Optimizing Performance of TMR Mixers

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Introduction

Total mixed rations **(TMR)** seem to be the feeding method of choice, at least for non-grazing situations (Spain et al., 1993). The principles of TMR caught on a few decades ago, but implementation and preparation developments continue. There are many configurations of equipment and layouts which accomplish TMR delivery. Many producers are beyond the question of "Should I use TMR?"; the question is now: "What is the optimal way to deliver my TMR?"

The term and acronym of TMR has been widely misused over the years. In the true sense of the intent, a TMR is a *totally mixed total ration* or a TMTR. If the complete ration is not in the mix, it is not total. If the ration is not properly blended, portions of what is delivered are not total. Proper management of a TMR delivery system requires control of several facets which can control feed uniformity (in other words … there are lots of things that can go wrong). James and Cox (2008) showed strong evidence that feeding programs are not well managed and that greater variation in feed delivered leads to reduced milk production.

Quality control issues regarding TMR delivery include:

- Uniformity among batches,
- Uniformity within batches,
- Particle size distribution,
- Minimizing labor requirements (but this is usually more a function of non-mixer equipment than the mixer itself),
- Low utilization of energy input (minor issue generally), and
- Long equipment life.

The intent of this manuscript is to discuss mixer management in light of these quality control issues. Mixer selection and operation can dramatically affect each of these.

Types and Features of TMR Mixers

Others have written about the different types of mixers currently available (Kammel and Leverich, 1990; Kammel et al., 1995). A quick review of some of the most common options is worth mentioning though, because the proper management of any mixer requires an understanding of the flow of material during the mixing process and during unloading. For details on any mixer type or brand, consult the operator's manuals, technical specialists, or conduct experiments on your own.

Some mixers rely primarily on tumble action to accomplish the blending. Reel, tumble, chain and slat, and ribbon mixers fit this category. Depending upon the brand and particular model, there may be features to facilitate incorporation of long hay or liquids, mixing of small batches, or to aid in material flow during mixing. Tumble action requires relatively little power since the feed just needs to be raised to fall again.

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Some mixers have a more positive displacement and aggressive mixing action. Auger mixers come in varying configurations (1, 2, 3, and 4 horizontal auger and single or twin vertical auger(s)). The different configurations have different features and material flow paths. Selling points vary among types and brands.

Material flow inside the mixer is a big deal. Proper blending requires that there be no dead spots or recirculating feed paths. While most mixers are designed with this in mind, some do not have sufficient material flow to adequately blend liquids which are added rapidly to the mixer. Some mixers do not have good material flow when the batch size is a small fraction of the mixer capacity. Many observers of TMR systems agree that one of the most common errors made in putting together a TMR delivery system is simply the mixer capacity. It is important to have proper size for several reasons:

- Allow for adequate blending without excessive mixing time (*which is generally accompanied by excessive particle size reduction*),
- Assure adequate blending of the ration,
- Optimize labor use for feeding, and
- Optimize equipment cost.

Mixer Capacity

Most mixers are not very effective at blending a ration when they are filled "too full". Some are not very effective mixing small batches. Mixer manufacturer information should be consulted to determine the range of batch sizes suitable for different mixers. Table 1 has suggested questions to ask mixer representatives.

Dry matter intake per animal is dependent upon animal characteristics and feed characteristics (NRC, 2001). While a simple approach is not sufficient for ration formulation and analysis, it is sufficient for mixer sizing. With non-lactating (dairy or beef) cattle, needed mixer capacity could be based on assumed intake of 2.5% of body weight. For lactating cows, the following intake estimating equation can be used to size the mixer (NRC, 2001, without the week of lactation adjustment, English units):

$$DMI = 0.372\ (FCM) + 0.118\ (BW).75$$

Where:

DMI = daily dry matter intake per animal, lb DM/day;

BW = body weight of the animal, lb; and

FCM = daily milk production level, lb/day of 4% fat corrected milk.

