TMR Delivery and Variability on the Farm

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Introduction

Total mixed rations (TMRs) seem to be the feeding method of choice, at least for non-grazing situations (Spain et al., 1993). Despite the need for an extra piece of equipment (maybe more), the benefits in animal performance have been shown to far outweigh the costs of implementing the concept. The principles of TMRs caught on a few decades ago, but developments in the implementation and preparation are continuing. 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 now is "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.

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)
- Long equipment life

The intent of this manuscript is to discuss mixer management in light of these quality control issues. Ways in which mixers are selected and used 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 operators 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.

Suggested questions to ask of your TMR mixer representative

* At what maximum percentage of "struck full" capacity is the 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 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 feedout 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?

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 paths of recirculating or non-mixing feed. 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 a proper capacity for several reasons:

Allow for adequate blending without excessive mixing time (and perhaps excessive particle size reduction)
Assure adequate blending of the ration
Optimize labor use for feeding
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 when filled with a very small batch. You should consult the mixer manufacturer to determine the range of batch sizes suitable for different mixers. (See sidebar on questions to ask of your mixer representative.)

The following information is included here to aid in the selection of properly sized TMR mixers. Dry matter intake per animal is dependent upon animal characteristics and feed characteristics (NRC, 2001). To estimate needed mixer capacity, a simple approach is sufficient (but it is likely not sufficient for ration formulation and analysis). Dry matter intake for lactating dairy cows can be estimated by:

$$DMI = .0488(BW) - .0000211(BW)^2 + .000000142(BW)^2(MILK)$$

Where:

DMI = daily dry matter intake per animal, lb DM/day
BW = body weight of the animal, lb
MILK = daily milk production level, lb 4% fat corrected milk/day

With non-lactating (dairy or beef) cattle, needed mixer capacity could be based on assumed intake of 2.5% of bodyweight. This will depend upon rate of growth and feeds fed.

For determining the size of a TMR mixer, one could assume a typical ration dry matter (DM) content of 60%. If DM content is below 50%, intake may be reduced (Beede, 1990). Also, with a range between 15 and 20 lb/ft^3, a typical TMR density is 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. Because so many TMR delivery system problems begin with improper sizing, an example is included here to emphasize the importance of proper capacity selection.

Optimizing the Mixer Operation

Besides proper mixer selection, day to day operation of this important piece of equipment should be carefully considered. Factors such as fill order (sequence of putting feedstuffs into the mixer), mixing time, mixing protocol, moisture levels of feedstuffs, 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*. 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

A TMR Mixer Sizing Example

The situation:

Two TMR batches per group per day
75 cows in high group
Average weight of 1450 lb, average production of 75 lb 4% FCM/day)
75 cows in low group
Average weight of 1350 lb, average production of 55 lb 4% FCM/day
40 dry cows, average weight of 1400 lb
55 growing heifers, average weight of 1000 lb
70 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 = 48.8 lb DM/cow/day (from equation)
   group: (48.8 lb DM/cow/day)(75 cows)/(2 batches/day) = 1830 lb DM/batch
   Low group individual: DMI = 41.6 lb DM/cow/day (from equation)
   group: (41.6 lb DM/cow/day)(75 cows)/(2 batches/day) = 1560 lb DM/batch
   Dry cows individual: DMI = (0.025)(1400) = 35 lb DM/heifer/day
   group: (35 lb DM/cow/day)(40 cows)/(2 batches/day) = 700 lb DM/batch
   Older heifers individual: DMI = (0.025)(1000) = 25 lb DM/heifer/day
   group: (25 lb DM/heifer/day)(55 heifers)/(2 batches/day) = 688 lb DM/batch
   Young heifers individual: DMI = (0.025)(500) = 12.5 lb DM/heifer/day
   group: (12.5 lb DM/heifer/day)(70 heifers)/(2 batches/day) = 437 lb DM/batch

2. Identify largest and smallest batches
   Largest batch 1830 lb DM
   Smallest batch 437 lb DM

3. Determine mixing capacity needed for largest and smallest batches
   Largest batch: 1830 lb DM @ 60% DM = 1830/.6 = 3050 lb as fed
   3050 lb @ 17 lb/cu ft = 3050/17 = 180 cu ft

   Smallest batch: 437 lb DM @ 60% DM = 437/.6 = 728 lb as fed
   728 lb @ 17 lb/cu ft = 728/17 = 43 cu ft

