MEASURING PHYSICALLY EFFECTIVE FIBER ON-FARM TO PREDICT COW RESPONSE

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INTRODUCTION

This paper is a follow-up to our 2005 Cornell Nutrition Conference paper entitled "Physically effective fiber for dairy cows: current perspectives". That paper provided a contemporary review of the concept of physically effective NDF (peNDF), the important assumptions inherent in the peNDF system, and preliminary work conducted at the Institute comparing commonly used particle-sizing systems. Presented here is an overview of the latest published research investigating animal response to dietary peNDF concentrations and the efficacy of various methods of on-farm peNDF determination.

It is important to understand the peNDF concept as originally defined by Mertens (1997) in order to properly evaluate current or proposed methodologies to monitor ration peNDF levels. Remember that peNDF was originally defined, from an analytical perspective, as the proportion of the original sample NDF that is found in particles retained on the 1.18-mm sieve when a dry forage or feed sample is sieved using a vertical shaking method (such as with the Tyler Ro-Tap equipment). By plotting ruminal pH by dietary peNDF derived from a review of literature, Mertens (1997) proposed that to ensure a ruminal pH of 6.0, dietary peNDF should be maintained at or above 21%. This has become the "gold standard" reference value for dietary peNDF. For on-farm application, the concept of peNDF has since been simplified to the proportion of DM retained as particles larger than the 1.18-mm sieve following dry vertical sieving multiplied by the %NDF of the sample, assuming an equal distribution of NDF between particles larger and smaller than the 1.18 mm sieve. This simplification is valid for many samples but less so for samples with considerable amounts of fine, non-NDF particulate matter, such as high concentrate total mixed rations (TMR). Regardless, the proportion of sample DM $\geq$1.18-mm sieve is commonly used as the physical effectiveness factor (pef) in the equation: peNDF = pef x %NDF.

Various methods have been proposed for the determination of pef using "as fed" forages in order to simplify the methodology and make it usable on-farm rather than requiring laboratory drying and analysis. Some of these methods include the Penn State Particle Separator (PSPS) wire mesh screen ($PSPS_{1.18}$; Kononoff et al., 2003), the total proportion of sample retained by the PSPS top 2 screens (19 mm and 8 mm; $PSPS_{8.0}$; Yang and Beauchemin, 2006 as an example), and the recently developed Z-Box system briefly described by Grant and Cotanch (2005) that uses 3.18- and 2.38-mm sieves. The question remains as to whether these on-farm particle-sizing tools yield pef values similar to the standard dry sieving method (Mertens, 1997). It has been assumed that

the on-farm tools provide measures of pef for forages and TMR that compare favorably with the target of 21% peNDF proposed by Mertens (1997) based on dry sieving.

CURRENT RESEARCH AND VARIABLE COW RESPONSE TO PENDF

Recent research investigating animal response to varied dietary peNDF concentrations as measured by the various particle separator techniques has been inconclusive. There appear to be differences in the ability of the various on-farm methods to measure pef values that mimic the pef measured using the standard dry sieving technique.

Yang and Beauchemin (2006a, c) fed barley silage-based diets of varying peNDF content to lactating dairy cows and observed the effect on chewing activity and ruminal pH. The dietary peNDF content was determined using the $PSPS_{8.0}$ method, the proportion of DM retained by the top-2 screens of the Penn State Particle Separator. Samples were presumably sieved as is, and proportion retained on each sieve was expressed on DM basis. An important point to consider is the fact that the dynamics of sieving a moist sample versus a dried sample do not equate to the expression of as-is sieving data on a DM basis. The process of drying the sample prior to sieving shrinks the particles resulting in a downward shift of particle size and peNDF value. The peNDF values of the TMR fed were 13.8, 11.8 and 10.5 for the high, medium and low peNDF diets. Refusals were analyzed to calculate the peNDF of the diet actually consumed, which resulted in peNDF of 14.5, 12.2 and 11.0%, respectively. Note that these dietary peNDF values are well below the recommended concentration of 21% of DM for maintaining rumen pH above 6.0 (Mertens, 1997). When the ruminal pH values for each diet are plotted on the peNDF x pH figure in Mertens (1997), it would predict that all three diets should result in ruminal pH in the 5.5 to 5.8 range, Figure 1a. The mean ruminal pH values observed were 5.62, 5.65 and 5.68 for the high, medium and low peNDF diets, with no significant differences by diet. Also, it is noteworthy that the cows consumed more peNDF than was fed in the TMR, suggesting sorting for long fiber and against fines, i.e. “reverse sorting”. This response by peNDF also would indicate some degree of ruminal acidosis. There were no dietary effects on eating; only min/d of ruminating was significantly affected by diet ($P < 0.05$).

