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Sources of variation in corn silage and total mixed rations of commercial dairy farms

Paula Turiello,*[1] PAS, Alejandro Larriestra,† Fernando Bargo,‡ Alejandro Relling,§ PAS, and William Weiss,§ PAS

*Departamento de Producción Animal, and †Departamento de Patología Animal, Universidad Nacional de Río Cuarto, Río Cuarto 5800, Argentina; ‡Facultad de Agronomía, Universidad de Buenos Aires, Buenos Aires 1417, Argentina; and §Department of Animal Sciences, The Ohio State University, Wooster 44691

ABSTRACT

Information on sources of variation in feed and diet characteristics is needed to develop appropriate strategies to reduce uncertainty and to separate true variation from that associated with measurements. The objectives were to determine sources of variation in DM content and particle size distribution in corn silage (CS) and TMR. Ten dairy farms in Argentina were visited on 3 consecutive days, samples of CS and TMR were taken, and an audit of feed management was conducted. Corn silage and TMR were sampled in duplicate each day. Variance components were calculated with the Mixed Linear Models of InfoStat for CS and Generalized Linear Mixed Models for TMR. For CS, the model included the effects of farm and day within farm, and for TMR, the model included farm, pen within farm, day within pen, and feed bunk site within pen. Residual effects accounted for sampling and analytical variation. Farm was the greatest source of variation for DM and particle size distribution of CS and TMR, explaining 40 to 92% of total variation. For CS, day within farm variation was greater compared with residual variation in DM (7 and 0.6%, respectively), meaning real changes occurred from one day to the other. For TMR, daily variation in DM content was high and possibly associated with feed management errors. For particle size distribution in TMR, sampling and assaying variation was greater than feed bunk site variation, indicating increased replication and averaging is needed to increase precision.

Key words: variation, dry matter, particle size distribution, total mixed ration

INTRODUCTION

Feed cost is the largest single expense in a dairy farm. Despite the development of accurate models to predict cow performance based on diet formulations, some issues involving sampling and feed analysis, and mixing and delivering the TMR, generate uncertainty regarding the composition of the ration actually delivered to a pen (St-Pierre and Weiss, 2015; Trillo et al., 2016). This uncertainty could lead to over- or underfeeding of nutrients and potentially have environmental and economic costs (St-Pierre and Weiss, 2015). Diet evaluation can also be difficult because of unknown variation in the physical and nutritional composition of TMR (Barmore, 2002).

The DM content of feeds determines the amount of nutrients being offered to the animals, and as ingredients are loaded according to weight, their moisture content is crucial in determining diet formulation and actual nutrient composition. The distribution of particle size (**PS**) in the TMR affects sorting behavior, which affects nutrient composition of the feed actually eaten by the cow (Kononoff et al., 2003b). These 2 variables are usually recommended as on-farm measurements to provide an indicator to monitor TMR consistency (Amaral-Phillips et al., 2001; Barmore and Bethard, 2005; Oelberg and Stone, 2014).

Inconsistency in the nutrient composition and PS of the TMR could affect cows. Day-to-day variation in nutrient composition of TMR had no or only minor effects on production measures in randomized, controlled studies (McBeth et al., 2013; Weiss et al., 2013; Yoder et al., 2013). However, observational studies found that herds that had greater variation in NE_l and PS in the ration fed to the cows had reduced milk yields and feed efficiency (Sova et al., 2014), and variation in concentrations of certain nutrients was positively correlated with variation in milk yields and composition (Rossow and Aly, 2013).

However, because of the experimental design, the variation in TMR composition and PS in those studies (Rossow and Aly, 2013; Sova et al., 2014) included sampling and analytical variation in addition to true day-to-day variation. Quantifying sources of variation in TMR composition and PS will aid interpretation of studies on the effects of variation and determine whether true day-to-day variation is indeed a concern. Specifically, changes in DM content in forages, such as corn silage (**CS**), could alter TMR nutrient composition and, therefore, cow performance if the ration is not adjusted for those changes. Our objectives

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[1] Corresponding author: mpturiello@ayv.unrc.edu.ar

Table 1. Farm characteristics[1]

