Modeling the Effect of Social Environment on Dry Matter Intake: Time Budget Behaviors and Stocking Density

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Introduction

Nutritional models rely on accurate dry matter intake (DMI), either by measuring or predicting it. Inaccurate DMI predictions can lead to over- and underfeeding of nutrients which translate into lost animal performance and(or) health, inefficiencies in nutrient use, and greater feed costs. Feeding behavior of cattle determines DMI, which is broadly controlled by ruminoreticular fill and chemostatic mechanisms but modulated by the animal's feeding environment (Grant and Albright, 1995). The combination of housing facilities and management routines define the physical and social environment within which cattle consume the feed. Mertens (1994) described these modulatory psychogenic factors and how they influence the animal's behavioral responses to inhibitory or stimulatory factors in the feed or feeding environment separate from the diet's energy or fill value. Social interactions, palatability, and other feed characteristics, as well as learning behavior, are all integral components of psychogenic modulation of DMI (Grant and Albright, 1995). Consequently, actual DMI may be conceptualized as predicted feed intake minus an adjustment for psychogenic factors.

In the future, nutritional models need to incorporate inputs for the feed and feeding environment, such as feeding frequency, stocking density (SD), grouping strategy, and other key psychogenic components to more accurately predict actual DMI. For example, we know that greater stocking density at the feed bunk and free-stall increases aggressive interactions, displacements, and alters meal patterns, rumination, and resting behavior, especially for subordinate cattle (Hill et al., 2009). Currently, research is limited that simultaneously measures feeding and other behavioral responses to the physical and social environment in addition to DMI. Much of the existing data on feeding behavior and DMI were collected using electronic feed bin systems, and it will be a challenge to adapt and apply these data to on-farm systems such as headlocks or post-and-rail feeders.

Previous papers have reviewed the specific influence of cattle grouping and feeding management on feeding behavior and DMI (Grant and Albright, 1995; Grant and Albright, 2001). However, considerable research has occurred since then, particularly for variable stocking density and shorter-term effects on feeding, resting, and rumination behavior. Importantly, these previous reviews did not evaluate the potential importance of resting and feeding behavior and time budgeting as an initial step in DMI prediction and ration formulation. There has been little work on quantifying the management effects on feed intake and creating a mathematical model with these relationships. In order to develop a model that can be used on-farm, we will need to utilize commonly obtained on-farm measures to predict eating time, as it is hard to measure. Therefore, the objective of this research effort was to create a model that accurately quantifies management decisions on DMI.

Model Development

The model is divided into five sections: 1) behavioral time budget, 2) stocking density measurement, 3) eating time prediction, 4) DMI prediction, and 5) physically effective undigested NDF240 (peuNDF240) adjustment to DMI (Figure 1). Four of the model components focus on management and the social environment, while the fifth component takes advantage of a database generated at Miner Institute of studies where forage source, particle size, and digestibility were varied and fed to high producing Holstein cows (Miller et al., 2020). The model was created using Vensim professional version 7.0a (Ventana Systems Inc., Harvard, MA). This model was designed to be used by dairy farmers or consultants who work with dairy farmers to input specific farm variables to assess the effect of management decisions on DMI, milk production, and behavior.