Yang and Beauchemin (2006b) conducted a similar trial with a corn silage-based TMR, measuring peNDF as either $peNDF_{8.0}$ or the dry sieve method to obtain $peNDF_{1.18}$. The high, medium and low fiber diets had $peNDF_{8.0}$ values of 17.6, 14.8, and 10.0, and $peNDF_{1.18}$ of 24.9, 24.7, and 23.7. Note the $peNDF_{8.0}$ indicates that the TMR should be low in peNDF, Figure 1b., whereas the $peNDF_{1.18}$ dry-sieve values indicate high peNDF values that should result in ruminal pH values greater than 6.0, figure 1c. The mean ruminal pH values were 6.08, 6.06 and 5.99 across diets and did not differ significantly among the diets. These data do not support the idea that $peNDF_{8.0}$ is accurate in determining peNDF compared with the dry sieving method. The lack of difference in ruminal pH across diets is not unexpected as all 3 diets had $peNDF_{1.18}$ values much greater than 21. In order to document a dietary difference in

chewing time or ruminal pH, it would be ideal to have treatments that bracket the critical peNDF value of 21.

Zebeli et al. (2006) conducted a meta-analysis of research trials examining peNDF measurements and cow responses. They reviewed 33 research experiments that used $peNDF_{1.18}$ and (or) $peNDF_{8.0}$ that monitored feed intake, chewing activity, ruminal fermentation, milk parameters, and digestibility. Their findings indicated that $peNDF_{8.0}$ was poorly related to ruminal pH (R^2=0.27), whereas $peNDF_{1.18}$ was more closely associated to ruminal pH (R^2=0.67). However, $peNDF_{1.18}$ was poorly associated with daily chewing (R^2=0.17) and rumination (R^2=0.24). This is troubling because the original biological definition of peNDF was as the fraction of NDF that stimulates chewing and forms the ruminal digesta mat (Mertens, 1997). Milk parameters were less sensitive to dietary peNDF, which is not surprising. Inclusion of forage digestible organic matter (FDOM) and rumen degradable starch intake (RDSI) improved the accuracy of rumen pH prediction of their models, indicating the importance of chemical composition and fermentability along with physical dimension of feed particles which again makes sense. The Zebeli et al. (2006) review also reaffirmed the concept that to maintain ruminal pH above 6.0 required a dietary $peNDF_{1.18}$ of 19%, as determined by dry vertical sieving, similar to the value that Mertens originally proposed of 21% of DM. The use of $PSPS_{8.0}$ to estimate peNDF was not advised based on this meta-analysis.