For determining the size of a TMR mixer, one could assume a typical ration DM content of 60%. If DM content is below 50%, intake may be reduced (Beede, 1990). Also, TMR density ranges from 15 to 20 lb/ft^3, with a typical value of 17 lb/ft^3 (Spain et al., 1993). Wetter rations containing large amounts of wet forages generally require more feed per day and may have a lower bulk density; both may contribute to the need for larger mixers. An example of mixer sizing is included in Figure 1.

Optimizing the Mixer Operation

Besides proper mixer selection, consistent day to day operation is required. Factors such as fill order (sequence of putting feedstuffs into the mixer), mixing time, mixing protocol, moisture levels of feedstuffs, and scale maintenance and calibration can all dramatically affect mix uniformity. When considering mix uniformity, there are two distinct types of variation: variation *among similar batches* and variation *within a single batch* (see Appendix). Variation *among batches* is controlled by monitoring feedstuff characteristics and using proper formulation and weighing. *Within batch* variation is controlled with proper mixer operation.

Variation among batches

Consider a simple base ration with 5 ingredients, not counting minerals (e.g., corn silage, haycrop silage, corn grain, soybean meal, and wheat midds). There are 15 reasons why the average energy concentration in the mixed ration may not be as formulated on paper or computer. Since energy concentration is a weighted average based on DM makeup of the mix, errors in the 5 ingredient weights, 5 ingredient DM concentrations, and 5 ingredient energy concentrations contribute to uncertainty or error in the final mix. There are ways to evaluate the sensitivity of TMR characteristics to variations in each of these variables. Buckmaster and Muller (1994) applied uncertainty analysis to blended livestock rations and concluded that nutrient concentrations in forages likely contribute most to *among batch* variation in TMR nutrient concentrations. The sensitivity of actual ration uncertainty to ingredient characteristic uncertainty depends upon the makeup of the ration; there is compelling evidence that frequent and good sampling of forages for chemical and physical quality attributes is necessary to keep the TMR properly formulated (Kertz, 1998; James and Cox, 2008).

Variability in crude protein concentration of TMR delivered was reported by James and Cox (2008). With means near 17.2%, the standard deviations were 1.4 to 2.1%, and the maximum to minimum range was as high as 12%. They noted significant differences between farms in loading accuracy, reflective of operator ability and diligence and equipment differences. Silages, in general, had the highest amount of deviations by load. Loading accuracy requires both accurate scales and careful mixer operators.

Forage moisture content can also vary substantially from week to week (sometimes day to day; Shaver, 2000). Figure 2 illustrates some typical variation in silage DM content with some data from real Pennsylvania dairy farms. As moisture content increases, the chemical quality attributes of the ration are diluted. As an example, consider a swing in moisture content such that the haycrop silage gets wetter (e.g., due to rain on a bunker or change in harvest-time conditions). Since protein in haycrop silage contributes considerably to the protein in the ration and since the ration is formulated based on weight with an assumed DM content, the ration will not have enough protein. Compounding the problem, the energy concentration on a DM basis may be increased due to the relative increased fraction of other ration ingredients. If by chance, intake becomes limited by physiological energy demand rather than physical fill, protein intake may be reduced due to both reduced DM intake and reduced protein concentration. In this scenario, as forage moisture varied without any compensation made at mixing time, the amount of protein and the protein:energy ratio got out of balance. Significant variations in DM content of any ingredient can have similar effects but perhaps on other ration attributes.

It is a simple to use a spreadsheet or a hand calculator to make up a table to account for varying ingredient moisture levels. Since rations are generally formulated on a DM basis, yet mixed on an "as is" or wet matter basis, a little time spent facilitating proper adjustments will be time well spent. If one forage is evaluated for moisture content daily (or perhaps every other day), the ration can be adjusted in a timely manner. With a microwave oven or vortex sample dryer (Buckmaster, 2005), moisture analysis of a forage sample can be done rapidly.