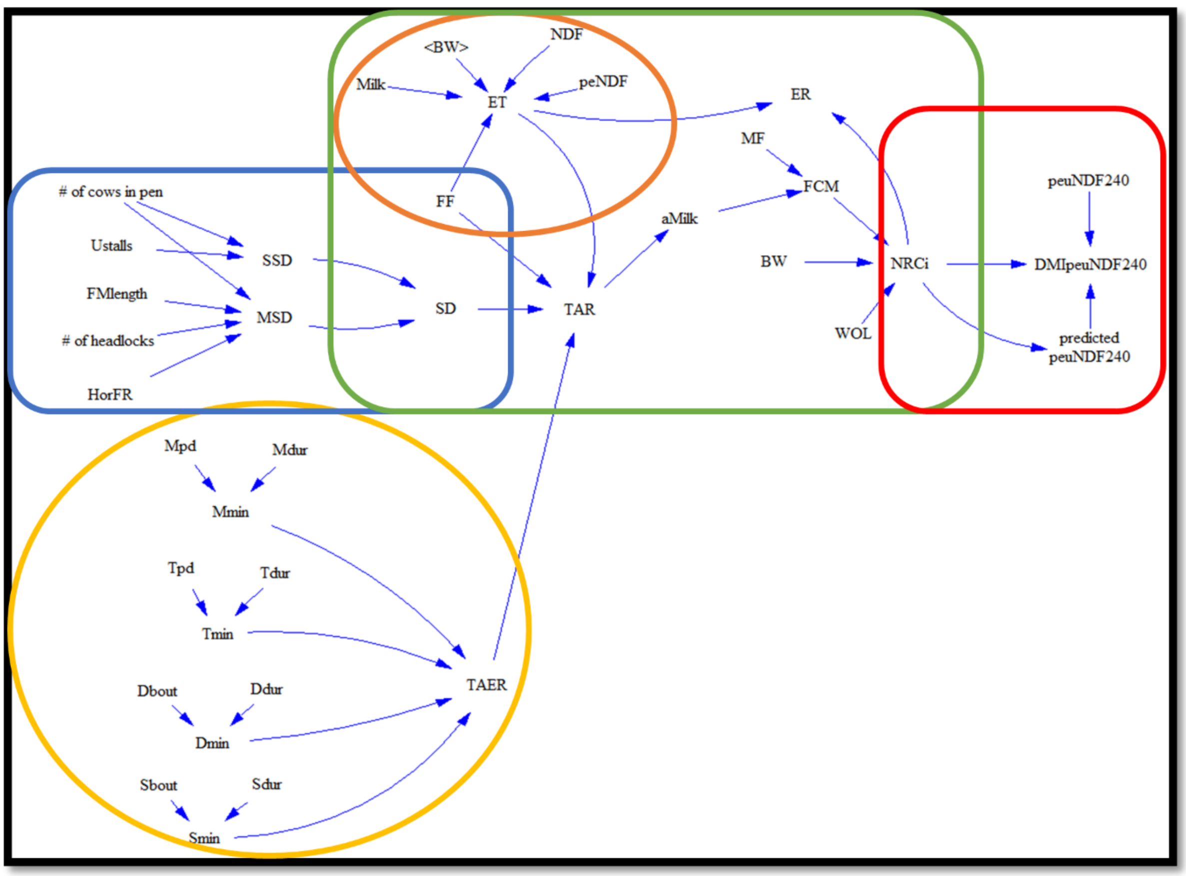

Figure 1. Schematic of the full management model. Yellow circle is the behavioral time budget section; blue rectangle is the stocking density measurement section; orange circle is the eating time prediction section; green rectangle is the DMI prediction section; and red rectangle is the peuNDF240 adjustment to DMI.

The foundation of this model is the behavioral time budget section (Figure 1, yellow circle). This is due to the negative effects that management decisions can have on DMI by not allowing a cow to exhibit her natural behaviors. Grant (2004) reported that a 24-h time budget could be used to describe any deviation from a cow's normal allocation of time to lying, eating, time outside the pen for milking, treatment, drinking, and social interactions. These time durations are intended to be adjusted based on the information for each farm, but it is understandable that not all farms will have this information.

In Figure 1, the section within the blue rectangle allows the calculation of a stocking density using the pen descriptors. The stocking densities are calculated on a free-stall and feed manger basis. The stall stocking density (SSD) is the number of cows in a pen divided by useable stalls (Ustalls) and multiplied by 100. The HorFR variable is used in the manger stocking density variable to choose whether to use the length of feed manger or the number of headlocks based on Friend et al. (1976). The manger stocking density (MSD) for headlocks was calculated as the number of cows in a pen divided by the number of 60-cm headlocks then multiplied by 100. The MSD for feed rails was calculated as the length of the feed rail (FMlength) divided by the number of cows. This was then multiplied by -201.82 and added to 226.37, and this calculation transformed the length of the feed rail per cow into a stocking density based on 100% SD being equal to 0.6 m/cow. Both the SSD and MSD are connected to the SD variable, which selects the largest of the two for the stocking density used for prediction. We decided to use the largest stocking density measurement to represent pens that either have more stalls or manger space; therefore, this approach will account for the resource (stall or manger) with the most competition.

