averaged 142% with a range of 58 to 228% (von Keyserlingk et al., 2012). The continued prevalence of overstocking reflects its positive association with profit per stall under certain economic scenarios (De Vries et al., 2016).

Economic analysis suggests that some degree of overstocking may be optimal if the focus is solely on profitability. De Vries et al. (2016) used published data to model the relationships among stocking density (stalls and feed bunk), lying time, and profit ($/stall/year). This economic analysis reported that profit per stall actually was maximized when stocking density was ≥100% in 67% of scenarios and ≥120% in 42% of scenarios of prevailing costs of production and milk price in the US (De Vries et al., 2016). The profitability of overstocking was a function of revenue gained by increasing production per stall, the cost of increasing or decreasing production per cow, variable costs (i.e., costs that vary with changes in milk production), and milk price (De Vries et al., 2016).

However, overstocking compromises the cow's ability to practice natural behaviors (Wechsler, 2007) which is a primary factor related to cow well-being. Overstocking interferes with the cow's ability to engage in normal feeding and resting behaviors, which comprise approximately 70% of the cow's day (Grant and Albright, 2001). Cows place priority on resting when forced to choose among resting, eating, and other behaviors (Metz, 1985; Munksgaard et al., 2005) which suggests that overstocking may limit their ability to meet their daily time budget, defined as 3 to 5 h/d of feeding, 10 to 14 h/d of lying, and 7 to 10 h/d of rumination (Grant and Albright, 2001; Gomez and Cook, 2010). Bach et al. (2008) were able to isolate the effect of management environment on cow performance using 47 dairy farms that were members of the same cooperative and fed the same TMR. Despite similar genetics and the same diet, average herd milk production ranged from 20.6 to 33.8 kg/d. Non-nutritional (i.e., management) factors explained 56% of the variation not attributable to nutrition, and free stall stocking density alone accounted for 32% of the variation among farms.

Higher stocking densities reduce feeding time and increase aggression at the feed bunk (Huzzey et al., 2006), may reduce rumination (Batchelder, 2000) or percentage of rumination occurring in stalls, decrease rumination while recumbent (Krawczel et al., 2012a), and reduce lying time (Fregonesi et al., 2007; Hill et al., 2009; Krawczel et al., 2012b). Overstocking also typically increases rate of feed consumption and meal size (Collings et al., 2011).

Stocking Density as a Sub-Clinical Stressor

The concept of subclinical stressors proposes that the combination of two stressors, such as sub-optimal housing design and poor feeding management, will be greater than either one in isolation. A subclinical stressor depletes the biological resources of the cow without generating a detectable change in function, which leaves the animal without the resources to respond to subsequent stressors (Moberg, 2000).

Subordinate cows may exhibit changes in behaviors that do not always result in clinical or visible outcomes such as lower milk production or altered health status. However, the sub-clinical stressor of stocking density would diminish her effectiveness against additional stressors, placing her in a state of distress. One could view overcrowding as a sub-clinical stressor and poor feed or feeding environment as the secondary stressor.

Recently, we have conducted several studies aimed at assessing the interactions between: 1) stocking density of free stalls and headlocks and 2) dietary physically effective neutral detergent fiber (peNDF) and undigested NDF at 240 hours of in vitro fermentation (uNDF240) or restrictions on feed accessibility.

Miner Institute Research on Overstocking and Physically Effective Fiber

In our first study, forty-eight multiparous and 20 primiparous Holstein cows were assigned to 1 of 4 pens (n = 17 cows per pen). Pens were assigned to treatments in a 4 x 4 Latin square using a 2 x 2 factorial arrangement. Two stocking densities (STKD; 100 or 142%) and 2 diets (straw, S and no straw, NS; Table 1) resulted in 4 treatments (100NS, 100S, 142NS, and 142S). Stocking density was achieved through denial of access to both headlocks and free-stalls (100%, 17 free-stalls and headlocks per pen; 142%, 12 free-stalls and headlocks per pen). Twelve multiparous and 4 primiparous ruminally fistulated cows were used to form 4 focal groups for ruminal fermentation data. Each focal group was balanced for DIM, milk yield, and parity. Ruminal pH was measured using an indwelling ruminal pH measurement system (Penner et al., 2006; LRCpH; Dascor, Escondido, CA) at 1-min intervals for 72 h on days 12, 13, and 14 of each period. Daily ruminal pH measurements were averaged over 10-min intervals. Measurements were then averaged across days and among cows into a pen average for each period.