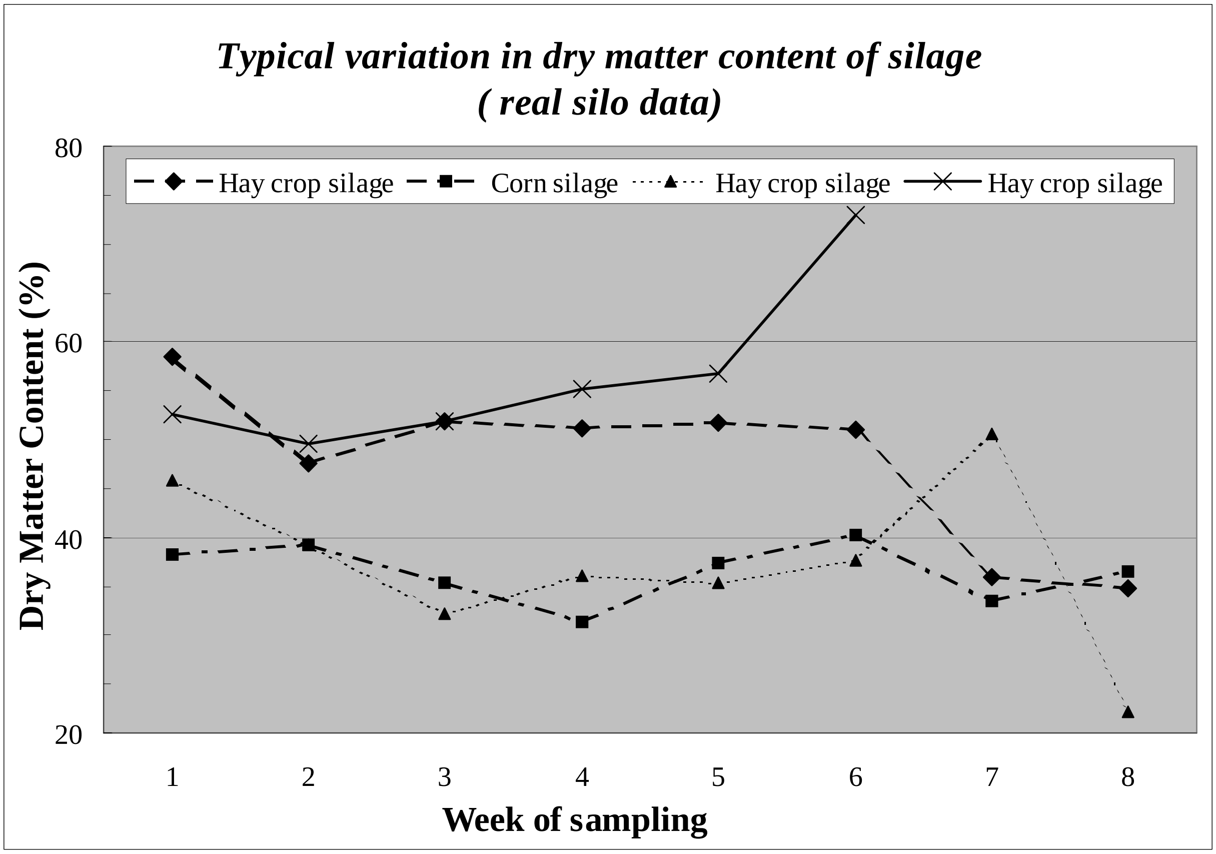
The mixer chosen should adequately blend batches ranging in size from about 40 to 180 cu ft. Since the mixer will not likely work best when full, its physical size must be larger. If the mixer type selected doesn't function well when over 70% full, the "struck full" capacity should be 180/.7 or about 267 cubic feet. Of course, one should account for group size which may vary throughout the year. Also consider expansion plans.

meal, 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 dry matter 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 "inputs". 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; however, it is clear that frequent sampling of forages for chemical and physical quality attributes is necessary to keep the TMR properly formulated.

Forage moisture content can also vary considerably from week to week (sometimes day to day). The graph below illustrates some typical variation in silage DM content with some data from real Pennsylvania dairy farms. As moisture content increases, it dilutes the chemical quality attributes in the ration. As an example, consider a swing in moisture content such that the haycrop silage is wetter. Since protein in a 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, at least on a DM basis, the energy concentration 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. For this scenario, as forage moisture varied with no 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 you analyze one forage for moisture content daily (or perhaps every other day), you can then adjust the ration 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 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. The sidebar of “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 5-8 minutes (better yet, count revolutions).
Stop the mixer except for unloading.