In Figure 1, the eating time prediction is presented within the orange circle. Lying and eating time are the two largest portions of a cow's daily time budget, but they typically cannot be measured easily on-farm. Therefore, it is essential to predict one, so that the other can be calculated by subtraction. In order to allow stocking density to affect lying time, we decided to predict eating time and calculate the lying time. The feeding frequency (FF) variable also influences eating time (ET). If FF was once per day, then there would be no adjustment to ET. If FF was two times per day, then ET would be increased by 3.5%. Finally, if FF was greater than two, then ET would be increased by 10% based on published relationships between frequency of feed delivery and eating time (Philips and Rind, 2001; DeVries et al., 2005; Mantysaari et al., 2006).

In Figure 1, within the green rectangle, the DMI prediction is presented. The time available for rest (TAR) variable was calculated as TAER minus the ET variable. Feeding frequency and SD were used to make an adjustment on TAR. The TAR variable then influenced the adjusted milk (aMilk) variable. We decided to evaluate the relationship between lying time and stocking density and milk yield and built a database using nine studies with 39 treatments (Hill, 2006; Fregonesi et al., 2007; Proudfoot et al., 2009; Krawczel et al., 2012a,b; Winckler et al., 2015; Campbell, 2017). The average SD was 126%, with a minimum of 75% and a maximum of 200%. The DMI and milk yield averaged 22.2 and 40.3 kg/d, respectively. So, in this proposed management model, stocking density affects lying time, which results in an adjustment to the milk yield, which is used to predict DMI. Finally, the NRCi variable is divided by ET and expressed as kg of DM per minute in the eating rate (ER) variable.

In Figure 1, the peuNDF240 adjustment of DMI is presented within the red rectangle. This adjustment was used to account for situations when the dietary peuNDF240 content negatively affects DMI. The NRCi variable was used to predict a peuNDF240 content in the predicted peuNDF240 variable. Then, if this variable was greater than the peuNDF240 variable, the peuNDF240 intake prediction was used in the DMIpeuNDF240 variable.

Data from studies included in the database for eating time, lying time, adjusted milk, and peuNDF240 intake predictions were analyzed using the MEANS procedure of SAS (version 9.4; SAS Institute Inc., Cary, NC), and were reported as descriptive statistics (mean ± standard deviation; minimum and maximum values). Predictions were created using multiple linear regression (MLR) using the REG procedure of SAS. Mean absolute error (MAE) was calculated as the absolute value of actual observation minus predicted value and was used to assess predictive ability.

Results and Discussion

All variable names used in the equations for the management model are described in Table 1, and the equations in the final model are listed in Table 2. To our knowledge, there has been no previous research that has built a mathematical model to capture the effects of stocking density and feeding frequency on behavior and performance of lactating dairy cattle using behavioral time budgeting as the foundation of the model.

In deciding whether to predict lying or eating time, it was essential to understand which behavior had more importance to the cow. Munksgaard et al. (2005) reported that, when cows are limited in access to feed and rest, lying time was prioritized over eating. The cows compensated for the decreased eating time by increased eating rate to maintain DMI (Munksgaard et al., 2005). Since cows can compensate for less time available for eating by increasing their eating rate to maintain DMI, we decided to predict it. In contrast, unfortunately, the cow that is rest-deprived cannot compensate and will be negatively affected.