Variation within batches

Variation within batches should be obviously minimized to assure that each "bite" from the bunk is truly a balanced, whole ration. Mixing time, mixing protocol, and fill order are the key variables to control to effect *within batch* variation. Different mixer types and sizes carry different recommendations regarding mixing protocol. Table 1, "Questions to ask the mixer representative", was compiled as a help to get answers to these issues. In the absence of specific recommendations regarding a particular type or brand of mixer, the following protocol should at least be considered:

- Fill the mixer without the mixer running,
- If hay or silage particle size reduction is not desired, place grains and small particle size feeds in first,
- Put long particle size forages in last,
- Mix for 5 to 8 minutes (better yet, count revolutions), and
- Stop the mixer, except for unloading.

The ideas behind this suggested protocol are to minimize size reduction during mixing and to assure adequate blending for a uniform and consistent ration. There are many situations where this protocol is not optimal due to the mixer type, the ration to be formulated, the location of feedstuffs and the feedbunk, etc.; however, these ideas should at least be considered. In some cases, the mixer is designed to perform size reduction so that hay may be a significant part of the ration. For these situations, be sure to monitor particle size distribution of the ration dropped into the feedbunk to assure that targets are being met. If a mixer is designed to do size reduction, take care to avoid excessive mixing time. Just to illustrate that there are different recommendations for different types of mixers, Figure 3 contains a few protocol recommendation examples.

Quality Assurance — Monitoring Your TMR

To get the best performance out of cows fed TMR, it is imperative to measure, mix, test, and monitor rations frequently. Closing the loop on feed delivery to measure the actual output and make changes will generally take more time, but **it is the only way to be sure things are done correctly – regardless of who does the work.**

To close the loop in TMR delivery systems, the quality of the delivered TMR should be monitored. This could be done using physically or chemically observable tracers. The tracer concept is useful for evaluating *within batch* variation.

The simple, on-farm type method of evaluating forage and TMR particle size distribution (Lammers et al., 1996; Kononoff et al., 2003a) has been widely used in the industry; with it, identifying physical tracers in the mix can be rapid. A check of the particle size distribution within the mix can also be a tool in evaluating mix uniformity (Jordan, 2001; Dahlke and Strobehn, 2009). By taking samples along the feedbunk, inconsistencies in blending can be identified. Particle size distribution analysis and/or a tracer count are not necessarily reflections of chemical quality attributes, but they are the easiest, quickest, and least costly tests to conduct; they can be done on the farm in minutes.

The growing emphasis on particle size distribution and effective fiber requires careful attention to mixer management. There is no doubt that mixing time and mixer type significantly affect particle size distribution (Heinrichs et al., 1999; Jordan, 2001). Based on data from real farm rations and mixing protocols, the percentage of long (> 0.71 inches) particle mass can easily be reduced by 35% (Heinrichs et al., 1999); mixer type, makeup of the ration, and mixing protocol are factors affecting particle size reduction. Effective fiber index systems have been proposed to link neutral detergent fiber (NDF) concentration and particle size distribution into one number (Buckmaster, 2000; Yang and Beauchemin, 2007; Dahlke and Strohbehn, 2009). Using an effective fiber index requirement to identify targets for particle size distributions of individual feedstuffs and the TMR provides a framework to monitor the mixing process even more closely.

Regular, complete laboratory testing of TMR samples can get expensive; in an effort to cut corners, many farmers and advisors test only the ingredients – but not the resultant TMR. With feed costs typically making up 40 to 50% of production costs, this may not be the best corner to cut. With some careful selection of samples, even laboratory analysis of multiple TMR samples from the same batch may be helpful. As mentioned previously, there are many reasons that the delivered ration may be different than the intended ration; closing the loop with some measurement of what is delivered is strongly encouraged. It is a given that the attributes of the ingredients must be known so that the ration is formulated properly from the start. The uncertainty analysis of Buckmaster and Muller (1994) can help in identifying which attributes or feeds should be sampled frequently to improve TMR consistency.