The ideas behind this suggested protocol are to minimize particle size reduction during mixing and to assure adequate blending for a uniform and consistent ration. There are many situations where this protocol is not optimum 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 do particle size reduction so that hay can be a significant part of the ration. For these situations, be sure to monitor particle size distribution of the ration delivered into the feedbunk to assure that targets are being met. If a mixer is designed to do particle size reduction, take care to avoid excessive mixing time. Just to illustrate that there are different recommendations for different types of mixers, here are a few protocol recommendation examples.

Sample recommendations for mixing protocol

Vertical Single Auger Mixer	Reel Mixer	Auger Mixer with 4 Horizontal Augers
* Silage or hay in first * Mix 3-4 min to cut to core of bale * Run mixer while loading * Mix and cut for 8-12 minutes	* Liquids in first * Small quantity ingredients in next * Run mixer slowly while loading * Mix 3-4 minutes after filling is complete	* Small quantity feeds neither first nor last * Add chopped hay last * Run mixer intermittently while loading * Mix for 2-8 minutes

Quality Assurance -- Monitoring your TMR

Britt (1993) observed that herds that get the most performance out of TMRs are the ones that measure, mix, test, and monitor rations daily. Engineers often deal with two types of systems: open loop and closed loop. Open loop systems have no feedback; when control is implemented, there is no looking back to see if the control was actually right, it is just assumed to be right. In closed loop systems, there is some sensing of the actual output, with a comparison of actual output to the desired output; if actual output is different from the target, the control system adjusts automatically. Far too many producers operate TMR delivery systems in open loop mode.

Sending an untrained operator to the field to chop corn silage would be an example of open loop control. That person may commence chopping, filling wagons one after the other, without regard for the actual moisture content or particle size. A trained operator should chop a small load then determine the moisture content. After observing (hopefully measuring!) particle size distribution, he or she would make decisions whether to continue or not, and whether to adjust the feedroll speed or not. Closed loop control (<u>making changes based on actual output</u>) will generally take more time, but when the target is worth achieving, it <u>is the only way to be sure "things are done right</u>" – <u>no matter who is doing the work</u>.

To close the loop in TMR delivery systems, the quality of the delivered TMR should be monitored. This could be done using physically observable tracers in the mix such as cotton seeds, whole soybeans, whole shelled corn, or corn cob chunks. This could also be done using chemically observable tracers such as salt. The tracer concept is useful for evaluating *within batch* variation.

Now that a simple, on-farm type method of evaluating TMR particle size distribution has been developed (Lammers et al., 1996), is widely used in the industry, and is readily available, identifying physical tracers in the mix is easier than ever before (see http://www.enasco.com/farmandranch/ProductDetail.do?&sku=C24683N). A check of the particle size distribution within the mix could be a tool in evaluating mix uniformity. By taking samples along the feedbunk (early in unloading, later, and near the end of unloading), you may be able to identify some inconsistencies in blending. 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 just a few minutes.

The growing emphasis on particle size distribution and effective fiber requires careful attention to mixer management. Mixing time has been proven to significantly alter particle size distribution (Buckmaster et al., 1997a; Heinrichs et al., 1999). Also, there is evidence that mixer type can have a large effect on particle size reduction (Buckmaster et al. 1997a; Heinrichs et al., 1999). Based on data from real farm rations and mixing protocols, the percentage of long (>0.71") particle mass can easily be reduced by 35% (Buckmaster et al., 1997a); obviously, mixer type, makeup of the ration, and mixing protocol are factors affecting particle size reduction. An effective fiber index system has been proposed to link neutral detergent fiber (NDF) concentration and particle size distribution into one number (Buckmaster et al., 1997b; Buckmaster, 2000). By weighting the NDF of the particles according to their particle size, one can assign an effectiveness rating (for stimulating rumination and formation of a rumen mat). If nutritionists can identify the effective fiber index "requirement", knowledge of particle size reduction during the mixing process can be used to set particle size distribution targets for individual feedstuffs in the ration. We are perhaps a couple years away from doing this accurately due to the lack of research data, but the principle of closing the loop of mixer control by measuring the outcome and changing the inputs is easy to implement and possible today.

Regular, complete laboratory testing of TMR samples can get expensive, so many farmers, in an effort to cut corners, test only the ingredients, but not the resultant TMR. With feed costs typically making up 40-50% 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 so many reasons that the delivered ration may be different than the intended ration, that 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, available in simple spreadsheet implementation) can help in identifying which attributes or feeds should be sampled frequently to improve TMR consistency.