Diets were similar except that the S diet had a portion of haycrop silage replaced with chopped wheat straw. Each diet was formulated to meet both ME and MP requirements. The TMR was mixed and delivered once daily at approximately 0600 h and pushed up approximately 6 times daily to ensure continuous feed availability. The diets were designed to differ meaningfully in peNDF) and uNDF measured at 30, 120, and 240 h of in vitro fermentation. Otherwise, the two diets were similar in analyzed chemical composition.

Ruminal pH results are presented in Table 2. As expected, increasing the peNDF content of the diet reduced the time spent below pH 5.8 ($P = 0.01$) as well as decreasing the severity of sub-acute ruminal acidosis (SARA) as observed through a reduction in area under the curve below pH 5.8 ($P = 0.03$). Higher stocking density increased time spent below pH 5.8 ($P < 0.01$) and tended to increase the severity of SARA ($P = 0.06$).

Furthermore, there was a trend for an interaction between stocking density and diet, indicating greater SARA when cows were housed at higher stocking density and fed the lower fiber diet. Importantly, greater stocking density had a larger effect on ruminal pH than changes to the diet, with a 1.4-h difference between 100 and 142% stocking density but only a 0.9-h difference between diets. Reductions in SARA through the addition of straw was observed at both stocking densities (0.4-h difference at 100% and 1.4-h difference at 142%), although there seemed to be greater benefit of boosting dietary peNDF or uNDF at the higher stocking density.

Eating time (238 min/d, SEM=4) and rumination time (493 min/d, SEM=9) did not differ among treatments (*P* > 0.10; Table 3). However, rumination within a free-stall as a percentage of total rumination decreased at higher stocking density. As resting and rumination are significant contributors to buffer production (Maekawa et al., 2002b), it is possible that this shift in the location of rumination may affect the volume or rate of buffer production, partially explaining the increased risk of SARA at higher stocking densities. Ruminal pH differences between diets are likely explained by increased buffer volume produced during eating and rumination for the straw diets as evidenced by Maekawa et al. (2002a) where increases in the fiber-to-concentrate ratio resulted in increased total daily saliva production.

Higher stocking density increased the latency to consume fresh feed; i.e., it took cows longer to approach the bunk and initiate eating with higher stocking density. Additionally, higher stocking density reduced lying time, but boosted the time spent lying while in a stall indicating greater stall-use efficiency. Overall, time spent standing in alleys increased markedly with overstocking.

Miner Institute Research on Overstocking and Reduced Feed Access

Nutrition models calculate nutrient requirements assuming that cows have ad libitum access to feed and are not overstocked. The reality is that many of the dairy cows in the US are fed under overstocked conditions – and increasingly farmers are feeding for lower amounts of daily feed refusals in an effort to minimize wastage of expensive feed. Consequently, we need to understand the interaction of stocking density and feed availability or restrictions on ruminal pH, behavior, and productive efficiency.

Using cows and a design similar to the previous study, two STKD (100 or 142%) were assessed. In experiment 2, we evaluated two levels of feed restriction (0 h or no restriction; NR) and 5 h of feed restriction (R) that resulted in 4 treatments (100NR, 100R, 142NR, and 142R). Feed restriction was achieved by pulling feed away from headlocks approximately 5 h before the morning feeding. Previous research has shown that blocking access to the feed bunk for 5 to 6 h/d mimics so-called "clean bunk" management (French et al., 2005).

The effect of stocking density and feed access on ruminal pH characteristics is shown in Table 4. Higher stocking density, as in experiment 1, increased risk for SARA with greater time spent below pH 5.8 (*P* = 0.02) and tended to increase severity (*P* = 0.09). While there were no differences in ruminal pH responses for the feed access treatment, there was a significant interaction between stocking density and feed access (*P* = 0.02), indicating an exacerbated risk for SARA when cows were housed at higher stocking density and had restricted access to feed. Compared to experiment 1, feed access when isolated did not have as great an impact on ruminal pH compared to differences in fiber levels of the diet. However, when combined with high stocking density, reduced feed access had a greater impact than the low fiber diets. The implications of these results on commercial dairy farms where overstocking and feeding to low levels of feed refusals is commonly practiced need to be better appreciated.

The bottom line is that overcrowding and feed restriction and the resulting negative effect on rumen conditions may well interfere with the cow's ability to respond to otherwise well-formulated rations.