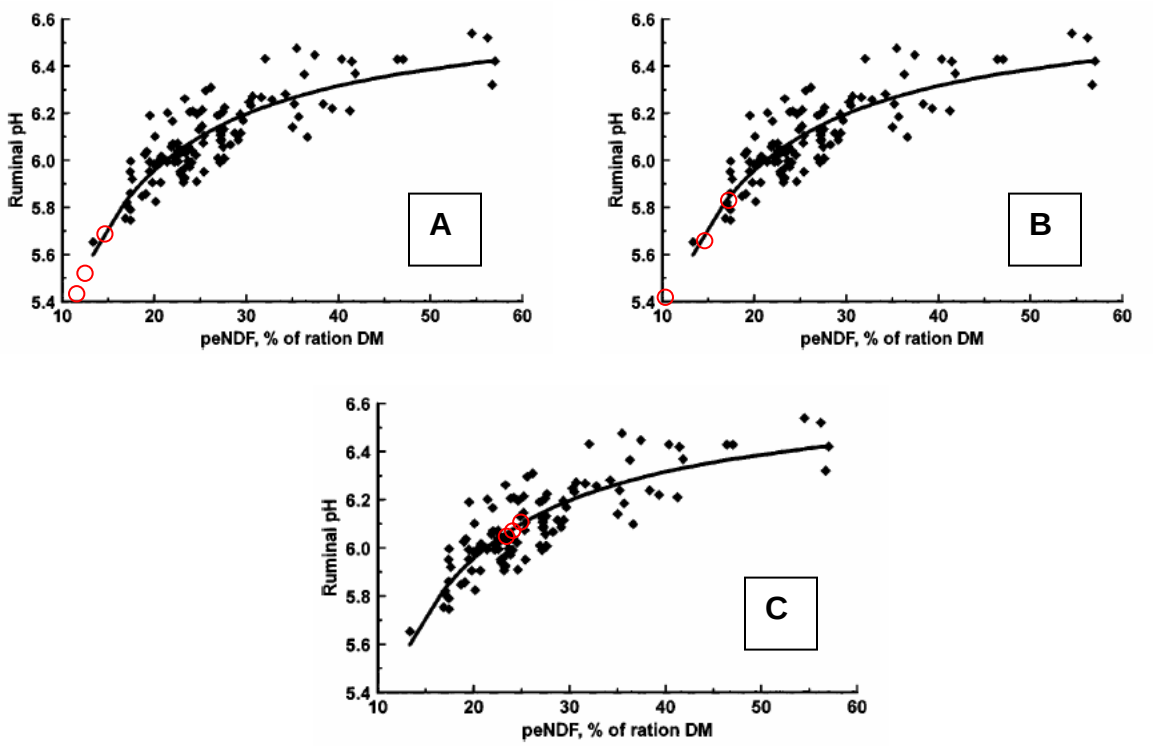

Figure 1. Ruminal pH data compared with original data from Mertens (1997) for Yang and Beauchemin (2006a, b, c).

DEVELOPMENT OF THE "Z-BOX" METHOD FOR ON-FARM ASSESSMENT OF PENDF

Despite the variable cow response to diets differing in peNDF, the need for a method to accurately determine peNDF with moist, as-fed samples still remains. Currently, nutritional models such as CNCPS and CPM-Dairy require peNDF as a key input to predict microbial output and animal response. Consequently, even though we still do not totally understand how to accurately predict cow response, nutritionists in the field require an on-farm system that results in pef values that agree with the standard method since it is most highly correlated with ruminal pH. The Z-Box system, previously developed at Miner Institute in cooperation with the Zen-Noh National Federation of Agricultural Co-operative Associations of Japan, appears to be such a device. The Z-Box is a 21 x 21 x 11 cm molded plastic box fitted with a clear plastic side and an open side for insertion of interchangeable sieves. The sieves that were evaluated were made of perforated steel with hole sizes of 1.14, 2.38, 3.18, 4.76 and 9.53 mm similar to the dimensions of the sieves used in Mertens (1997) dry sieving procedure. Table 1 contains the sieve specifications.

Table 1. Specifications for the sieves used in development of the Z-Box tool for on-farm measurement of physical effectiveness factors.

Hole diameter (mm)	Pattern	Open area (%)	Thickness (mm)
1.14	straight	36	0.5
2.38	diagonal	33	0.9
3.18	diagonal	40	0.9
4.76	diagonal	50	0.9
9.53	diagonal	51	1.5

A series of tests were conducted to determine the method that most accurately estimated $peNDF_{1.18}$ as determined by dry sieving. The series of tests included: sample shaking method, sample size, and appropriate sieve dimension that resulted in the best approximation of $peNDF_{1.18}$.

Sample Shaking Method

There were four methods of shaking tested:

1. 50 V-shakes: vigorous vertical shaking (20-25 cm up/down motion with 2 full shakes per second) for 50 shakes, with ¼ rotation of the box every 10 shakes.
2. 50 H-shakes: vigorous horizontal shaking (15 cm left/right motion with 1.4 full shakes per second) for 50 shakes, with ¼ rotation of the box every 10 shakes.
3. Total shakes: vigorous vertical shaking of the box until no material passed through
4. 1.5 minute shake: vigorous vertical shaking of the box for 1.5 minutes

The vertical shaking motion was chosen to simulate the motion of the dry vertical sieving system with the Ro-Tap equipment, whereas the horizontal motion was chosen

to simulate that of the PSPS. The vigorous shaking ensured adequate sample particle separation and exposure to the sieving surface.