Experimenting on the Farm

Mixer experiments

There may be a need for some on-the-farm experimenting with the TMR mixer. Buckmaster and Muller (1992) compared 2 mixer types using particle size distribution and chemical attributes to track uniformity. While experiments like theirs can be expensive and require statistical analysis, there is room for simple, "take a look and make a decision" type experiments on the farm. Some suggestions follow.

Consider experimenting with mixing protocol. Depending upon the type of mixer and the material flow in the mixer, location of the placement of ingredients into the mixer or the sequence of loading can affect mix uniformity and the resulting particle size distribution. By changing one thing at a time, and with some simple replication (do the same thing at least 3 times), you may be able to observe some meaningful differences in outcome. If the mixer is generally run when ingredients are put in, try leaving it off until the all ingredients are in. If you usually run the mixer for 10 minutes or 150 rotations of some drive sprocket, try cutting it in half to see if anything changes.

If you suspect significant size reduction is occurring during mixing, fill the mixer with a single forage to the volume of a typical batch. Operate the mixer as though it were a complete ration for the length of time a ration is typically blended. Measure the particle size distribution of the original silage and of the "blended" silage. Statistical analysis may be required, but trends or large differences may become obvious. Replication is important; do not rely on results from just one test.

A variation on the single forage mixing test to evaluate particle size reduction is a single forage ration with a tracer added in "a corner" or particular spot in the mixer. Tracers such as a bucket of corn cobs (sort some orts to get some), whole shelled corn, whole cottonseeds, miniature carrots, marshmallows, or other easily physically identifiable/countable items may help assess mix uniformity. Be careful to choose tracers which will not be hazardous to animals which may consume the feed and tracers that are added in controlled quantities. If the tracer is weighed or counted, be sure all samples are the same size or that the tracer concentration is normalized to sample size (e.g., kernels per 3 lb sample, not kernels per sample if samples vary from 1 to 3 lb).

Evaluating sorting

There has been considerable emphasis placed on cattle sorting TMR in the bunk (Kononoff et al., 2003b; Leonardi and Armentano, 2003; Vassallo, 2006; DeVries et al., 2007; Dahlke and Strohbehn, 2009). Most conclude that animals sorted against (leaving behind) large particles; however, Sword and Buckmaster (2002) showed that harvest or processing method is important because shredded silage, even though it contained long particles, was sorted less than chopped silage.

Table 2 contains a sorting example to illustrate that worry regarding sorting problems may sometimes be unfounded. Consider a situation where an "as recommended" (Heinrichs and Kononoff, 2002) TMR was delivered with size fractions of 7, 38, 38, and 17% on each of the Penn State sieves. Even if refusals (at 5%) had very different size fractions of 50, 50, 0, and 0% on each sieve, the consumed ration would have had a size distribution of 5, 37, 40, and 18%. Emphasis should be on what is consumed, not what is left behind. Emphasis should be on the consumed ration, not on sorting or consumption within a size range. For the example in Table 2, using the physically effective $NDF_{8.0}$ ($peNDF_{8.0}$) approach of Yang and Beauchemin (2007), the 42% long material (> 0.31") consumed would likely be acceptable.

If sorting is a bona fide issue, as Shaver (2000) suggested, sorting can be addressed by altering TMR delivery in the following manners:

- Feed smaller amounts more frequently,
- Add less hay or process hay finer,
- Roll-process corn silage, and
- Tie up fines with molasses or a similar product.

An alternative is to actually offer slightly more long material so that even with slight sorting, the consumed ration meets the target (Table 2, bottom portion). Monitoring is the key. Even if sorting exists, consistency of the consumed ration may be possible.

Summary

Select a mixer with both maximum and minimum capacities and batch sizes in mind. Be aware of the material flow in the mixer and manage the fill order and mixing time to achieve the most uniform blend in the least amount of time. Monitor ingredient moisture levels, particularly forages by determining DM content regularly. Close the control loop on TMR delivery systems by measuring physical and chemical characteristics of your TMR as it is delivered in the bunk. Consider simple experimentation on the farm which may help you understand how the mixer is working. Monitor the consumed ration.