Food for Thought: Re-Assessing Industry Feeding Management Norms

Several recommendations for facility design and management have become dairy industry norms – for instance providing 60 cm (or 24 in) of manger space per cow. A stocking density at the feed bunk of 100% commonly refers to providing 60 cm/cow. The goal of this section of the paper is evaluate what research tells us regarding the adequacy of common industry guidelines for feeding management.

Competition for feed. Cows have a naturally aggressive feeding drive and exert up to 226 kg of force against the feed barrier as they reach for feed (Hansen and Pallesen, 1998). To put this in perspective, 102 kg of force causes tissue bruising. Cows will injure themselves in an attempt to eat if we do not properly manage the feeding system to ensure feed accessibility. Even more importantly, a feeding environment that chronically frustrates a cow's drive to access feed may train her over time to become a less aggressive feeder (Grant and Albright, 2001).

Are 60 cm (24 in) of bunk space per cow - the industry standard - sufficient from the cow's perspective? A study by Rioja-Lang et al. (2012) addressed this question by providing subordinate cows with a choice: they could choose to eat a low palatability feed alone or they could choose a high palatability feed that came with a dominant cow located either 20, 45, 60, or 76 cm away. When feeding space was highly restricted (i.e., 20 or 45 cm) most subordinate cows chose to eat the low palatability feed alone. But, even with 60 or 76 cm of feed space about 40% of subordinate cows still chose to eat alone. This research suggests that some cows will settle for less desirable feed to avoid competition even when bunk space exceeds the current industry standard.

So, a key management question is: are 60 cm/cow of bunk space enough? With this space, cows cannot access feed all together. In fact, research that evaluated 60, 76, or 91 cm/cow of manger space observed less fighting and more feeding as feeding space increased. It seems that, if you ask the cow based on research results, the answer is "no": 60 cm/cow is insufficient for optimal feeding behavior.

Feeding frequency. Delivery of fresh feed stimulates feeding behavior more than return from the parlor or feed push up (DeVries and von Keyserlingk, 2005). In a study that investigated herd-level management and milk production, Sova et al. (2013) found a benefit of twice over once daily feeding with dry matter intake increasing 1.4 kg/d while milk yield increased by 2.0 kg/d. With 2x feeding of a TMR, more feed was available throughout the day and there was less feed sorting. Other research has found that greater feeding frequency of the TMR improves rumen fermentation, enhances rumination, and boosts eating time. The positive response to greater feeding frequency is more noticeable during heat stress conditions (Hart et al., 2014).

However, some research indicates that the positive response to greater feed delivery may diminish at high frequencies, such as 4 or 5 times per day (reviewed by Grant, 2015). In these cases, greater feeding frequency enhances eating time but also reduces resting time by up to 12%. Enhancements in feeding time cannot be at the expense of time spent resting.

Feed push-up. Effective feed push-up strategy is critical for ensuring that feed is within easy reach of the cow and is a function of the number of times per day and when the feed push up occurs. A study conducted at the University of Arizona (Armstrong et al., 2008) evaluated the effect of feed push up each half-hour for the first two hours after feed delivery versus only once per hour.

Greater frequency of feed push up during the two hours after feed delivery resulted in more milk and improved efficiency with no impact on stall resting time (Table 5). The number of times that feed is pushed up throughout the day is important, but this research highlights the critical importance of timing of feed push up. When deciding a feed push up strategy, we need to focus on ensuring that feed is easily within reach of the cow during the highly competitive two hours following feed delivery.

Feed refusals and availability. For competitive feeding situations, each 2%-unit increase in feed refusals is associated with a 1.3% increase in sorting (Sova et al., 2013). Likewise, milk/DMI decreases by 3% for each 1% increase in sorting. Research has found little effect of feed refusal on efficiency of milk production over a fairly wide range of 2.5 to 16% refusals. On farm experience suggests that a refusal target of approximately 3% works well for lactation pens, but fresh pens should be closer to 6 or 7% to ensure that feed availability is never limiting given the important relationship between feed intake and incidence of metabolic disorders.

How long can the feed bunk be empty? The cow's motivation to eat increases markedly after only 3 h without feed (Schutz et al., 2006). In addition, when feed access time was restricted by 10 hours per day, from 8:00 pm to 6:00 am, feed intake was reduced by 1.6 kg/d coinciding with twice as many displacements at feeding (Collings et al., 2011). When this temporal feed restriction was combined with overcrowding (1:1 or 2:1 cows per feeding bin) there was a 25% increase in feeding rate during the first 2 h after feed delivery (i.e., slug feeding).