Sample Size

Given the dimensions of the Z-Box, the volume available for adequate sample movement and presentation at the sieve surface limited the sample size. Consequently, it was decided to test 50 and 100 g of TMR to address the concern that with such a small amount it would be difficult to obtain a representative sample of the feed and also to ensure adequate particle separation during sieving. Three TMR of varied forage and concentrate composition were chosen to evaluate sample size. The TMR were a 1) growing heifer, high-forage TMR, 2) close-up dry cow TMR, and 3) high production, lactating cow TMR. Table 2 shows the ingredient composition of the TMR.

Table 2. Dry matter, physical effectiveness factor, and ingredient mix of TMR.

Item	Dry Cow	Heifer	High Group
DM (%)	58.7	34.2	49.5
$pef_{1.18}$ [1] (%)	79.1	72.5	66.2
Haycrop silage (% as fed)	--	95.3	27.9
Corn silage (% as fed)	56.1	--	43.7
Straw (% as fed)	--	4.4	1.3
Hay, alfalfa-grass (% as fed)	10.2	--	--
Beet pulp (% as fed)	10.2	--	2.4
Cottonseed, whole (% as fed)	--	0.3	3.1
Concentrate mix (% as fed)	23.8	--	21.6

[1]physical effectiveness factor as determined by standard Ro-Tap method.

Z-Box Sensitivity Test for Forages Ranging in pef Value

Corn silage and hay crop silage ranging in pef values were artificially created to test the sensitivity of the Z-Box system. Forage samples were separated with the PSPS into >19 mm, >8 to <19 mm and <8 mm fractions: i.e. long, medium, and short particles. For each forage, a “long” particle sample was created by combining 2 parts long with 1 part medium. A medium fiber length sample was a recombination of 1 part each of the long, medium and short particles. The short forage was comprised of 1 part medium to 2 parts short particles.

Results of the Z-Box Testing

Initial testing of the shake method and sieve aperture across CS, HCS and TMR samples indicated that the 1.14-mm and the 9.53-mm aperture sieves were poor predictors of $pef_{1.18.}$ The 1.5 minute and total shake methods were considered arbitrary and too time consuming for repeatable on-farm analyses. Figures 2 to 4 have pef values for each shake method plotted by sieve aperture for the various samples. The dashed horizontal line represents the $pef_{1.18}$ value for that sample. Data points above

the dashed line indicate over prediction of $pef_{1.18}$ whereas values below the reference line underestimate $pef_{1.18}$. For corn silage, both the vertical and horizontal shake method with the 3.18 mm screen resulted in accurate prediction of $pef_{1.18}$, Figure 2. The $pef_{1.18}$ value for HCS was most closely matched using the V-shake method with the 4.76-mm screen, Figure 3. For TMR, the V-shake with 2.18-mm screen was most accurate, Figure 4.

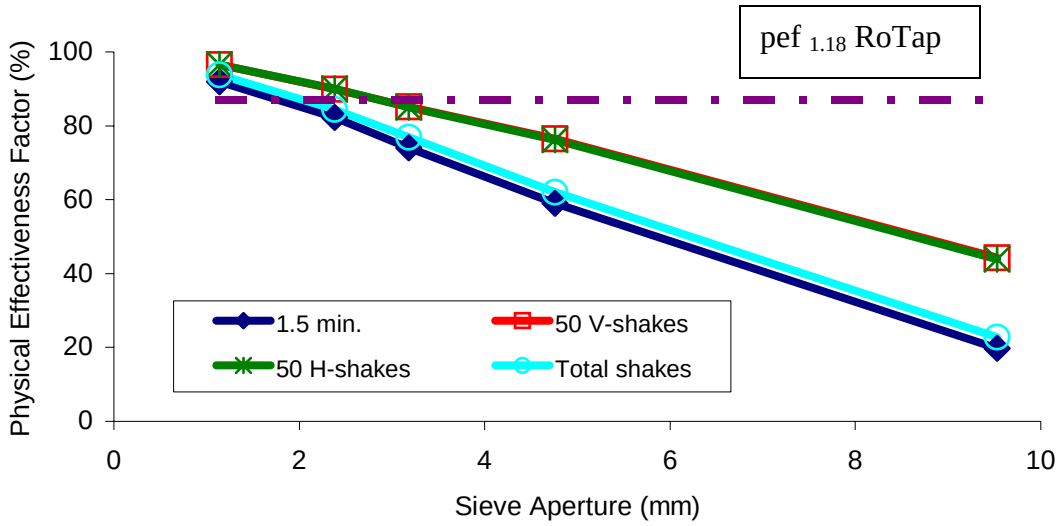

Figure 2. Z-Box pef values obtained by different shaking methods across sieve aperture dimension for corn silage.