Farm	Lactating cows	Lactating pens	Daily milk production (kg)	Added water in TMR	Mixer design
1	310	4	6,000	No	Horizontal
2	390	5	10,700	Yes	Horizontal
3	100	3	2,500	No	Horizontal
4	310	4	7,600	Yes	Vertical
5	125	2	3,000	No	Horizontal
6	147	3	4,200	No	Vertical
7	290	3	6,600	No	Vertical
8	380	3	9,000	Yes	Horizontal
9	380	5	10,500	Yes	Vertical
10	350	5	9,500	Yes	Horizontal

[1]A total of 10 farms were evaluated in this study. Note that not every lactating pen was enrolled in the study.

were to determine and quantify the sources of variation (farm, day, sampling + analytical) in DM content and PS distribution of CS and TMR in 10 commercial dairy farms in Córdoba, Argentina.

MATERIALS AND METHODS

Farm Characteristics

This study was conducted under the regulations of the committee of research ethics of Universidad Nacional de Río Cuarto. Ten dairy farms in southern Córdoba Province, Argentina (33.1244019 S, 64.3772949 W), feeding a TMR to their lactating cows were enrolled in this study (Table 1). Dairy farms were visited on 3 consecutive days during the summer of 2015 (February 5 to April 21), and an audit on feed management and facilities was conducted in each farm. The average size of farms was 270 lactating cows, ranging from 100 to 390 cows. Average individual milk yield ranged from 19.4 to 28.6 kg/d. Only one dairy farm had concrete feed bunks with headlocks, whereas the other dairy farms had wooden, canvas, plastic, or metal feed bunks with access from both sides. In one farm, the feeder cleaned out the feed bunks daily; in the rest, the manager or producer expressed that they did it irregularly according to their needs. All farms included CS in lactating cow diets. Seven farms stored CS in piles and the rest in bags. Of all farms, 90% fed ground corn, alfalfa hay, and soybean meal, and 70% fed at least one wet ingredient (distillers, brewers, or high-moisture corn) to their lactating cows (Table 2). Half of the dairy farms added water (3 to 36% of as-fed TMR) when preparing the ration in the mixer. Across all TMR preparations, residual TMR in the mixer wagon was usually found and considered as a source of variation contributing to pen, day, and feed bunk site variation in TMR offered to the cows. Farms had 1 or 2 feeders, but they only had one person primarily responsible for TMR preparation. Across all farms, 60% of the feeders were never formally trained in mixer wagon use and TMR preparations.

Sampling and Analysis

During each of the 3-d sampling periods, farms were visited daily during the morning when the first TMR was prepared and delivered to the lactating dairy cows. If feed bunks had residual feed in them, they were not cleaned out before sampling in an effort to not interfere with normal feed bunk management. The TMR was sampled im-

Table 2. Ingredient composition of TMR from 27 pens on 10 dairy farms[1]

Ingredient	No. of pens	Inclusion rate (mean ± SD, %)	Range[2] (%)
Corn silage	27	35.7 ± 10.9	15.2–57.9
Hay-crop silage	9	23.1 ± 18.7	4.6–53.9
Alfalfa hay	24	14.5 ± 6.2	4.9–25.7
Corn grain	24	23.5 ± 8.5	3.4–36.4
Soybean meal	24	12.5 ± 4.3	5.3–21.8
Wet by-products[3]	14	10.4 ± 3.5	4.9–16.0
Dry by-products[4]	8	21.1 ± 13.7	7.3–39.5
Water	14	16.2 ± 11.4	3.0–36.0

[1]A total of 10 farms and 27 pens within farms were evaluated in terms of number of pens that included each ingredient in their TMR, mean inclusion rate, and range of inclusion in those pens using the ingredient.

[2]Range of inclusion of each ingredient in those pens using that feed.

[3]Wet by-products included wet distillers grains with solubles, high-moisture corn, and brewers grains.

