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Description and evaluation of a net energy intake model as a function of dietary chewing index

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ABSTRACT

Previously, a linear relationship has been found between net energy intake (NEI) and dietary chewing index (CI) of the diet for different types of cattle. Therefore, we propose to generalize and calibrate this relationship into a new model for direct prediction of NEI by dairy cows from CI values (CI_{NE}; min/MJ of NE). Furthermore, we studied the forage-to-concentrate substitution rate in this new NEI model. To calibrate the model on a diverse set of situations, we built a database of mean intake from 14 production experiments with a total of 986 primi- and multiparous lactating dairy cows of different breeds fed 136 different diets ad libitum. The NEI were estimated by the Nordic feed evaluation system. The CI_{NE} value of diets was estimated from the intake of concentrate, intake of forage neutral detergent fiber (NDF_f), particle length of forage, indigestible NDF_f/NDF_f, body weight, NDF_f/body weight, and the content of NE in DM. We show that the slope values in this regression are proportional to the squared intercepts, giving the nonlinear equation $NEI = NEI_0 - k \times NEI_0^a \times CI_{NE}$, where the parameter k represents the decline in NEI with the increasing CI_{NE} of the diet and a was estimated to have a value of 2, implying a constant maximum daily chewing time. The intercept NEI_0 in the regression of NEI on CI_{NE} may be interpreted as metabolic net energy intake capacity of the cows fed without physical constraints on intake. Based on experimental data, the maximum chewing time was estimated as $1/(4 \times k)$. The NEI_0 values were parameterized as a linear function of metabolic body size, energy-corrected milk yield (kg/d), days in milk, and days in milk squared. Prediction accuracy was evaluated by mean square prediction error (MSPE) and its decomposition into central tendency, regression, and disturbance, across and within experiments on independent data from 19 experiments including 812 primi- and multiparous lactating dairy cows of different breeds fed 80 different diets ad libitum. The NEI model predicted NEI with an MSPE of 8% of observed, and across the 19 experiments the error central tendency, error regression, and error disturbance were 4.2, 40.6, and 84.9% of MSPE, respectively. The described intake model implies a variable forage-to-concentrate substitution rate as a nonlinear function of NEI_0, CI_{NE} of forage, and supplementation of concentrate.
Key words: intake capacity, maximum chewing time, substitution rate

INTRODUCTION

Performance and productivity of high-yielding dairy cows is closely linked to their energy intake (Friggens et al., 1995). Feed intake is driven by energy demands for maintenance, growth, milk production, and reproduction (Romney and Gill, 2000) and is controlled by an interaction between animal and dietary characteristics (Mertens, 2007). The dietary characteristics include the proportion of concentrate and forage characteristics, such as NDF concentration, digestibility of OM, physical form, DM content, and fermentation characteristics (Allen, 1996, 2000). Accurate predictions of voluntary feed intake are important in the formulation of optimal diets to support the productivity of cows (Allen, 1996). However, evaluations (Krizsan et al., 2014; Jensen et al., 2015a) of the NRC (2001), Zom et al. (2012), Gruber et al. (2004), TDMI (Huhtanen et al., 2011), and NorFor (Volden et al., 2011) models showed that these models all had a fairly high prediction error (SD) of 1.5 to 3 kg of DMI/d, and a systematic overprediction at high DMI and underprediction at low DMI. These discrepancies could be due to variable substitution rates

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between forages and concentrates depending on the energy balance and intake (Faverdin et al., 1991, 2011). Randby et al. (2012) found a quadratic increase in DMI at increasing concentrate intake, and interactions among forage quality and concentrate intake with week of lactation. In addition, a quadratic decreasing intake of forage NDF (**NDF_f**) per BW was found at increasing concentrate supplementation (Randby et al., 2012). Feed intake is considered to be physically constrained by NDF_f concentration of high-forage diets (Allen, 1996), with a maximum NDF_f intake of 1.2 to 1.3% of BW (Mertens, 1994). Intake models generally predict DMI (Faverdin, 1992; Ingvartsen, 1994), which is associated with net energy intake (**NEI**). Nørgaard and Mølbak (2001) introduced an NEI model that implies a variable substitution rate depending on the degree of metabolic or physical constraint on intake, concentrate intake, and forage quality. The substitution rate varies between zero at high-forage diets with high NDF_f per BW and −1 at high concentrate intake and low NDF_f intakes (Jensen, 2015). The NEI model by Nørgaard and Mølbak (2001) describes a negative linear relationship between NEI and the corrected dietary chewing index value [**CI_{NE}**; min/MJ of net energy (**NE**)] within experiments of lactating dairy cows, dry cows, growing bulls, and steers. The estimated intercept values [**NEI_0**; MJ of NE/kg of metabolic BW (**$BW^{0.75}$**)] for the individual experimental group of cattle are interpreted as their metabolic NEI capacity when rumen fill approaches zero. The NEI_0 of lactating cows, nonlactating cows, and growing cattle was shown to be 1.5 ± 0.16, 0.87 ± 0.11, and 0.83 ± 0.11, respectively. The objective of our study was to further develop and apply the NEI model described by Nørgaard and Mølbak (2001) by parameterization and evaluation on dairy cows fed different diets, and to demonstrate the variable substitution rate between forage and concentrates based on the model.