Another manner of closing the loop in the TMR delivery system is to use the scales as feedback in addition to the weighing of ingredients. Rations are based on assumed intake levels. By knowing exactly what was delivered and weighing refusals (which, by the way should not be zero!, Lammers et al., 1994), you can check your intake assumption. Knowing that intake is not what you thought or what it should be is the starting point towards fixing it. If intake is not what you thought, you should reformulate the ration so that the animals are getting the daily nutrient requirements or determine why intake is low or excessive and attempt to remedy that.

Experimenting on the Farm

Kammel et al. (1995) suggested that mixer design and dairy feeding are both an art rather than a science. As time passes, hopefully this is becoming less true, but there is some truth to this. Because there are some gray areas and less black and white than most of us would like, there may be a need for some on-the-farm experimenting with the TMR mixer. Buckmaster and Muller (1992) compared two mixer types and worked through the statistical analysis required; they used particle size distribution and chemical attributes to track uniformity. Experimentation may bring to mind sophisticated statistical data analysis, expensive replication, and tremendous resource commitments. While these cannot be ruled out or considered unnecessary, there is room for simple, “take a look and make a decision” type experiments on the farm. Here are some suggestions worth trying.

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 resulting particle size distribution. By changing one thing at a time, and with just 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 and see if anything changes.

If you suspect significant particle size reduction during mixing, fill the mixer 70% full of only a single forage. Run 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. You may need to seek advice and counsel from someone knowledgeable about basic statistics, but most anyone can spot trends or large differences. Replication is important, so don’t 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 water added in “a corner” or particular spot in the mixer. An on-farm analysis of moisture content of several samples taken from the unloading chute (with perhaps varying mixing times) could give an indication of mix uniformity. As mentioned above, tracers (such as a bucket of corn cobs, whole shelled corn, whole cotton seeds) or other easily physically identifiable/countable items may also be a help in assessing mix uniformity. Be careful, though, to choose tracers which will not be hazardous to animals which may consume the feed and tracers that are added in controlled quantity. If the tracer is weighed or counted, be sure the samples are consistent in size or that the tracer concentration is normalized.

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 dry matter 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.

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APPENDIX: Statistics review relevant to TMR mixing performance

Part 1. Evaluating uniformity of mix – identifying the confidence interval of a measure

An example analysis of one mixer with one measure (quality or other characteristic) follows.

Table 1. Sample ingredient data.

Ingredient	Mass into mix (kg)	Dry matter concentration (decimal)	Crude protein concentration[a] (% of dry matter)
Alfalfa silage	700	0.45	19.0
Corn silage	950	0.35	8.4
Corn grain	225	0.88	10.0
Soybean meal	125	0.88	49.9

[a] mean from 3 samples

Mix characteristics. Expected mix concentrations of dry matter and crude protein in the mix are computed as the weighted averages of contributions from each ingredient:

$$DM_{mix} = \frac{(700\bullet0.45 + 950\bullet0.35 + 225\bullet0.88 + 125\bullet0.88)}{(700+950+225+125)} = 0.478 \text{ or } 47.8\% \text{ dry matter}$$

$$CP_{mix} = \frac{(700\bullet0.45\bullet19.0 + 950\bullet0.35\bullet8.4 + 225\bullet0.88\bullet10.0 + 125\bullet0.88\bullet49.9)}{(700\bullet0.45 + 950\bullet0.35 + 225\bullet0.88 + 125\bullet0.88)}$$

$$= .017 \text{ or } 17.0\% \text{ of dry matter}$$

Table 2. Sample mixer uniformity data (10 minutes of unloading time).

Sample No.	Time of collection[a] (minutes)	Crude protein concentration (% of DM)
1	1	16.4
2	3	17.7
3	5	15.4
4	7	15.9
5	9	13.4

Mix statistics. The mean, standard deviation, and coefficient of variation of the crude protein concentration for the mix in table 2 are:

M_{CP} = (16.4 + 17.7 + 15.4 + 15.9 + 13.4) / 5 = 15.8% of DM

$$S_{CP} = \left\{\left[\sum_{i=1}^{n}\left(X_i - \overline{X}\right)^2\right]/(n-1)\right\}^{1/2}$$

$$= \{[(16.4-15.8)^2 + (17.7-15.8)^2 + (15.4-15.8)^2 + (15.9-15.8)^2 + (13.4-15.8)^2]/4\}^{1/2}$$

$$= 1.57$$

CV_{CP} = 100•S/M = 100•1.57/115.8 = 10.0%

Based on this data, a 95% confidence interval (α=0.05) for crude protein concentration in the sample diet is:

$$M \pm \left(t_{n-1,1-\alpha/2} \cdot S\right)/n^{1/2} = 15.8 \pm 2.776 \bullet 1.57/5^{1/2}$$