[4]Dry by-products included soybean hulls, whole cottonseed, and sunflower meal.

mediately after delivery at the beginning and at the end of the feed bunk (not including the first and the last 2 m of the feed bunk). At each site, within a 2-m area, 15 handfuls (approximately 2 kg as fed) of TMR were put into a bag. Duplicate samples were taken at each site, having 2 independent samples at the beginning and 2 at the end of the bunk daily. A total of 324 TMR samples were targeted to be taken from 27 pens, sampled daily during 3 consecutive days in 2 feed bunk sites in duplicate. However on a given day, 2 pens in a farm were not fed; therefore, only 316 TMR samples were collected.

Corn silage was sampled from the loader bucket by taking 5 handfuls from each of 2 to 3 loads to make a composite sample (approximately 2 kg, as fed). This was done twice, having 2 independent samples of each farm daily. Some of the dairy farms involved in the study included CS as the sole forage source in the TMR, whereas others used CS plus other conserved forages such as alfalfa or grass silages. A total of 64 samples of CS were collected because one farm fed 2 different CS during 2 d. For DM content, CS samples from the first day on one farm had to be discarded because the bags were filled with water from melted ice before arrival to the laboratory, making the final number of samples 62 for DM. The PS was measured before the samples got wet, so 64 samples were available for PS.

Samples of CS or TMR were mixed and subsampled according to St-Pierre and Weiss (2015). Samples were then quartered, and 2 quarters were discarded. With the remaining material, the same procedure was repeated and used to determine PS distribution (~1.5 L) and the rest was placed into a bag and sent to a local commercial laboratory (AQUA Lab, Río Cuarto, Córdoba, Argentina) for DM determination.

Particle size distribution was determined using the Penn State Particle Separator (Kononoff et al., 2003a) and strictly following its protocol by the same trained person for each pen, each day. Residues on each sieve were weighed separately, and proportions were calculated on an as-fed basis using a logarithmic-normal distribution (Kononoff et al., 2003a). The remaining subsamples were stored in a refrigerated box for 2 to 12 h and then taken to the laboratory for DM analysis (65°C for 24 h).

Calculations and Statistical Analysis

Descriptive statistics were calculated using the Summary Statistics procedure (InfoStat; Di Rienzo et al., 2016). Variance components were calculated for CS with the Extended and Mixed Linear Models Procedure and for TMR the Generalized Linear Mixed Effects procedure was used (InfoStat; Di Rienzo et al., 2016). The model included the random effects of farm and day within farm for CS. For TMR the model included farm, pen within farm, day within pen and farm, and feed bunk site within day and pen. Residual error accounted for sampling and analytical variation. In a separate analysis, the fixed effect of added water (yes or no) was added to the TMR model to determine the effect of adding water to the TMR.

Partial correlation coefficients were calculated between the proportion of particles of TMR and those for CS retained on each sieve, using farm as a fixed effect. The CV of TMR of each sieve was calculated from the 4 samples taken daily from each pen. The Extended and Mixed Linear Model procedure was used to compare CV of PS distribution from farms using vertical or horizontal mixers considering type of mixer as a fixed effect and pen within farm as random effect. To determine the correlation between PS CV and hay inclusion rate, Pearson correlations were calculated. Particle size CV was calculated as the average of the daily CV for each pen at each farm.

RESULTS AND DISCUSSION

CS DM Content

Across all farms, CS DM content averaged 34.3%, varying from 28.3 to 45.1% (10th–90th percentiles; Table 3). The mean daily range (10th–90th percentile) within farm was 3 percentage units (Table 3) but varied between 0.9 and 5.4 percentage units. Farm was the greatest source of variation for DM content of CS (Table 4). Many characteristics of CS are farm dependent (Johnson et al., 2002; St-Pierre and Weiss, 2015), which highlights the importance of CS sampling at each farm for accurate diet formulation rather than relying on table values.

Although within-farm variation accounted for only 7.6% of total variation in DM, it was mostly explained by day (92.1%). Day-to-day variation could be explained by different material ensiled along the bags or different sites of a pile removed for feed out. Although environmental conditions could increase daily variation in DM content, all the CS was covered and was never sampled when raining. Day-to-day SD was 1.6 percentage units over the 3-d period, whereas St-Pierre and Weiss (2015) found an average within-farm daily SD of 1.2% for DM content of CS over a 14-d period. In our study, some farms showed a daily SD as low as 0.3%, but others had higher values (2.3%). This demonstrates that different sampling frequency should be recommended to different farms. In this study, 6 of 10 farms sampled the CS only once or twice a year.