So, although a common management goal is to minimize feed wastage, empty bunks are counterproductive and time when the feed bunk is functionally empty needs to carefully managed. Ideally, feed should always be within easy reach of the cow, but certainly no more than 3 h/d based on the very little published research.

Conclusions

Stocking density exhibited a consistent negative effect on rumen pH and increased the risk for SARA. The presence of additional stressors in combination with stocking density exacerbated these negative effects on rumen pH, although the magnitude varied depending on the type of stressor. Manipulation of the feeding environment can help mitigate the negative effects of stocking density, such as increasing peNDF or uNDF240 in the diet or minimizing time without access to feed. In contrast, the combination of overcrowding and feed restriction can have profound negative consequences for rumen pH.

As new information is published we need to continually re-assess our feeding management recommendations. If we ask the cow for her opinion using well-designed studies and field observations, we will design optimal feeding environments that promote natural behaviors and optimize feed intake.

References

Armstrong, D. V., T. R. Bilby, V. Wuthironarith, W. Sathonghorn, and S. Rungruang. 2008. Effect of different feed push-up schedule on milk production, feed intake and behavior in Holstein dairy cows. J. Anim. Sci. 86:253 (Abstr.).

Bach, A., N. Valls, A. Solans, and T. Torrent. 2008. Associations between nondietary factors and dairy herd performance. J. Dairy Sci. 91:3259-3267.

Batchelder, T. L. 2000. The impact of head gates and overcrowding on production and behavior patterns of lactating dairy cows. In Dairy Housing and Equipment Systems. Managing and Planning for Profitability. Natural Resource, Agriculture, and Engineering Service Publ. 129. Camp Hill, PA.

Collings, L.K.M., D. M. Weary, N. Chapinal, and M.A.G. von Keyserlingk. 2011. Temporal feed restriction and overstocking increase competition for feed by dairy cattle. J. Dairy Sci. 94:5480-5486.

De Vries, A., H. Dechassa, and H. Hogeveen. 2016. Economic evaluation of stall stocking density of lactating dairy cows. J. Dairy Sci. 99:3848-3857.

Fregonesi, J. A., C. B. Tucker, and D. M. Weary. 2007. Overstocking reduces lying time in dairy cows. J. Dairy Sci. 90:3349-3354.

French, P., J. Chamberlain, and J. Warntjes. 2005. Effect of feed refusal amount on feeding behavior and production in Holstein cows. J. Anim. Sci. 83 (E-Suppl.1): 175(Abstr.)

Goering, H. K. and P. J. Van Soest. 1970. Forage analyses. Agriculture Handbook 379. Agric. Res. Serv. U.S. Dept. of Agriculture.

Gomez, A., and N. B. Cook. 2010. Time budgets of lactating dairy cattle in commercial freestall herds. J. Dairy Sci. 93:5772-5781.

Grant, R. J. 2015. Economic benefits of improved cow comfort. Available on line at: http://www.dairychallenge.org/pdfs/2015_National/resources/Novus_Economic_Benefits_of_Improved_Cow_Comfort_April_2015.pdf

Grant, 2016. Determining optimal feeding environment for dairy cattle. Feedstuffs. vol. 88. no. 4. April 4, 2016.

Grant, R. J., and J. L. Albright. 2001. Effect of animal grouping on feeding behavior and intake of cattle. J. Dairy Sci. 84(E-Suppl.):E156-E163.

Hansen, K., and C. N. Pallesen. 1998. Dairy cow pressure on self-locking feed barriers at different positions. Pages 312-319 in Proc. Fourth Intern. Dairy Housing Conf., St. Louis, MO. Amer. Soc. Agric. Engin.

Hart, K. D., B. W. McBride, T. F. Duffield, and T. J. DeVries. 2014. Effect of frequency of feed delivery on the behavior and productivity of lactating dairy cows. J. Dairy Sci. 97:1713-1724.

Huzzey, J. M., T. J. DeVries, P. Valois, and M.A.G. von Keyserlingk. 2006. Stocking density and feed barrier design affect the feeding and social behavior of dairy cattle. J. Dairy Sci. 89:126-133.

Krawczel, P. D., C. S. Mooney, H. M. Dann, M. P. Carter, R. E. Butzler, C. S. Ballard, and R. J. Grant. 2012a. Effect of alternative models for increasing stocking density on the short-term behavior and hygiene of Holstein dairy cows. J. Dairy Sci. 95:2467-2475.