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Table 1. Suggested questions to ask a TMR mixer representative.

At what maximum percentage of "struck full" capacity is this mixer still effective?
Can this mixer effectively mix small batches? How small?
What is the recommended fill order of solid ingredients?
If I use molasses, fat, or other liquid supplements, when and where should I put them into the mixer?
What is the minimum recommended mixing time or number of revolutions?
Do I need to run the mixer as it is being filled?
Is there a limit to the amount of long hay I can put into the ration? What form(s) can it be in?
Can I accurately control feed-out or emptying rate?
How do I maintain and assure scale accuracy?
Are there places to avoid when putting ingredients into the mixer?
How much power does it take to run this mixer?

Table 2. Example of TMR sorting data analysis.

Size range[a] (inches)	Offered (% of ration)	Offered, amount based on 1 ton of TMR (lb)	Refused (% of ration)	Refused amount, based on 5% refusal of complete blend (lb)	Consumed amount (offered-refused) (lb)	Consumed (% of ration)	(intake/offered) (%)
Ration[b] with suspected sorting problem							
> 0.75	7	140	50	50	90	5	68
0.31 to 0.75	38	760	50	50	710	37	98
0.05 to 0.31	38	760	0	0	760	40	105
< 0.05	17	340	0	0	340	18	105
Slight change to solve the problem, even with slight sorting (consumed ration meeting target)							
> 0.75	9	180	50	50	130	7	77
0.31 to 0.75	38	760	50	50	710	38	94
0.05 to 0.31	36	720	0	0	720	38	106
< 0.05	17	340	0	0	340	18	105

[a]Based on Penn State University sieve set described by Kononoff et al., 2003a.
[b]Target distribution of 7, 38, 38, and 17% respectively for the sieves (Heinrichs and Kononoff, 2002)

The situation:

Two TMR batches per group per day
150 cows in high group
Average weight of 1450 lb, average production of 75 lb 4% FCM/day
150 cows in low group
Average weight of 1350 lb, average production of 55 lb 4% FCM/day
80 dry cows, average weight of 1400 lb
110 growing heifers, average weight of 1000 lb
140 growing heifers, average weight of 500 lb

The charge:

Determine mixer capacity requirement

A solution:

1. Determine the size range of the batches
   High group individual: DMI = 56 lb DM/cow/day (from equation)
   group: (56 lb DM/cow/day)(150 cows)/(2 batches/day) = 4170 lb DM/batch
   Low group individual: DMI = 47 lb DM/cow/day (from equation)
   group: (47 lb DM/cow/day)(150 cows)/(2 batches/day) = 3510 lb DM/batch
   Dry cows individual: DMI = (0.025)(1400) = 35 lb DM/cow/day
   group: (35 lb DM/cow/day)(80 cows)/(2 batches/day) = 1400 lb DM/batch
   Older heifers individual: DMI = (0.025)(1000) = 25 lb DM/heifer/day
   group: (25 lb DM/heifer/day)(110 heifers)/(2 batches/day) = 1380 lb DM/batch
   Young heifers individual: DMI = (0.025)(500) = 12.5 lb DM/heifer/day
   group: (12.5 lb DM/heifer/day)(140 heifers)/(2 batches/day) = 880 lb DM/batch

2. Identify largest and smallest batches
   Largest batch 4170 lb DM
   Smallest batch 880 lb DM

3. Determine mixing capacity needed for largest and smallest batches
   Largest batch: 4170 lb DM @ 60% DM = 4170/0.6 = 6950 lb as-fed
   6950 lb @ 17 lb/cu ft = 6950/17 = 410 cu ft

   Smallest batch: 880 lb DM @ 60% DM = 880/0.6 = 1460 lb as-fed
   1460 lb @ 17 lb/cu ft = 1460/17 = 86 cu ft

The mixer chosen should adequately blend batches ranging in size from about 90 to 400 cu ft. Since the mixer will not likely work best when full, it's physical size must be larger. If the mixer type selected doesn't function well when over 70% full, the "struck full" capacity should be 400/0.7 or about 570 cubic feet. If group size varies throughout the year, this should be considered as well as plans for expansion. Perhaps only one batch per day should be prepared for the non-lactating groups on this farm.