OR

one can be 95% sure that CP concentration is between 13.8 and 17.7% of dry matter

Table 3. Selected values of the t distribution ($t_{n-1,1-\alpha/2}$).

df	$t_{df,0.975}$	$t_{df,0.990}$	df	$t_{df,0.975}$	$t_{df,0.990}$
1	12.706	31.821	16	2.120	2.583
2	4.303	6.965	17	2.110	2.567
3	3.182	4.451	18	2.101	2.552
4	2.776	3.747	19	2.093	2.539
5	2.571	3.365	20	2.086	2.528
6	2.447	3.143	22	2.074	2.508
7	2.365	2.998	24	2.064	2.492
8	2.306	2.896	26	2.056	2.479
9	2.262	2.821	28	2.048	2.467
10	2.228	2.764	30	2.042	2.457
11	2.201	2.718	35	2.030	2.438
12	2.179	2.681	40	2.021	2.423
13	2.160	2.650	45	2.014	2.412
14	2.145	2.624	50	2.009	2.403
15	2.131	2.602	60	2.000	2.390

Reference: Kleinbaum and Kupper, 1978.

Part 2. Comparing uniformity of mix – comparing the CVs of a measure, not the measure itself.

Sample data illustrating comparisons among mixers or mixing protocols follows.

Table 4. Sample summarized data from mixer experiments[a].

Batch Number	CV of Crude protein concentration	
	Standard mixer	With modifications
1	10.0	7.5
2	6.5	10.5
3	14.7	6.2
4	16.8	3.8

[a] All batches with the same ingredient combination and mixing protocol.

To compare the standard mixer with the one that has been modified, the CVs are compared and significant differences noted. Using the t-test, the standard deviations of the CVs in Table 4 are needed.

$$M_{CV,\ standard} = (10.0 + 6.5 + 14.7 + 16.8) / 4 = 12.0$$

$$S_{CV,\ standard} = \{ [(10.0\text{-}12.0)^2 + (6.5\text{-}12.0)^2 + (14.7\text{-}12.0)^2 + (16.8\text{-}12.0)^2 + \ ] / 3 \}^{1/2}$$

$$= 4.64$$

Similarly,

$$M_{CV,\ modified} = (7.5 + 10.5 + 6.2 + 3.8) / 4 = 7.0$$

$$S_{CV,\ modified} = \{ [(7.5\text{-}7.0)^2 + (10.5\text{-}7.0)^2 + (6.2\text{-}7.0)^2 + (3.8\text{-}7.0)^2 + \ ] / 3 \}^{1/2} = 2.79$$

The pooled standard deviation is the weighted average of the individual standard deviations and is computed as computed as

$$S_{pooled} = [(n_1\text{-}1)\bullet S_{1^2} + (n_2\text{-}1)\bullet S_{2^2}] / (n_1\text{+}n_2\text{-}2)$$

which for the example in Table 4 is

$$S_{CV,pooled} = [3\bullet 4.64 + 3\bullet 2.79] / (4\text{+}4\text{-}2) = 3.72$$

The T statistic is computed for comparison to a tabled value as

$$T = \frac{M_1 - M_2}{S_{pooled} \bullet (1/n_1 + 1/n_2)^{1/2}}$$

which for the example in Table 4 is

$$T = \frac{12.0-7.0}{3.72 \bullet (1/4+1/4)^{1/2}} = 1.90$$

Since this is smaller than the tabled value of 2.447 for α=0.05 and 6 degrees of freedom (n_1+n_2-2), we cannot be 95% confident that the modifications significantly improved mix uniformity. Had T been greater than 2.447, we could be 95% confident that the modifications had significantly improved mix uniformity. (The T=1.90 corresponds to a confidence level of approximately 87%.)

Some points to ponder:

- In this example, 40 samples (8 batches, 5 CP measurements per batch) were used yet did not prove a difference between the mixers or mixing protocol.
- Whether the CV average of 12% for the standard mixer too much to begin with would depend on among batch variation control, the animals being fed, and the number of samples (5 in the example case) used to compute the 12% CV (which determines confidence level).
- There is more to a ration than the CP concentration (or any single nutritive measure). Even though CP variation may be acceptable, a check that variation of other characteristics (such as energy or particle size distribution) may be necessary.
- With analysis of a nutritive measure (such as CP, NDF, etc.), the expected mean should be similar among batches generated with different mixers or mixing protocols as long as ingredients, weights, etc. are similar. However, if the analysis is particle size distribution, checks on what happens to the mean as well as what happens to the variation are needed.