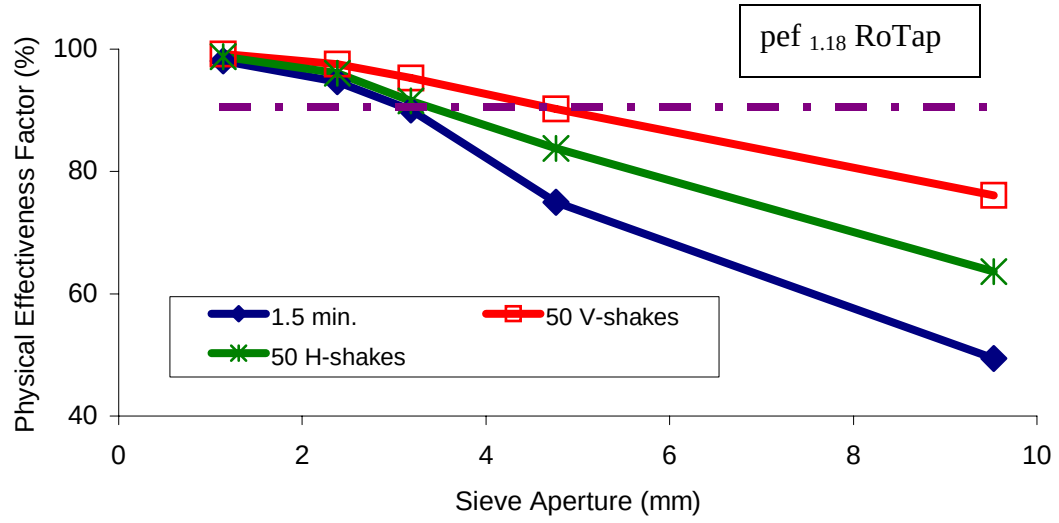

Figure 3. Z-Box pef values obtained by different shaking methods across sieve aperture dimension for HCS.

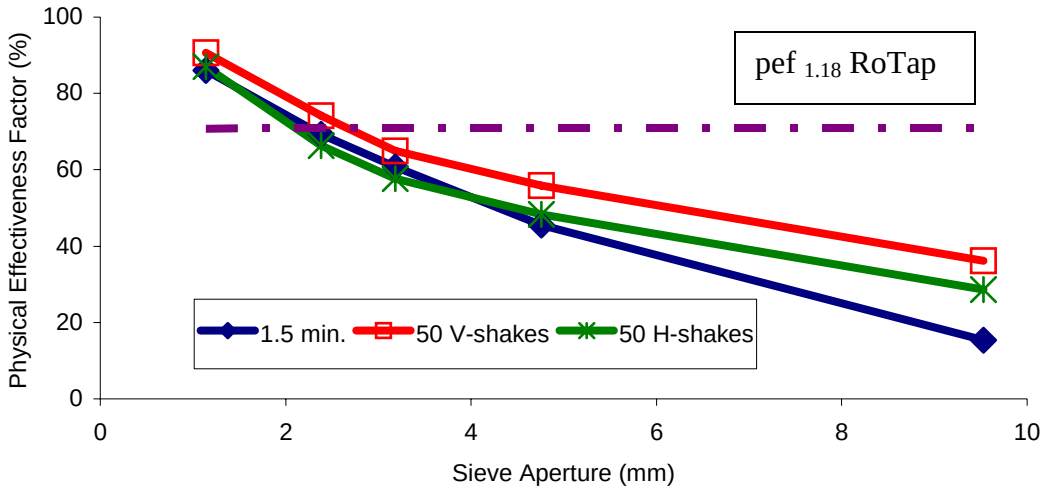

Figure 4. Z-Box pef values obtained by different shaking methods across sieve aperture dimension for TMR.

Based on these results it was decided to continue testing with the vertical and horizontal shaking methods using the 2.38-mm, 3.18-mm and 4.76-mm sieves. It also became apparent that corn silage and haycrop silages would require different sieve sizes for accurate pef determination.