To assure that the eating time prediction would be applicable on a farm we decided to use measures that are routinely quantified on-farm. The on-farm measures we selected were dietary NDF content, peNDF content, milk yield, and BW. Dado and Allen (1994) and Roseler et al. (1997) reported a positive relationship between milk yield and DMI. This makes sense as the amount of energy intake is one of the main factors that affect milk production. Oba and Allen (2000a,b) reported that cows fed low NDF concentration diets had greater DMI and spent less time eating compared to cows fed high NDF concentration diets. Dado and Allen (1994) also reported a moderate positive correlation between eating time and DMI. Based on previous research, we were confident of variable selection, but needed to create and validate the DMI prediction equation.

Table 1. Description and units of the variables used in equations in the management model.

Variable	Unit	Description
# of cows in pen	n	Number of cows in pen
# of headlocks	n	Number of headlocks for a pen
aMilk	kg	Predicted milk using stocking density with an adjustment for feeding frequency
BW	kg	Average body weight of cows in pen
DMIpeuNDF240	kg	Predicted dry matter intake using physically effective undigested neutral detergent fiber at 240-h
Dbout	n	Number of drinking bouts per day
Ddur	min	Average length of the drinking bouts
Dmin	min	Product of drinking bouts and drinking duration
ER	kg/min	Eating rate based on NRC (2001) DM intake and eating time
ET	min/d	Predicted eating time
FCM	kg/d	4% fat-corrected milk
FF	n	Number of feedings per day
HorFR	1 or 0	Whether the pen has headlocks or feed rail
FMlength	m	Length of feed rail for a pen
MSD	%	Stocking density of manger
Milk	kg/d	Average milk production of a pen
MF	%	Average milk fat content of a pen
Mdur	min	Average length of milking
Mmin	min/d	Product of milking duration and milkings per day
Mpd	n	Number of milkings per day
NDF	% of DM	Neutral detergent fiber content of the diet
NRCi	kg/d	NRC intake prediction
peNDF	% of DM	Physically effective NDF content of the diet
peuNDF240	% of DM	Physically effective undigested NDF at 240 h content of diet
Predicted peuNDF240	% of DM	Predicted physically effective undigested NDF at 240 h content of the diet
Smin	min/d	Product of social bouts and social duration
Sbout	n	Number of social bouts per day
Sdur	min	Average length of social bouts
SSD	%	Stall stocking density of a pen
SD	%	Larger of the stall stocking and manger stocking density
TAER	min/d	Time for eating and resting
TAR	min/d	Resting time with feeding frequency and stocking density adjustment
Tdur	min/d	Product of treatment minutes and treatments per day
Tmin	min	Average length of treatments
Tpd	n	Number of treatments per day
Ustalls	n	Stalls cows can use in a pen
WOL	n	Average week of lactation of the pen

We used six studies of high producing dairy cows fed high and low forage diets containing different sources of forages and varying forage particle sizes to create prediction equations for eating time (Kononoff et al., 2003; Cotanch et al., 2014; Miller et al., 2017; Smith et al., 2018; Coons et al., 2019; Miller et al., 2020). The MLR analysis to predict eating time accounted for 68% of the variance using NDF content, peNDF, BW, and milk yield. A large proportion of the accounted variance for eating time was from the milk yield (37.5%) and NDF content (25.3%). Our results agree with previous research that also found milk and dietary fiber content to be important when predicting DMI (Dado and Allen, 1994; Roseler et al., 1997; Oba and Allen, 2000a,b).

To test the predictive ability of the equation from MLR, we compiled 13 published studies with 50 treatments using lactating Holstein dairy cows that included DMI, milk yield, eating time, BW, NDF content, and peNDF content (Grant et al., 1990; Beauchemin et al., 2003; Yansari, et al., 2004; Yang et al., 2006, Yang et al., 2007; Yang et al., 2009; Hart et al., 2013; Hart et al., 2014; Farmer et al., 2014; Campbell et al., 2015; Crossley et al., 2017; Campbell et al., 2017; Crossley et al., 2018). The mean absolute error (MAE) of eating time was calculated using the prediction equation from MLR using the 13 published studies split into different groups (all, multiparous, primiparous, and mixed). The eating time prediction equation had the best predictive ability for multiparous cows with a MAE of 30 min/d. In contrast, the eating time prediction equation for the other groups had a similar MAE of 41 min/d. To our knowledge, there has not been previous research that attempted to predict eating time using on-farm measures. Our eating time prediction had a good initial predictive ability, with an average MAE of 41 min/d, however, there is a need to continue to improve this prediction.