Krawczel, P. D., L. B. Klaiber, R. E. Butzler, L. M. Klaiber, H. M. Dann, C. S. Mooney, and R. J. Grant. 2012b. Short-term increases in stocking density affect the lying and social behavior, but not the productivity, of lactating Holstein dairy cows. J. Dairy Sci. 95:4298-4308.

Maekawa, M., K. A. Beauchemin, and D. A. Christensen. 2002a. Effect of concentrate level and feeding management on chewing activities, saliva production, and ruminal pH of lactating dairy cows. J. Dairy Sci. 85:1165-1175.

Maekawa, M., K. A. Beauchemin, and D. A. Christensen. 2002b. Chewing activity, saliva production, and ruminal pH of primiparous and multiparous lactating dairy cows. J. Dairy Sci. 85:1176-1182.

Mertens, D.R. 2002. Physical and chemical characteristics of fiber affecting dairy cow performance. Proc. 2002 Cornell Nutrition Conf., Dept. Anim. Sci., Cornell Univ., Ithaca, NY. pp. 125-144.

Metz, J. H. M. 1985. The reaction of cows to a short-term deprivation of lying. Appl. Anim. Behav. Sci. 13:301–307.

Mitlöhner, F. M., J. L. Morrow-Tesch, S. C. Wilson, J. W. Dailey, and J. J. McGlone. 2001. Behavioral sampling techniques for feedlot cattle. J. Anim. Sci. 79:1189–1193.

Moberg, G. P. 2000. Biological response to stress: implications for animal welfare. In: Moberg, G. P. and J. A. Mench (eds) The Biology of Animal Stress. CAB. International, Wallingford, UK, pp. 1-21.

Munksgaard, L., M. B. Jensen, L. J. Pedersen, S. W. Hansen, and L. Matthews. 2005. Quantifying behavioural priorities – Effects of time constraints on

behavior of dairy cows, Bos Taurus. Appl. Anim. Behav. Sci. 92:3-14.
NFACC. 2009. Code of practice for the care and handling of dairy cattle. Dairy Farmers of Canada and the National Farm Animal Care Council, Ottawa, Ontario, Canada.
Olofsson, J. 1999. Competition for total mixed diets fed for ad libitum intake using one or four cows per feeding station. J. Dairy Sci. 82:69-79.
Penner, G. B., K. A. Beauchemin, and T. Mutsvangwa. 2006. An evaluation of the accuracy and precision of a stand-alone submersible continuous ruminal pH measurement system. J. Dairy Sci. 89:2132-2140.
Rioja-Lang, F. C., D. J. Roberts, S. D. Healy, A. B. Lawrence, and M. J. Haskell. 2012. Dairy cow feeding space requirements assessed in a Y-maze choice test. J. Dairy Sci.; 95:3954-3960.
Sova, A. D., S. J. LeBlanc, B. W. McBride, and T. J. DeVries. 2013. Associations between herd-level feeding management practices, feed sorting, and milk production in freestall dairy farms. J. Dairy Sci. 96:4759-4770.
Schutz, K., D. Davison, and L. Matthews. 2006. Do different levels of moderate feed deprivation in dairy cows affect feeding motivation? Appl. Anim. Behav. Sci. 101:253-263.
Tilley, J. M. A. and R. A. Terry. 1963. A two-stage technique for the in vitro digestion of forage crops. Grass and Forage Sci. 18:104-111.
USDA. 2010. Facility characteristics and cow comfort on U.S. dairy operations, 2007. US Dept. Agric.-Anim. Plant Health Insp. Serv.-Vet. Serv., Cent. Epidemiol. Anim. Health, Fort Collins, CO.
Von Keyserlingk, M.A.G., A. Barrientos, K. Ito, E. Galo, and D. M. Weary. 2012. Benchmarking cow comfort on North American freestall dairies: lameness, leg injuries, lying time, facility design, and management for high-producing Holstein dairy cows. J. Dairy Sci. 95:1-10.
Wechsler, B. 2007. Normal behavior as a basis for animal welfare assessment. Anim. Welfare 16:107-110.

Table 1. Ingredient composition and analyzed chemical composition (dry matter basis) of TMR samples for NS (No Straw) and S (Straw) experimental diets.