Sample size determination results are presented in Table 3. Both the 50- and 100-g sample sizes were tested using the 2 shaking methods and 2.38-mm and 3.18-mm sieves. The obtained pef value was expressed as a percentage of the $pef_{1.18}$ and then ranked for accuracy, with a value of 100% being unity between the Z-Box and Ro-Tap pef values. Rankings were averaged within sample size resulting in the 50-g sample having an average rank of 3.8 and the 100-g sample having an average rank of 5.2. It was concluded that the 50-g sample was the optimum sample size to process through the Z-Box. Both the dry cow and high-cow TMR were corn silage-based rations resulting in greater accuracy with the 2.38 and 3.18 screens. The heifer TMR, which was primarily HCS, resulted in poor pef prediction, but as noted above, HCS pef values were most accurately determined with the 4.76-mm screen.

Table 3. Test of sample size by TMR type and shaking method.

			Dry Cow TMR		Heifer TMR		High TMR	
Sample	Sieve	Method	%$pef_{1.18}$[1]	Rank[2]	%$pef_{1.18}$[1]	Rank[2]	%$pef_{1.18}$[1]	Rank[2]
50g	2.38	50 V	95.6	3	123.2	4	106.7	3
		50 H	93.8	4	119.2	3	**101.0**	1
	3.18	50 V	81.8	7	**114.8**	2	93.1	4
		50 H	81.0	8	**107.7**	1	87.7	6
100g	2.38	50 V	107.1	5	129.0	7	118.6	8
		50 H	111.1	6	131.0	8	116.1	7
	3.18	50 V	**96.6**	1	125.5	5	**103.3**	2
		50 H	**104.0**	2	126.5	6	107.5	5

[1] %$pef_{1.18}$ = $pef_{Z\text{-}Box}/pef_{1.18}$ * 100

[2] Rank = Rank of accuracy for method and screen predicting pef within sample.

The sensitivity test results clearly indicated the greater predictive accuracy of the 4.76-mm screen for HCS samples. The long, medium, and short HCS samples replicated $pef_{1.18}$ with the 4.76-mm screen more closely than the 3.18-mm screen. (Table 4). The %$pef_{1.18}$ value was nearly 100% for each of the 3 HCS particle lengths. For corn silage, the 3.18-mm screen resulted in %$pef_{1.18}$ values of nearly 100%, and generally within 4 units of pef (Table 4). Variation among technicians performing the tests was very low as noted by the low inter-assay coefficients of variation (CV). Variability within technician was also low as noted by the CV values of nearly 3 or less.

Table 4. Sensitivity test of Z-Box across haycrop and corn silages of varying particle lengths as determined by $pef_{1.18}$.

Forage	Particle Length	$Pef_{Ro\text{-}Tap}$[1]	CV-$pef_{Ro\text{-}Tap}$	Sieve	%$pef_{Ro\text{-}Tap}$[2]	CV-inter[3]	CV-intra[4]
Hay Crop	Long	88.6	0.57	3.18	108.4	0.67	0.54
Silage				**4.76**	**100.9**	**1.31**	**0.50**
	Medium	81.2	0.68	3.18	114.4	0.54	0.51
				4.76	**102.3**	**2.61**	**1.74**
	Short	72.5	0.53	3.18	122.2	1.38	1.28
				4.76	**96.2**	**3.41**	**3.18**
Corn	Long	92.0	0.33	2.38	104.7	0.52	0.22
Silage				**3.18**	**102.6**	**0.62**	**0.34**
	Medium	89.2	0.33	2.38	104.3	0.75	0.50
				3.18	**99.1**	**0.67**	**0.63**
	Short	87.0	0.70	**2.38**	**103.7**	**1.74**	**0.42**
				3.18	95.6	2.22	0.66

[1] $pef_{Ro\text{-}Tap}$ = physical effectiveness factor as determined by Ro-Tap Shaker Method

[2] %$pef_{Ro\text{-}Tap}$ = $pef_{Z\text{-}Box}/pef_{Ro\text{-}Tap}$ * 100

[3] inter-assay coefficient of variation (between technicians)

[4] intra-assay coefficient of variation (within technician)

Based on the results of these preliminary tests, a final procedure was determined for further field-testing of the Z-Box for robustness. The sample size of 50 g may not allow for a representative sample of the forage or TMR to be analyzed under all conditions. To accommodate this concern, 3 replicates per sample should be sieved through the Z-

