

Feeding Management: Dietary Characteristics, Feeding Environment, and Dairy Cow Feeding Behavior

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Introduction

Providing an optimal 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 response, and 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). Consequently, the management goal 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.

In addition, based on research to-date and practical on-farm observations, recommended feeding management practices include (Grant, 2016): 1) providing consistent feed quality and quantity along the entire length of the feed bunk, 2) keeping bunk stocking density $\leq 100\%$ (≥ 60 cm/cow), 3) feeding total mixed ration (**TMR**) 2x/day, 4) ensuring that feed is pushed-up during the 2 hours after feed delivery, 5) targeting approximately 3% feed refusals for cow groups except for fresh pen, which should be closer to 7%, and 6) making certain that the feed bunk is empty no more than 3 h/d (ideally never).

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, and 2) re-assessing industry norms for feeding management.

Overstocking and Cow Responses

A primary factor that influences feeding behavior and feed intake is stocking density. Overstocking is a common occurrence in the US dairy industry. A USDA-

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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 association with maximizing profit per stall (De Vries et al., 2016).

Current 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 around 120% stocking density for prevailing costs of production and milk price in the US. 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 reduces 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 practice 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. The housing environment explained 56% of this variation and free stall stocking density accounted for 32% of the variation among farms by itself.

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

Stocking Density as a Subclinical Stressor

The concept of subclinical stressors suggests that the summation of two stressors, such as housing and feeding management, will be greater than either in isolation. A subclinical stressor depletes the animal's biological resources without generating a detectable change in function, which leaves the animal without the resources to respond to subsequent stressors (Moberg, 2000). Therefore, subordinate animals 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 subclinical stressor of

stocking density would diminish her effectiveness against additional stressors, placing her in a state of distress. Additional stressors are likely to occur due to constant changes in feeding and cow management.

Experiment 1. 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 with 14-d periods 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). Pen served as the experimental unit.

Diets were similar except that the S diet had a portion of haycrop silage replaced with chopped wheat straw and soybean meal. 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. The diets were designed to differ meaningfully in physically effective neutral detergent fiber (**peNDF**) and undigested NDF (**uNDF**) measured at 30, 120, and 240 h of *in vitro* fermentation. Otherwise, the two diets were similar in analyzed chemical composition.

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

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 subacute 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.

Cows were milked 3 times daily and milk yields were recorded electronically on d 8 to 14 of each period. Milk samples were collected across 6 consecutive milkings for each cow on d 13 and 14 of each period and analyzed for composition. Ingestive, rumination, and lying behavior as well as the location (feed bunk, stall, alley, standing or lying) of these performed behaviors were assessed on all cows using 72-h direct observation at 10-min intervals (Mitlöhner et al., 2001) on d 8, 9, and 10 of each period.

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.

There were no differences in DM intake among treatments, although as expected the straw diet increased both peNDF and uNDF_{om240} intake. Changes in milk production were small, which would be expected given the short periods (14-d) used in this study (Table 4).

Experiment 2. 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 the majority of 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 on ruminal pH, behavior, and productive efficiency.

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 with 14-d periods using a 2 x 2 factorial arrangement. As in experiment 1, two STKD (100 or 142%) were used. In experiment 2, we evaluated 2 levels of feed restriction (0-h or no restriction; **NR**) and 5-h of feed restriction (**FR**) that resulted in 4 treatments (100NR, 100FR, 142NR, and 142FR). As in experiment 1, 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) and pen served as the experimental unit.

Feed access was achieved through pulling feed away from headlocks approximately 5 h before the next 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). Sixteen multiparous ruminally fistulated cows were used to form 4 focal groups for ruminal fermentation data. Each focal group was balanced for days in milk, milk yield, and parity.

The effect of stocking density and feed access on ruminal pH characteristics is shown in Table 5. 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 understood.

Food for Thought. Re-Assessing Industry Feeding Management Norms

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 24 in (60 cm) 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 restrictive (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 implies that some cows will settle for less desirable feed to avoid competition even when bunk space exceeds the current industry standard.

Feeding frequency. Delivery of fresh feed stimulates feeding behavior more than return from the parlor or feed push up. 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 should not 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 6). 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.

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 is restricted by 10 hours per day, from 8:00 pm to 6:00 am, feed intake is reduced by 1.6 kg/d coinciding with twice as many displacements at feeding (Collings et al., 2011). When this temporal feed restriction is combined with overcrowding (1:1 or 2:1 cows per feeding bin) there is a 25% increase in feeding rate during the first 2 h after feed delivery (i.e., slug feeding).