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Table 2. Equations used in the management model[1].

Variable	Unit	Description
aMilk	kg	0.04065 x TAR + 11.2444
DMIpeuNDF240	kg	IF THEN ELSE(peuNDF240 > predicted peuNDF240, (-0.9798 x peuNDF240)+32.848, NRCi)
ER	kg/min	NRCi / ET
ET	min/d	IF THEN ELSE(FF = 1, (-70.3442 + (BW x -0.3241) + (Milk x 4.04145) + (NDF x 13.2501) + (peNDF x -3.06001)), IF THEN ELSE(FF = 2, 1.035 x (70.3442 + (BW x -0.3241) + (Milk x 4.04145) + (NDF x 13.2501) + (peNDF x -3.06001)), IF THEN ELSE(FF > 3, 1.1 x (-70.3442 + (BW x -0.3241) + (Milk x 4.04145) + (NDF x 13.2501) + (peNDF x -3.06001)), 1)))
FCM	kg/d	(0.4 x aMilk) + (15 x (aMilk x (MF / 100)))
MSD	%	IF THEN ELSE(HorFR = 1, # of cows in pen / # of headlocks x 100, (FMlength / # of cows in pen) x -204.818 + 226.373)
NRCi	kg/d	((0.372 x FCM) + (0.0968 x BW^0.75)) x (1-EXP(-0.192 x (WOL+3.67)))
Predicted peuNDF240	% of DM	-((NRCi - 32.848) / (0.9798))
SSD	%	# of cows in pen / Ustalls x 100
SD	%	MAX(MSD, SSD)
TAER	min/d	1440 - (Dmin + Mmin + Smin + Tmin)
TAR	min/d	IF THEN ELSE(FF > 4, ((-0.00191 x SD + 1.19199) x (TAER - ET)) x 0.88, ((-0.00191 x SD + 1.19199) x (TAER - ET)))

[1]All other variables are as defined in Table 1.

The eating time prediction equation was used in the ET variable. The variable TAR was calculated by subtracting the ET variable from the TAER variable. We then made an adjustment for stocking density and feeding frequency. Stocking density was defined as the number of animals per resource, such as stall or headlock, usually expressed as percent for stalls and meters per cow for manager space. Overstocking is defined as having more animals than resources and has become a common practice on dairy farms (von Keyserlingk et al., 2012). The only variable in the model directly affected by stocking density is TAR, and this decision was based on previous research that described the relationship between stocking density and daily resting time.

Several short-term studies have investigated the effect of overstocking on DMI, and in general there is no effect (Batchelder, 2000; Collings et al., 2011; Krawczel et al., 2012b; Campbell et al., 2015; Wang et al., 2016; Campbell et al., 2017; Crossley et al., 2017). Cows that are overstocked above 130% spent less time lying compared to cows stocked at 100%, and importantly, overstocking did not affect eating time (Fregonesi et al., 2007; Hill et al., 2009; Krawczel et al., 2012b; Campbell et al., 2015; Campbell et al., 2017). The extra time created by reduced resting with overcrowding was not spent eating, but rather standing idle in the alley (Fregonesi et al., 2007; Hill et al., 2009; Krawczel et al., 2012b; Campbell et al., 2015; Campbell et al., 2017). This increased standing time can have negative effects on health such as poor hoof health, greater serum cortisol, and lower growth hormone, which could lead to lower milk production (Munksgaard and Lovendahl, 1993; Singh et al., 1993; Grant, 2004; Cooper et al., 2007). Although overstocking did not affect milk yield, this could be due to the studies being short-term in nature (Krawczel et al., 2012b; Campbell et al., 2015; Campbell et al., 2017; Crossley et al., 2017). There is a need for future overstocking research to focus on the longer-term effects on DMI and milk yield.