The effect of day-to-day variation in the DM content of the silage on cows probably depends on the DM content of the silage, its dietary inclusion rate, and feed management (i.e., level of refusals). An abrupt decrease in DM content of silage reduced short-term milk yields when TMR delivery rates were not adjusted (i.e., less DM was fed; Mertens and Berzaghi, 2009), but when adequate DM was delivered, abrupt changes in silage DM content did not affect production (McBeth et al., 2013). Knowing whether silage DM changed before TMR delivery may reduce the risk of reduced milk yield, because delivery rates can be changed. Conversely, feeding excess TMR at all times may compensate for variation in silage DM. That approach, however,

Table 3. Descriptive statistics for DM content and particle size (PS) distribution of corn silage[1]

Item	Mean (%)	SD (%)	10th–90th percentile (%)
Full data set (n = 64 samples)[2]			
DM	34.3	6.43	28.3–45.1
PS distribution			
>19.0 mm	12.2	7.92	4.5–22.5
19.0 to 8.0 mm	65.7	7.74	55.4–76.5
8.0 to 1.18 mm	19.9	7.56	11.7–33.7
<1.18 mm	2.3	2.21	0.0–5.8
Within-farm ranges (n = 10 farms)[3]			
DM content	23.7–45.7	1.3 (0.3–2.3)	3.0 (0.9–5.4)
PS distribution[4]			
>19.0 mm	5.1–22.0	4.3 (1.3–13.3)	10.8 (3.2–29.0)
19.0 to 8.0 mm	56.0–76.9	4.3 (1.6–11.3)	10.7 (4.3–25.1)
8.0 to 1.18 mm	9.9–32.3	2.5 (0.6–5.3)	6.5 (1.4–14.7)
<1.18 mm	0.0–6.5	0.8 (0.0–1.8)	2.0 (0.0–4.4)

[1]Samples came from 11 corn silages from 10 different farms, sampled in duplicate for 3 consecutive days (1 corn silage was sampled only 2 d).

[2]Values from Full data set are percentages; values from Within-farm ranges are in percentage units (ranges).

[3]Values of SD and 10th to 90th percentiles are expressed as averages with ranges in parentheses.

[4]Heinrichs and Kononoff (2002).

inflates feed costs and may result in a buildup of spoiled feed in the feed bunk if the bunks are difficult to clean out.

In our study, the error associated with sampling and assay (i.e., residual) was less than that reported by St-Pierre and Weiss (2015), who used a similar sampling protocol on 11 farms sampled daily for 14 d (SD for sampling + analytical was 0.48 vs. 1.29, respectively). A possible reason for the difference is that in the study by St-Pierre and Weiss (2015), multiple samplers were involved, but in this study, all samples were taken by the same person.

CS PS Distribution

Proportion of particles retained on each of the sieves for CS is shown in Table 3. On average the CS had more mass on the >19-mm (12.2%) screen than recommended

Table 4. Farm, day-to-day, and residual variation and estimated variance partitioning in DM content and particle size (PS) distribution in corn silage[1]

	SD (%)			SD as % of total variance		
Item	Farm	Day	Residual	Farm	Day	Residual
DM content	5.82	1.60	0.48	92.4	7.0	0.6
PS distribution[2]						
$\log_{10}$ >19.0 mm	0.21	0.16	0.10	55.3	32.1	12.6
$\log_{10}$ 19.0 to 8.0 mm	0.03	0.03	0.02	40.9	40.9	18.2
$\log_{10}$ 8.0 to 1.18 mm	0.15	0.06	0.05	78.7	12.6	8.7
$\log_{10}$ <1.18 mm	0.27	0.2	0.14	55.0	30.2	14.8

[1]Samples came from 11 corn silages from 10 different farms, sampled in duplicate for 3 consecutive days (one corn silage was sampled on only 2 d). Variance was partitioned into farm-to-farm variance (Farm), day-to-day variance (Day), and sampling and analytical variation (Residual).

[2]Heinrichs and Kononoff (2002). Proportion of particles transformed to logarithm.