Box with results averaged for accurate pef determinations. The finalized procedure for predicting pef of “as fed” forages and TMR using the Z-Box Method is as follows:

1. Obtain representative sample of forage or TMR (approximately 600 g)
2. Quadrant sample into 150 g quadrants
3. Divide one 150 g quadrant into three 50 g sub samples (~200-250ml volume)
4. Place Z-Box, plexiglass side down, on scale and tare.
5. Place sub-sample (~50 g) into Z-Box and record “initial” weight
6. Insert appropriate sieve for the forage/TMR and snap onto box.
   a) CS – 3.18 mm
   b) HCS – 4.76 mm
   c) TMR – 2.38 or 3.18 mm
7. Invert Z-Box and vertically shake vigorously (20-25 cm up/down with ~2 full shakes per second) for 50 shakes, with ¼ rotation of box every 10 shakes
8. After shaking, invert Z-Box, remove lid and screen, place on the scale, and record weight of material remaining, “retained”.
9. Empty material, and load Z-Box with another ~ 50 g sub sample, following procedures outlined above.
10. Repeat process again for third sub sample.
11. Calculate pef as (cumulative retained grams)/(cumulative initial grams).

We conducted a lactation study to compare the pef determined with the Z-box or the standard dry sieving procedures to the chewing response of the cow. Four diets were formulated to contain approximately 34.7 to 38.5% corn silage and 9.1 to 10.1% alfalfa-grass silage. Oat hay was added to three diets at 14.9% of dry matter and either chopped coarse, medium, or fine. The fourth diet served a low-forage NDF control. The TMR resulted in $pef_{1.18}$ of 63.3, 59.9, and 55.0 for the coarse, medium, and fine diets, respectively. The Z-box pef for the same TMR were 61.0, 58.0, and 56.0 measured using the 3.18-mm sieve. So, there was good agreement between the two methods in calculating pef. When the diets were fed to lactating Holstein cows to measure total chewing response, the pef (defined as change in total chewing time relative to the control diet) was 65.4, 40.1, and 53.7, respectively for the coarse, medium, and fine diets. Except for the intermediate particle size diet, the biological pef agreed well with the pef measured in the lab using the Z-box or the standard dry sieving method. The medium diet inexplicably resulted in less chewing response than the fine diet resulting in a lower than expected pef value.

CONCLUSIONS

The Z-Box tool described in this paper provides on-farm measures of pef for silages and TMR that agree well with pef measured using the standard dry sieving procedure.

REFERENCES

Cook, N.B., and K. V. Nordlund. 2004. Behavioral needs of the transition cow and considerations for special needs facility design. Vet Clinics Food Anim. 20:495-520.

Grant, R. J., and K. W. Cotanch. 2005. Physically effective fiber for dairy cows: current perspectives. pp 61-70 in Proc. Cornell Nutr. Conf. for Feed Manufacturers. October 18-20. Syracuse, NY.

Kononoff, P. J., A. J. Heinrichs, and D. R. Buckmaster. 2003. Modification of the Penn State Forage and Total Mixed Ration Particle Separator and the effects of moisture content on its measurements. J. Dairy Sci. 86:1858-1863.

Mertens, D. R. 1997. Creating a system for meeting the fiber requirements of dairy cattle. J. Dairy Sci. 80:1463-1482.

Yang, W. Z., and K. A. Beauchemin. 2006a. Effects of physically effective fiber on chewing activity and rumen pH of dairy cows fed diets based on barley silage. J. Dairy Sci. 89:217-228.

Yang, W. Z., and K. A. Beauchemin. 2006b. Physically effective fiber: method of determination and effects on chewing, ruminal acidosis, and digestion by dairy cows. J. Dairy Sci. 89:2618-2633.

Yang, W. Z., and K. A. Beauchemin. 2006c. Increasing the physically effective fiber content of dairy cow diets may lower efficiency of feed use. J. Dairy Sci. 89:2694-2704.

Zebeli, Q., M. Tafaj, H. Steingass, B. Metzler, and W. Drochner. 2006. Effects of physically effective fiber on digestive processes and milk fat content in early lactating dairy cows fed total mixed rations. J. Dairy Sci. 89:651-668.