Since the previous research did not show a direct relationship between overstocking and DMI, we decided to use the relationship between lying time and stocking density. In Figure 1, we present the relationship between SD and relative response for lying time. The MLR analysis to predict lying time accounted for 76% of the variance using stocking density (Figure 1). Our results agree with Grant (2015), and we were able to account for more variation.

The TAR variable was adjusted by FF as any FF greater than or equal to five times per day may reduce lying time by 12% (Philips and Rind, 2001; DeVries et al., 2005; Mantysaari et al., 2006). There is relatively little published research on feeding frequency and even less on its effect on cow behavior. The TAR variable was adjusted by SD and FF variables and was then used to predict a milk yield in the aMilk variable. Again, we used the database to re-evaluate this relationship. The MLR analysis to predict milk yield accounted for 36% of the variance using lying time (Figure 2). Our results were in agreement with Grant (2015), and we were able to account for more variation. So, we used this revised equation based on our database in the aMilk variable. Unfortunately, there is a limited amount of published data for the effect of overstocking on lying time and lying time on milk yield, which limits our ability to check the predictive ability of our predictions.

The aMilk variable was used to calculate a FCM value which is used in the NRC (2001) DMI prediction in the NRCi variable. The decision to use the Dairy NRC (2001) equation was based on its common use in the dairy industry. The ER variable was calculated using the ET and NRCi variables. As stated earlier, cows that are overstocked will increase their eating rate to maintain DMI, so the ER variable could be used to assess how well the model captures this behavior. There are limited data on eating rate due to the difficulty and cost of measurement. Future research needs to focus on effects of stocking density on chewing behaviors such as eating and ruminating.