Table 5. Descriptive statistics for DM content and particle size (PS) distribution of TMR[1]

Variable	Mean (%)	SD (%)	10th–90th percentile (%)
Full data set (n = 316)[2]			
DM	45.1	5.98	37.9–52.6
PS distribution			
>19.0 mm	13.9	9.28	2.7–27.0
19.0 to 8.0 mm	38.2	12.96	20.0–55.1
8.0 to 1.18 mm	35.3	6.36	27.3–43.8
<1.18 mm	12.7	6.14	4.3–20.2
Within-farm ranges (n = 10 farms)[3]			
DM	38.9–50.5	3.5 (1.4–6.6)	7.7 (3.3–13.3)
PS distribution[4]			
>19.0 mm	2.7–24.5	5.6 (1.3–10.1)	14.1 (2.4–27.3)
19.0 to 8.0 mm	18.6–54.1	5.7 (3.2–12.1)	14.8 (8.6–33.6)
8.0 to 1.18 mm	29.4–43.2	4.3 (2.5–5.9)	11.4 (6.0–15.0)
<1.18 mm	4.8–18.5	3.1 (2.2–4.5)	8.0 (5.7–11.5)

[1]TMR samples came from 27 pens of 10 different farms, sampled at the beginning and at the end of the feed bunk in duplicate on 3 consecutive days. Two pens were not fed 1 d (8 samples less) during the study.

[2]Values from Full data set are percentages; values from Within-farm ranges are in percentage units (ranges).

[3]Values of SD and 10th to 90th percentiles are expressed as averages with ranges in parentheses.

[4]Heinrichs and Kononoff (2002).

by Heinrichs and Kononoff (2002). However, the range in the proportion of mass with PS >19 mm among silages and across silage was great (4.5 to 22.5% considering the 10th–90th percentiles) as was the CV (65%). The CV for the PS fractions <8 mm were also high (38 to 96%). Because PS of silage is primarily a function of chop length at harvest (i.e., farm specific), within-farm variation and ranges of 10th to 90th percentiles in PS were substantially less. For the different PS fractions, average within-farm ranges were between 2.0 and 10.8 percentage units compared with 5.8 to 18.0 percentage units across farms. Depending on the PS fraction, farm accounted for 41 to 79% of the total variation (Table 4). The proportion of variation caused by sampling and analysis ranged from about 9 to 18%, which was much greater than that for DM. Sampling bias in PS is likely because of selective loss of smaller particles (e.g., dropping through fingers when collecting samples), whereas DM content is more uniform across PS (Bhandari et al., 2007). Assay bias is also likely because although some variables can be controlled (the volume of the sample used, the speed at which one shakes the boxes, and the stroke length), others cannot (the DM content of the sample; Kononoff et al., 2003a).

Within farm, variation among different PS was not necessarily consistent. For example, farm 7 had large variation in the 2 largest PS fractions, but variation was small on the 2 smallest fractions.

Day-to-day variation in PS distribution within farm composed 13 to 41% of total variation depending on the PS fraction (Table 4). Day-to-day variation in PS could be caused by nonuniform distribution of particles within silage piles or bags or by different chopping conditions during harvest. The cause could not be determined in this study.

DM Content of TMR

Dry matter content of TMR by pen and farm is shown in Table 5. Rations had a mean DM content of 45.1%, with 80% of the samples between 37.9 and 52.6%. In this study, 10 of 27 pens (belonging to 6 farms) were fed a TMR with less than 40% DM at least once during the 3-d period, and most of those TMR (80%) were prepared with additional water. None of the TMR sampled had >60% DM.

More than 50% of the variation in TMR DM content was explained by farm and an additional 18% was explained by pen within farm (Table 6). Farm variation could be explained by facilities, general feeding management, feeder, mixer wagon type, and maintenance, among others. Different diets were formulated for different pens, which likely caused much of the pen-to-pen and farm-to-farm variation. Variation between formulated and fed diet could not be estimated because we did not have access to the formulas made by the nutritionists.