MATERIALS AND METHODS

Modeling Data

Relationships between the NEI of lactating dairy cows and the CI_{NE} values of their diets were analyzed on intake data from 14 Nordic experiments, including a total of 136 treatment means using 986 lactating dairy cows (both primiparous and multiparous) at lactation stages ranging from 25 to 275 DIM (mean 114 DIM). The use of literature data hindered use of individual data. The cows were tied up or loose housed, and were fed TMR (66 treatment means) or forage ad libitum supplemented with restricted amounts of concentrate (70 treatment means). The breeds included were Norwegian Red (24 treatment means), Finnish Ayrshire (16 treatment means), Jersey (16 treatment means), Danish Red (16 treatment means), and Danish Holstein (64 treatment means). The average BW of the treatment groups ranged from 415 to 706 kg. The included experiments were retrieved from a Nordic database and both Latin square and continuous designs were represented. All experiments used were previously published studies conducted in Denmark, Finland, and Norway (Thuen, 1989; Aaes, 1993; Kristensen, 1999; Rinne et al., 1999; Lund, 2002; Randby, 2003; Schei et al., 2005; Nielsen et al., 2007; Weisbjerg, 2007; Kristensen and Weisbjerg, 2008; Prestløkken et al., 2008; Bossen et al., 2009; Weisbjerg et al., 2013). The mean, standard deviation, minimum, and maximum values of DMI, NEI, and ECM are presented in Table 1.

Table 1. Dry matter intake, net energy intake (NEI), and ECM yield of the 14 experiments expressed as mean, SD, minimum, and maximum[1]

Item	Mean	SD	Minimum	Maximum
DMI (kg of DM/d)	18.6	2.5	12.7	24.0
NEI (MJ of NE/d)	120	16.2	84.9	160
ECM (kg/d)	27.7	5.4	17.1	49.7

[1]Data consist of 136 treatment means from 986 lactating dairy cows in 14 experiments conducted in Denmark, Finland, and Norway.

Forages used in the 14 indoor experiments included 23 grass and grass-clover silages, 2 alfalfa silages, 5 maize silages, 3 whole-crop silages, 1 alfalfa hay, 3 grass hays, and 3 treated or untreated straws, with a mean theoretical chopping length (**TCL**; mm) of 10 to 100 mm and a forage proportion of the diet DM ranging from 15 to 84% (mean = 59.4, SD = 14.0). Table 2 presents mean and standard deviation of nutrient composition of the total diets and of the forage used in the experiments.

Table 2. Nutritional characteristics of the diets from 136 treatment means in 14 indoor experiments expressed as mean, SD, minimum, and maximum

Item	Mean	SD	Minimum	Maximum
OMD[1] (%)	75.0	2.56	65.5	81.7
CP[2] (g/kg of DM)	157	21.6	117	227
NDF_t[3] (g/kg of DM)	364	56.7	187	516
NDF_f[4] (g/kg of DM)	471	103	269	761
$iNDF_t$[5] (g/kg of DM)	71.7	19.0	33.8	133
CI_{DM}[6] (min/kg of DM)	39.6	8.90	19.0	62.6

[1]Organic matter digestibility as percentage of diet OM.
[2]Crude protein concentration of diet DM.
[3]Neutral detergent fiber concentration of diet DM.
[4]Neutral detergent fiber concentration of forage DM.
[5]Indigestible neutral detergent fiber concentration of diet DM.
[6]NorFor chewing index of diet DM (Nørgaard et al., 2011).