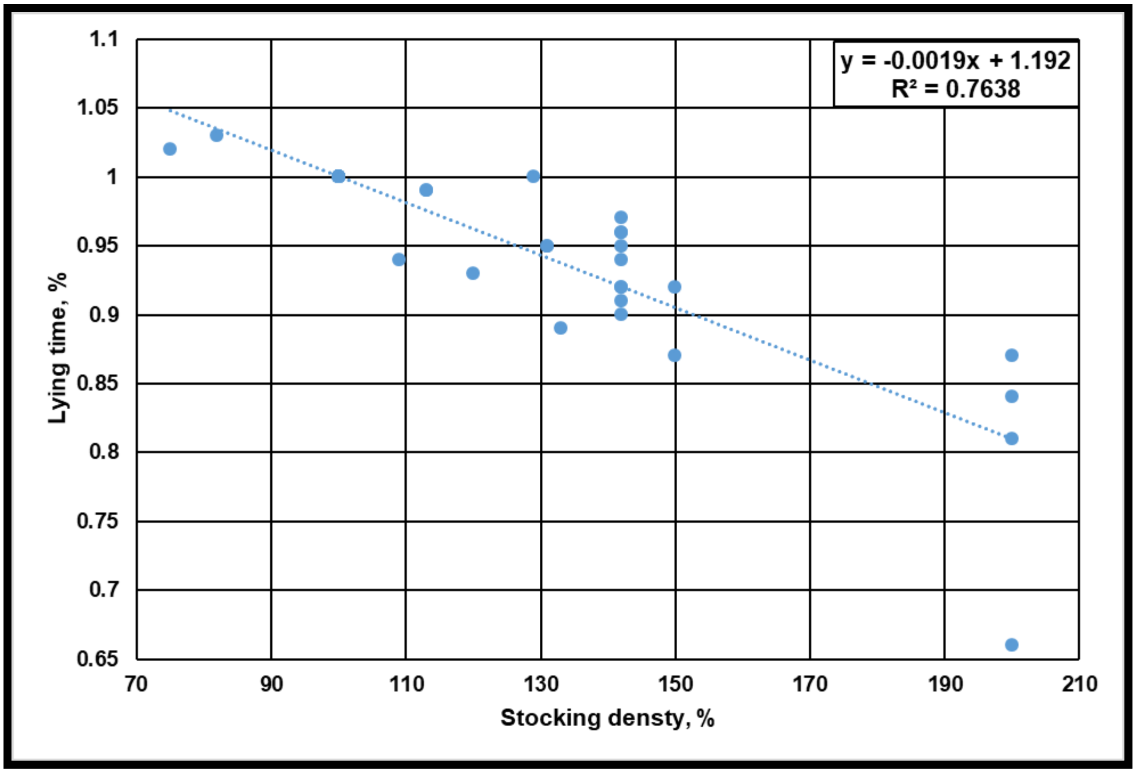

Figure 1. Relationship between stocking density and lying time for management model.

Recent research has focused on fiber characteristics such as particle size and indigestibility and their effects on DMI (Smith et al., 2018). Smith et al. (2018) investigated the relationship between peNDF and uNDF240 in lactating dairy cow diets. They created a measure called peuNDF240, which is the product of the dietary pef and uNDF240 and was intended to integrate the effects of particle size and NDF indigestibility into one number. The peuNDF240 was highly related to DMI and chewing behavior (Smith et al., 2018). To explore this new measure's relationship with DMI further, we created a database with five studies with 16 treatments (Cotanch et al., 2014; Miller et al., 2017; Smith et al., 2018; Coons et al., 2019; Miller et al., 2020).

The MLR analysis to predict DMI accounted for 60% of the variance using peuNDF240 (Figure 3). This result agrees with the findings of Smith et al. (2018) and can be used to adjust DMI dependent on the peuNDF240 content of the diet. In the management model, we used the NRCi variable to predict a peuNDF240 content. If the dietary peuNDF240 content was greater than the predicted peuNDF240, then we used the regression equation created from the database. There is limited research using these new fiber measures, and it is important to restrict these inferences to similar diets (corn silage with hay and fibrous byproducts).