Figure 1. TMR mixer sizing example.

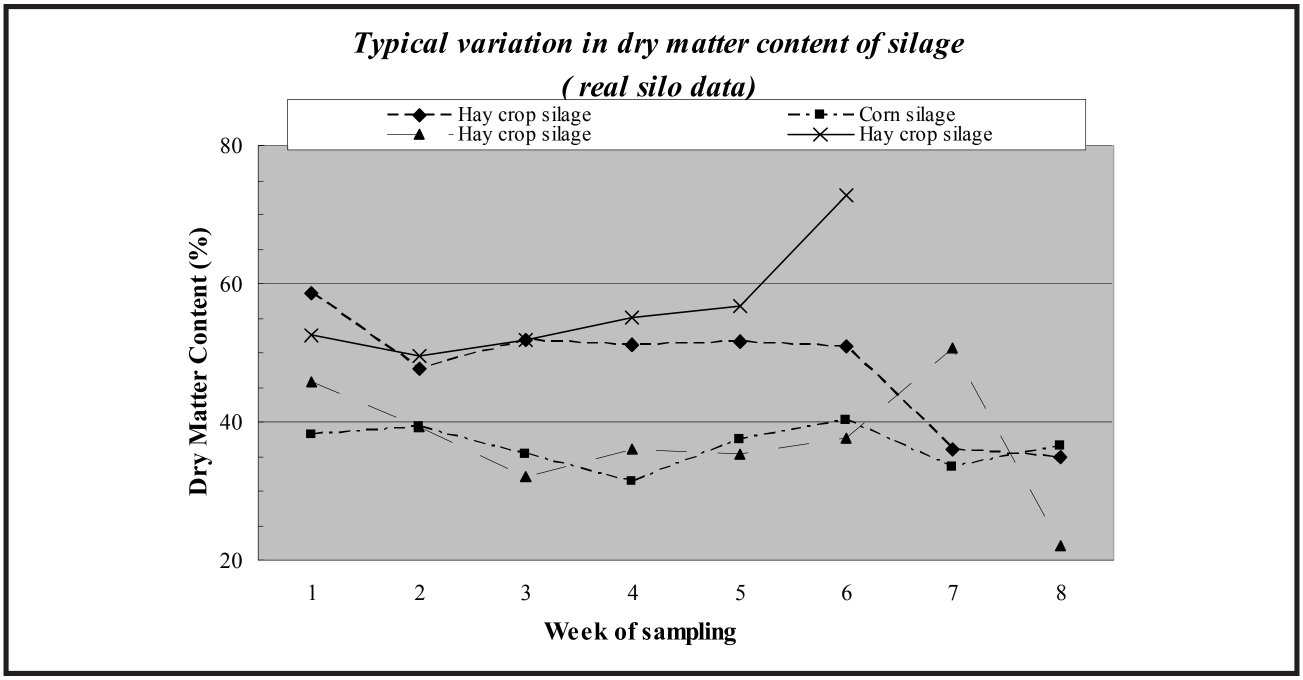

Figure 2. Changes in dry matter content over time.

Vertical Single Auger Mixer

*Silage or hay in first
*Mix 3 to 4 minutes to cut to core of bale
*Run mixer while loading
*Mix and cut for 8 to 12 minutes

Reel Mixer

* Liquids in first
* Small quantity ingredients in next
* Run mixer slowly while loading
* Mix 3 to 4 minutes after filling is complete

Auger Mixer with 4 Horizontal Augers

* Small quantity feeds neither first nor last
* Add chopped hay last
* Run mixer intermittently while loading
* Mix for 2 to 8 minutes

Figure 3. Sample recommendations for mixing protocol..

APPENDIX: TMR Variability Analysis Examples

Example 1 contains simple calculations to assess within batch variation. Five data points would be about the absolute minimum to use; 10 data points or more would be much better.