Table 6. Farm, pen, day-to-day, feed-bunk-site, and residual variation in DM content and particle size (PS) distribution of TMR (n = 316)[1]

	SD (%)					SD as % of total variance				
Item (n = 316)	**Farm**	**Pen**	**Day**	**Site**	**Res**	**Farm**	**Pen**	**Day**	**Site**	**Res**
DM	4.5	2.61	2.6	1.6	1.3	52.9	17.9	18.4	6.6	4.2
PS distribution[2]										
$\log_{10}$ >19.0 mm	0.29	0.15	0.10	0.10	0.12	58.5	16.5	7.6	7.2	10.2
$\log_{10}$ 19.0 to 8.0 mm	0.15	0.06	0.04	0.02	0.03	74.7	13.2	6.5	1.7	3.9
$\log_{10}$ 8.0 to 1.18 mm	0.05	0.04	0.03	0.03	0.03	41.6	24.9	11.6	10.7	11.3
$\log_{10}$ <1.18 mm	0.24	0.07	0.10	0.08	0.09	66.3	5.9	11.9	7.5	8.4

[1]TMR samples came from 27 pens of 10 different farms, sampled at 2 sites within feed bunk (at the beginning and end of the feed bunk) in duplicate for 3 consecutive days. Two pens were not fed 1 d (8 samples less) during the study. Variance was partitioned into farm-to-farm variance (Farm), pen-to-pen variance (Pen), day-to-day variance (Day), feed-bunk-site variation (Site), and sampling and analytical variation (Res).

[2]Heinrichs and Kononoff (2002). Proportion of particles transformed to logarithm.

The SD for day for DM content of TMR was 2.6%, which accounts for 40% of within-farm variation approximately (Table 6). Day-to-day variation in DM content of the TMR could be related to changes in DM content of the CS and also day-to-day variation in actual inclusion rates of each ingredient in the TMR and residual TMR left in the mixer. Variation in the DM content of other wet ingredients (hay-crop silage, wet distillers with solubles, high-moisture corn, brewers grains) may explain some of the variation, but their inclusion rates were <16% of as-fed TMR.

Day-to-day variation in DM content in TMR can reduce DMI and milk yield if the variation results in inadequate feed DM delivery (Mertens and Berzaghi, 2009), but it did not affect DMI or milk yield when adequate DM was delivered to cows (McBeth et al., 2013). The day-to-day variation within some farms may have been great enough to influence intake and milk yield if cows were fed for low orts.

Causes of feed bunk variation in TMR have been described by Oelberg and Stone (2014). In this study, variation in DM content of TMR along the feed bunk was similar to residual variation, suggesting variation in DM content along the feed bunk could be explained by sampling and assay.

Day-to-day and within–feed bunk variation in DM content differed between farms that added water to the TMR and those that did not (Table 7). Adding water reduced the day SD and site SD by about half compared with not adding water. Possible reasons for lesser within–feed bunk and day-to-day variation when water is added to the TMR include longer mixing times (not measured in this study). Additionally, the DM content of water is constant (i.e., 0%), but it reduces the inclusion rate of ingredients that have variable DM content, which should reduce day-to-day variation.

Residual SD (i.e., sampling plus analytical) in our study (Table 6) was less than the variation reported by St-Pierre and Weiss (2015) for TMR samples collected on 50 farms

Table 7. Farm, pen, day, feed-bunk-site, and residual variance for DM content of TMR with or without added water[1]

	With added water		Without added water	
Item	**SD (%)**	**Var[2] (%)**	**SD (%)**	**Var (%)**
Farm	3.75	50.5	3.93	41.3
Pen	2.79	28.0	2.35	14.7
Day	1.85	12.3	3.31	29.3
Site	0.93	3.1	2.01	10.8
Residual	1.3	6.1	1.21	3.9

[1]Samples of TMR came from 14 pens of 5 different farms that added water to the preparation, and from 13 pens of 5 different farms that did not add water to the preparation. Samples were taken at the beginning and end of the feed bunk in duplicate on 3 consecutive days, but because 2 pens were not fed 1 d during the study, number of samples was 316 (164 and 152 from samples with or without added water, respectively). Variance was partitioned into farm-to-farm variance (Farm), pen-to-pen variance (Pen), day-to-day variance (Day), feed-bunk-site variation (Site), and sampling and analytical variation (Residual).

