INTERACTIONS BETWEEN THE FEED AND FEEDING ENVIRONMENT

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INTRODUCTION: IMPORTANCE OF FEEDING ENVIRONMENT

The dairy industry continues to sharpen its focus on efficiency of feed use. Providing an optimal feeding environment enhances the cow's response to her diet, in particular ensuring adequate feed availability. For example, 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). Not many management factors elicit this magnitude of production response.

When cattle are grouped, competition at the feed bunk is inevitable. Even with unlimited access to feed, cows will 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 aggressive feeding activity and optimal intake of a well-formulated diet include:

- feed availability and accessibility,
- stocking density that results in a level of competition that doesn't hinder feed access, and
- no restrictions on resting or ruminating activity.

Foremost among the factors that influence feeding behavior and feed intake is stocking density. Overstocking is a too 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 association with maximizing profit per stall (De Vries et al., 2016).

This paper shares recent research conducted at Miner Institute on the influence of stocking density and its interactions with key components of the diet and feeding environment: physically effective and undigested fiber and feed availability. In the future, we intend to explore the interaction of stocking density with feed delivery frequency and push-up strategy. For all of the experiments, the primary focus is on ruminal pH responses and how the interaction of stocking density and feeding environment affect it.

OVERSTOCKING AND ITS EFFECT ON COW RESPONSES

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; Hill et al., 2009; Krawczel et al., 2012b). Overstocking also increases rate of feed consumption and meal size (Collings et al., 2011).

Taken together, it is reasonable to predict that higher stocking density will negatively affect ruminal pH, although this has not been measured to-date.

STOCKING DENSITY AS A SUB-CLINICAL 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, subdominant 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 sub-clinical 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. Understanding the effects of stocking density with additional management stressors such as low-fiber diets or feed restriction are the next steps in alleviating stress and improving the well-being and long-term productive efficiency of lactating dairy cows housed in free-stall barns.

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.

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]Standard error of the means.
[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).

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 NDF (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 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 ($P = 0.06$).

Table 2. Ruminal 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.

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.

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 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 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 time/kg peNDF, min	80.3	72.6	82.4	75.0	3.1	0.39	0.02	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

Eating time (238 min/d, SEM=4) and rumination time (493 min/d, SEM=9) did not differ among treatments ($P > 0.10$). However, rumination within a free-stall as a percent 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 $uNDF_{om}240$ intake. Changes in milk production were small, which would be expected given the short periods (14-d) used in this study.

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).

	100%		142%			*P*-value		
	NS	S	NS	S	SEM	STKD	Diet	STKD x Diet
Intake responses								
DMI, kg/d	25.4	25.3	25.3	25.2	0.4	0.78	0.69	0.87
NDF intake, kg/d	7.5	8.3	7.2	8.0	0.3	0.23	<0.01	0.91
peNDF intake, kg/d	6.2	6.8	6.0	6.6	0.3	0.42	0.02	0.95
$uNDF_{om}240$, 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, kg/d	42.6	42.4	42.7	41.5	0.8	0.25	0.09	0.23

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 stocking densities (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 (R) that resulted in

4 treatments (100NR, 100R, 142NR, and 142R). 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.

Table 5. Ruminal 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.

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.

Further analyses for the experiment are currently underway and include behavioral responses, pen-level feed intake, and lactational performance.

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. However, manipulation of the feeding environment can help mitigate the negative effects of stocking density, such as increasing peNDF in the diet or reducing time without feed.

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