Example 2 contains calculations to assess among batch variation. The key is to evaluate variation in the blend (via standard deviation, coefficient of variation **(CV)**, or confidence intervals) rather than the mean of the measure used. The example was done evaluating the CV of batch CV so that confidence intervals on within batch CV can be computed. Additionally, the confidence interval was computed based on 25 samples.

Example 3 is a comparison of feed delivery methods. To determine if a new procedure improved blend uniformity, a t-test was used to determine if the new procedure led to a reduced within batch CV. Such tests require many samples; to illustrate why more data are needed, if just two of the fraction of long material numbers in example 3 were changed by 1.0, the t-test p-value would be near 0.10. Of course, there would be nothing wrong with implementing an inexpensive change in protocol, even if you were not positive of an improvement, if there was a hint that uniformity of delivery was improving.

	A	B	C	D	E
3	**Example 1: Within batch variation assessment**				
4					
5	As a tracer, 15 lb of whole shelled corn was added for each ton of TMR which otherwise did				
6	not contain whole kernels. Samples were pulled along the feed bunk using the quartering				
7	technique to get samples that were about 2 lb each. Each sample was separated using the				
8	Penn State separator. In addition to assessing particle size, the kernels were easy to identify				
9	and count since they all end up on the sieve with 5/16" diameter holes. Results here are the				
10	counts of kernels per sample.				
11					
12	Determine the confidence interval on kernel counts as a % of the mean value.				
13					
14	Sample number	Kernel count			
15	**collected at different times during unloading or varied places along the feedbunk**				
16	1	15			
17	2	13			
18	3	10			
19	4	12			
20	5	14			
21					
22					
23	Average	12.8	<=AVERAGE(b14:b18)		
24	Std. Deviation	1.9	<=STDEV(b14:b18)		
25	CV	15.0	<=100*b21/b20		
26	90% confidence range	1.41	<=CONFIDENCE(0.1,b21,5)		
27	90% confidence, %	11.1	<=100*b23/b20		
28	**90% are within this % of the mean**				
29					
30					

	A	B	C	D	E	F	G
3	**Example 2: Among batch variation evaluation**						
4							
5	Five replicate, similar batches were made with:						
6	* the same mixer						
7	* the same ingredients from the same structures (but with some variability)						
8	* the same sequence of fill order						
9	* the same mixer operator and procedure						
10							
11	Samples were pulled along the feed bunk using the quartering technique to get samples that were						
12	about 2 lb each. Each sample was separated using the Penn State separator. Since hay was added as						
13	part of the ration to increase effective fiber, particle size analysis was used to determine the % of long						
14	particles (those on the top PSU sieve) from each sample. The results here are the % of sample mass						
15	which was on the top sieve.						
16							
17	Determine within batch variation and among batch variation.						
18							
19		Batch #1	Batch #2	Batch #3	Batch #4	Batch #5	
20	Sample number	% long mass	% long mass	% long mass	% long mass	% long mass	
21	**collected at different**						
22	**times during unloading** 1	8.2	10.0	9.4	12.0	5.5	
23	**or varied places along** 2	7.0	9.5	7.8	7.0	7.2	
24	**the feedbunk** 3	5.5	6.0	7.6	8.1	3.4	
25	4	9.2	7.4	10.7	10.3	3.8	
26	5	8.0	8.0	8.5	8.0	8.0	
27	**Within batch analysis**						batch 1 formulas
28	Average	7.6	8.2	8.8	9.1	5.6	<=AVERAGE(b23:b27)
29	Std. Deviation	1.4	1.6	1.3	2.0	2.0	<=STDEV(b23:b27)
30	CV	18.5	19.8	14.5	22.3	36.3	<=100*b30/b29
31	90% confidence range	1.0	1.2	0.9	1.5	1.5	<=CONFIDENCE(0.1,b30,5)
32	90% confidence, %	13.6	14.5	10.7	16.4	26.7	<=100*b32/b29
33	90% lower end	6.5	7.0	7.9	7.6	4.1	<=b29-b32
34	90% higher end	8.6	9.4	9.7	10.6	7.1	<=b29+b32
35							
36							
37	**Among batch analysis of the CVs**						
38		Average batch CV	22.3	<=AVERAGE(B30:F30)			
39		Std. deviation of batch CV	8.3	<=STDEV(B30:F30)			
40		CV of batch CVs	37.4	<=100*C39/C38			
41		90% confidence range of batch CVs	6.1	<=CONFIDENCE(0.1,C39,5)			
42		90% confidence of batch CVs, %	27.5	<=100*C41/C38			
43							
44						min among	max among
45	**Analysis of 25 sampled meal portions**					batches	batches
46		Average of meal portions	7.8	<=AVERAGE(B22:F26)		5.6	9.1
47		Std. Deviation of meal portions	2.0	<=AVERAGE(B22:F26)		1.3	2.0
48		CV of meal portions	25.6	<=100*C47/C46		14.5	36.3
49		90% confidence range of meal portions	1.5	<=CONFIDENCE(0.1,C47,5)		0.9	1.5
50		90% confidence of meal portions, %	18.8	<=100*C49/C46		10.7	26.7
51		90% lower end of meal portions	6.4	<=C46-C49		4.1	7.9
52		90% higher end of meal portions	9.3	<=C46+C49		7.1	10.6