	NS	S
Ingredient, % of DM		
Conventional corn silage	39.72	39.73
Haycrop silage	6.91	2.33
Wheat straw, chopped	---	3.45
Citrus pulp, dry	4.82	4.82
Whole cottonseed, linted	3.45	3.45
Soybean meal, 47.5% solvent	---	1.12
Molasses	3.20	3.20
Concentrate mix	41.89	41.88
Chemical composition		
CP, % of DM	15.0	15.1
NDF, % of DM	30.8	30.1
Acid detergent lignin, % of DM	3.8	3.8
Starch, % of DM	25.0	25.5
Sugar, % of DM	7.4	8.1
Ether extract, % of DM	5.9	5.7
7-h starch digestibility, % of starch	73.3	74.3
Physically effective $NDF_{1.18\text{-mm}}$, % of DM[1]	23.9	25.9
30-h uNDFom, % of DM[2]	13.1	14.9
120-h uNDFom, % of DM[2]	9.0	10.2
240-h uNDFom, % of DM[2]	8.5	9.7

[1]peNDF determined with method described by Mertens (2002).
[2]undigested NDF determined with method described by Tilley and Terry (1963) with modifications (Goering and Van Soest, 1970).

Table 2. Rumen pH responses to diets containing straw (S) or no straw (NS) fed at 100 or 142% stocking density (STKD).

	100%		142%			*P*-value		
Variable	NS	S	NS	S	SEM	STKD	Diet	STKD x Diet
Mean pH	6.17	6.13	6.09	6.10	0.03	0.07	0.62	0.39
Minimum pH	5.70	5.67	5.62	5.59	0.05	0.11	0.53	0.95
Maximum pH	6.63	6.58	6.56	6.53	0.04	0.07	0.22	0.68
Time pH < 5.8, h/d	2.29	1.90	4.12	2.77	0.41	<0.01	0.01	0.10
AUC < 5.8 pH, pH x unit[1]	0.38	0.19	0.58	0.34	0.10	0.06	0.03	0.75

[1]¬Area under the curve.

Table 3. Behavioral responses for cows fed diets containing straw (S) or no straw (NS) at 100 or 142% stocking density (STKD).

	100%		142%			*P*-value		
	NS	S	NS	S	SEM	STKD	Diet	STKD x Diet
Eating time, min/d	233	237	242	240	4	0.13	0.76	0.48
Eating time/kg NDF, min	31.0	28.7	34.1	30.0	1.3	0.04	0.01	0.35
Eating, bouts/d	6.8	6.7	7.0	6.9	0.1	0.60	0.11	0.64
Meal length, min/meal	34.8	36.4	35.6	37.0	0.9	0.43	0.11	0.90
Eating latency for fresh feed, min	20	28	39	40	4	0.02	0.35	0.46
Length of first meal, min	39	43	41	44	2	0.23	0.02	0.66
Rumination time, min/d	498	491	489	496	9.0	0.72	0.96	0.19
Rumination time/kg NDF, min	65.8	59.4	68.0	61.8	2.2	0.21	<0.01	0.95
Rumination within stall, % of total	86.2	86.0	80.5	81.1	<0.1	<0.01	0.96	0.60
Lying time, min/d	832	827	779	797	11	<0.01	0.56	0.31
Lying time within stall, % of use	89.7	89.9	91.7	92.8	<0.01	0.01	0.39	0.50
Time spent in alley, min/d	121	125	192	181	9	<0.01	0.65	0.37

Table 4. Rumen pH responses as influenced by stocking density (STKD) and feed restriction (FR; no restriction, NR; 5-h restriction, R).

	100%		142%			*P*-value		
Variable	NR	R	NR	R	SEM	STKD	FR	STKD x FR
Mean pH	5.96	6.03	5.98	5.89	0.06	0.14	0.80	0.08
Minimum pH	5.42	5.50	5.51	5.39	0.07	0.81	0.78	0.12
Maximum pH	6.49	6.61	6.48	6.53	0.04	0.25	0.06	0.29
Time pH < 5.8, h/d	6.62	5.23	6.78	8.77	1.27	0.02	0.49	0.02
AUC < 5.8 pH, pH x unit[1]	1.66	1.24	1.73	2.55	0.63	0.09	0.52	0.11

[1]¬Area under the curve.

Table 5. Greater feed push up in hours after feed delivery improves dairy efficiency.

Cow response	1 time/hour	2 times/hour
Dry matter intake, kg/d	18.8	18.2
Milk, kg/d	27.9[b]	29.7[a]
Milk/DMI, kg/kg	1.48[b]	1.63[a]
Lying in stall, % of cows	45.3	43.8

[ab]Means within row differ ($P < 0.05$).