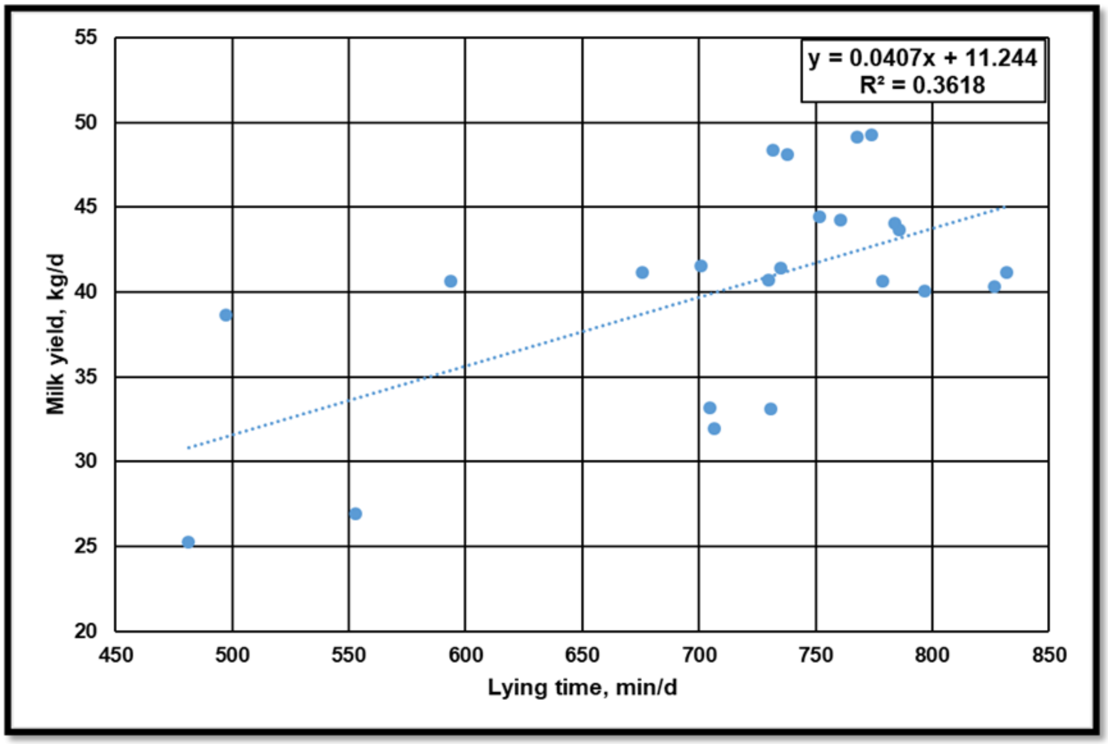

Figure 2. Relationship between lying time and milk yield for management model.

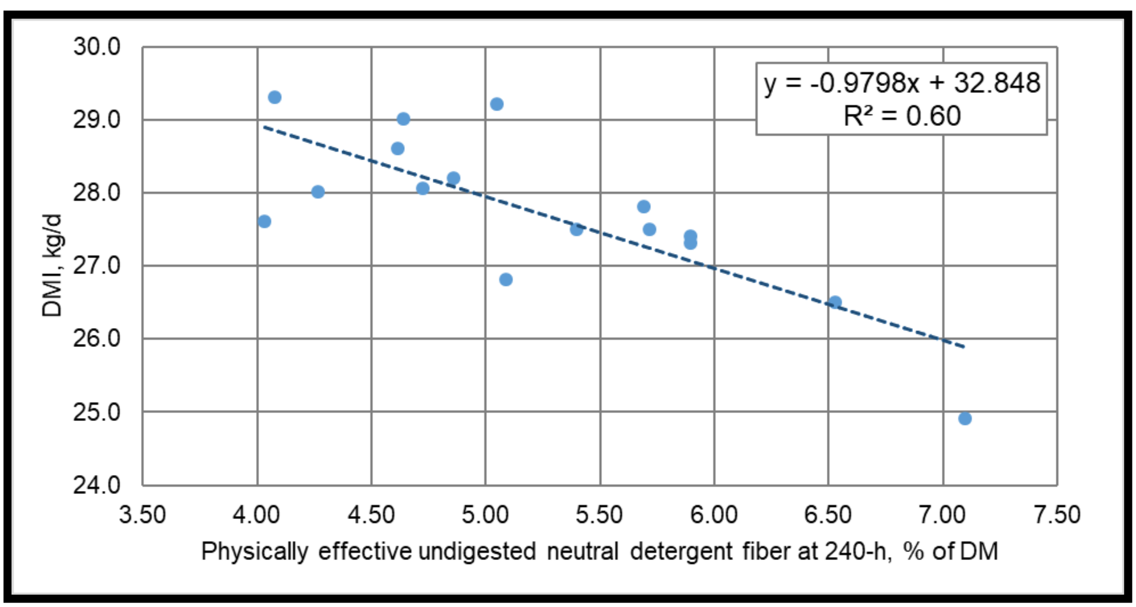

Figure 3. Relationship between physically effective undigested neutral detergent fiber at 240-h and dry matter intake for management model.

Conclusions

This study's objective was to create a model that accurately quantifies the effects of stocking density and feeding frequency on behavior and performance of lactating dairy cattle. The foundation of the management model is the time budget with lying and eating being the most significant time allotments. The eating time was predicted using common on-farm measures (NDF content, peNDF, BW, and milk yield) and had a good predictive ability with a mean absolute error of 41 min/d. Stocking density affected lying time, which accounted for 76% of the variance in lying time. The adjusted lying time was then used to predict a milk yield, which accounted for 36% of the variance in milk yield. Intake was affected by peuNDF240 content of the diet as the peuNDF240 increased DMI decreased. The peuNDF240 accounted for 60% of the variance in DMI. The management model appears to have potential to be a useful tool for producers and consultants, although more data and research are needed to validate the model. We expect to conduct this validation over the next year.

Take Home Messages

- Eating time can be predicted using on-farm measures.
- Lying time has a large influence on milk production.
- The peuNDF240 content of the diet increases the dry matter intake decreases.

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