Conclusions

Stocking density exhibited a consistent negative effect on ruminal pH and increased the risk for SARA. The presence of additional stressors in combination with

stocking density exacerbated these negative effects on ruminal 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 uNDF240om in the diet or minimizing time without access to feed.

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. Recommended feeding management based on the latest research includes:

- Management that enhances rest and rumination
- Feed available on demand
- Consistent feed quality and quantity along the length of the bunk
- Bunk stocking density $\leq 100\%$ (≥ 60 cm/cow)
- Feed push up focused on 2 hours after feed delivery
- About 3% feed refusal target
- Bunk empty no more than 3 h/d (ideally never)

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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	SEM ¹
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	0.3
NDF, % of DM	30.8	30.1	0.4
Acid detergent lignin, % of DM	3.8	3.8	0.1
Starch, % of DM	25.0	25.5	0.5
Sugar, % of DM	7.4	8.1	0.4
Ether extract, % of DM	5.9	5.7	0.1
7-h starch digestibility, % of starch	73.3	74.3	0.9
Physically effective NDF _{1.18-mm} , % of DM ²	23.9	25.9	0.7
30-h uNDFom, % of DM ³	13.1	14.9	0.3
120-h uNDFom, % of DM ³	9.0	10.2	0.2
240-h uNDFom, % of DM ³	8.5	9.7	0.2

¹ SEM = Standard error of the mean.

² peNDF determined with method described by Mertens (2002).

³ Undigested NDF determined with method described by Tilley and Terry (1963) with modifications (Goering and Van Soest, 1970).

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

Variable	100%		142%		SEM ¹	<i>P</i> -value		
	NS	S	NS	S		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 ²	0.38	0.19	0.58	0.34	0.10	0.06	0.03	0.75

¹ SEM = standard error of the mean.

² Area under the curve (pH x unit).

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

Item	100%		142%		SEM ¹	P-value		
	NS	S	NS	S		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 time/kg peNDF, min	37.8	35.1	41.3	36.4	1.7	0.11	0.03	0.44
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 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								
Total, min/d	498	491	489	496	9.0	0.72	0.96	0.19
Per kg NDF, min	65.8	59.4	68.0	61.8	2.2	0.21	<0.0	0.95
Per kg peNDF, min	80.3	72.6	82.4	75.0	3.1	0.39	0.02	0.95
Ruminating in 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 within stall, % of use	89.7	89.9	91.7	92.8	<0.01	0.01	0.39	0.50
Time in alley, min/d	121	125	192	181	9	<0.01	0.65	0.37

¹ SEM = standard error of the mean.

Table 4. Short term (14-d periods) feed intake and milk yield as influenced by stocking density (STKD) and diets containing straw (S) or no straw (NS)

Item	100%		142%		SEM ¹	P-value		
	NS	S	NS	S		STKD	Diet	STKD x Diet
Intake responses								
DM, kg/d	25.4	25.3	25.3	25.2	0.4	0.78	0.69	0.87
NDF, kg/d	7.5	8.3	7.2	8.0	0.3	0.23	<0.01	0.91
peNDF, kg/d	6.2	6.8	6.0	6.6	0.3	0.42	0.02	0.95
uNDF _{om240} , kg/d	2.2	2.5	2.1	2.5	0.1	0.50	<0.01	0.22
Lactational responses								
Milk, kg/d	41.2	40.4	40.7	40.0	0.7	0.21	0.06	0.79
SCM, ² kg/d	42.6	42.4	42.7	41.5	0.8	0.25	0.09	0.23

¹ SEM = standard error of the mean.

² SCM = solids-corrected milk.

Table 5. Ruminal pH responses as influenced by stocking density (STKD) and feed restriction (NR = no restriction; FR = 5 h restriction)

Item	100%		142%		SEM ¹	P-value		
	NR	FR	NR	FR		STKD	R ²	STKD x R
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 ³	1.66	1.24	1.73	2.55	0.63	0.09	0.52	0.11

¹ SEM = standard error of the mean.

² R = effect of feed restriction (NR vs. FR).

³ Area under the curve (pH x unit).

Table 6. Greater feed push up in hours after feed delivery improves 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/dry matter intake, kg/kg	1.48 ^b	1.63 ^a
Lying in stall, % of cows	45.3	43.8

^{ab} Means within row differ ($P < 0.05$).

SESSION NOTES