[2]Var = percentage of total variance attributable to each source.

Table 8. Particle size distribution variation (CV) by mixer design (vertical vs. horizontal, n = 79)[1]

	Vertical mixer (n = 31)		Horizontal mixer (n = 48)		
Item	Mean	SE	Mean	SE	*P*-value
>19.0 mm	21.1	2.61	32.2	2.10	0.003
19.0 to 8.0 mm	7.4	0.94	7.1	0.76	0.799
8.0 to 1.18 mm	6.1	0.85	7.0	0.69	0.410
<1.18 mm	12.6	3.86	18.5	3.14	0.244

[1]From the percentage of particles retained in each sieve and the bottom pan from the 4 TMR samples taken daily (for 3 d) from each pen (27 pens from 10 farms), the CV were calculated. Two pens were not fed 1 d. The CV were calculated from rations prepared with a vertical mixer (n = 31) or horizontal mixer (n = 48).

over a 12-mo period (1.3 vs. 2.9%). This likely reflects differences in sampling protocols and the greater number of samplers used by St-Pierre and Weiss (2015).

PS Distribution of TMR

On average (Table 5), the TMR had more mass with PS >19 mm than the recommended 2 to 8% (Heinrichs and Kononoff, 2002). However, because PS distribution of TMR was extremely variable among samples (CV ranging from 18 to 66% depending on the PS fraction), means have limited value. Based on recommendations by Heinrichs and Kononoff (2002), 9, 50, 76, and 90% of the samples were in the recommended range on the top, middle, and bottom sieves and pan, respectively.

Standard deviations of PS distribution were about twice as great as those reported by Sova et al. (2014); however, calculation methods differ, making direct comparisons difficult. Besides method, other potential reasons for the difference in SD between studies may be ingredient related (e.g, inclusion rate of forage), forage management (e.g., chop length of CS), or related to TMR mixing practices. Ingredient make-up of the TMR was not reported by Sova et al. (2014). In our study we found no significant correlation between PS distribution variation of the TMR of each pen and hay inclusion rate ($P > 0.05$).

Variance components for PS distribution of TMR are shown in Table 6. For all the sieves and the bottom pan, the most important factor explaining variation was farm. As expected, pen within farm was also an important source of variation, probably due to different formulations and preparations for each pen. Day-to-day variation within pen contributed about 6 to 12% of total variation (depending on PS fraction). Increased day-to-day variation in PS (specifically proportion of material on top screen) has been associated with reduced milk yields (Sova et al., 2014).

Residual variation was greater than variation from feed bunk site, meaning comparing results from TMR samples within a feed bunk can be misleading. Although variation in TMR along the feed bunk could be due to feed management errors (worn mixers, unlevel mixers, the way water is added to the TMR, loading position, time spent mixing after the addition of the last ingredient; Oelberg and Stone, 2014), it could also be sampling and analytical variation, considering the method was according to the protocol made by the same person for each feed bunk. Within specific PS fractions, proportion of sample within a screen for CS was not correlated with PS of TMR ($P > 0.43$). This indicates that either variation in PS of other ingredients was substantial, inclusion rates of ingredients varied substantially, or PS of the CS changed during TMR mixing.

Rations prepared with vertical mixers had a lower ($P < 0.01$) CV on the top sieve (21.1%) compared with rations prepared with horizontal mixers (32.2%). There were no differences found on the other sieves (Table 8).

IMPLICATIONS

Farm was the major source of variation for both DM and PS distribution of CS and TMR, suggesting measures of variation must be calculated for specific farms. True (i.e., that not caused by sampling or assay) daily variation in DM content of TMR within a pen resulted in a good measurement to monitor daily TMR consistency. This variation was great enough that based on other studies, it may affect DMI and milk yield. To use PS distribution results to monitor TMR consistency, nutritionists should recognize that data obtained may lack precision, indicating increased replication and averaging is needed. Differences in daily PS distribution of TMR from a single data point or differences at the feed bunk from 2 sites would be difficult to detect because of sampling and analytical errors.

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LITERATURE CITED

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