	A	B	C	D	E	F
3	**Example 3: Among batch variation comparison**					
4						
5	Five replicate, similar batches were made with:					
6	* the same mixer					
7	* the same ingredients from the same structures (but with some variability)					
8	* the same sequence of fill order					
9	* the same mixer operator but a different procedure					
10						
11	Samples were pulled along the feed bunk using the quartering technique to get samples that were					
12	about 2 lb each. Each sample was separated using the Penn State separator. Since hay was added as					
13	part of the ration to increase effective fiber, particle size analysis was used to determine the % of long					
14	particles (those on the top PSU sieve) from each sample. The results here are the % of sample mass					
15	which was on the top sieve.					
16						
17	Determine if the new procedure made a significant difference (improvement).					
18						
19		Batch #1	Batch #2	Batch #3	Batch #4	Batch #5
20	Sample number	% long mass	% long mass	% long mass	% long mass	% long mass
21	**collected at different times during unloading or varied places along the feedbunk**					
22	1	8.9	10.3	7.0	10.2	6.5
23	2	7.1	9.0	8.6	6.3	6.9
24	3	8.8	6.6	7.0	7.4	5.1
25	4	10.1	7.8	7.2	9.0	5.0
26	5	8.0	9.2	8.2	8.3	7.4
27	**Within batch analysis**					
28	Average	8.6	8.6	7.6	8.2	6.2
29	Std. Deviation	1.1	1.4	0.7	1.5	1.1
30	CV	13.0	16.5	9.8	18.1	17.5
31						
32			alternative mixing		baseline procedure	
33	**Among batch analysis of the CVs**		procedure		from example 2	
34		Average batch CV	15.0		22.3	
35		Std. deviation of batch CV	3.5		8.3	
36		CV of batch CVs	23.2		37.4	
37		90% confidence range of batch CVs	2.6		6.1	
38		90% confidence of batch CVs, %	17.1		27.5	
39						
40	**T test results of comparing CVs**					
41		0.055	<=TTEST(b31:f31,'example 2'!b31:f31,1,2)			
42						
43	**Analysis of 25 sampled meal portions**					
44		Average of meal portions	7.8		7.8	
45		Std. Deviation of meal portions	1.4		2.0	
46		CV of meal portions	18.3		25.6	
47		90% confidence range of meal portions	1.1		1.5	
48		90% confidence of meal portions, %	13.4		18.8	
49		90% low of meal portions	6.8		6.4	
50		90% high of meal portions	8.9		9.3	
51						
52	**T test results of comparing meal portions**					
53		0.494	<=TTEST('example 2'!b23:f27,b23:f27,1,2)			