Monitoring Total Mixed Rations and Feed Delivery Systems

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KEYWORDS

• Total mixed ration (TMR) • TMR Audit • Mixing factors
• Penn State Particle Separator (PSPS) • Percent coefficient of variation • Sampling

KEY POINTS

- Total mixed rations (TMRs) are formulated to contain a combination of feedstuffs that provide the right balance of nutrients in every bite consumed.
- Poorly mixed TMRs negatively impact animal performance and health.
- A system has been developed to monitor the feeding process and the consistency of the TMR (TMR Audit is a system developed by Diamond V dairy technical specialist to evaluate TMR consistency. 2008).
- There are 9 main factors in the TMR mixing process that can each create variation in the TMR.
- Facing silage from bunkers and piles and premixing the defaced silage with a loader bucket or mixer wagon makes the silage more consistent in moisture and nutrients and is a key to minimizing variation between formulated and prepared diets.
- Mixing feedstuffs into a uniform TMR requires a lifting and dropping action created by augers, reels, paddles, or a combination of these elements in mixers.
- The Penn State Particle Separator (PSPS) is a useful tool to evaluate particle size variation in a TMR and to evaluate TMR consistency.
- TMR consistency or mix quality can be determined by performing PSPS analysis on 10 equally spaced samples of freshly delivered TMR along the feed bunk.

Videos of pushing, lifting, and mixing defaced haylage as it is made into a pile; mixing and unloading haylage that was stored in a bag; mixing action of a well-maintained vertical mixer and lack of proper mixing action of a vertical wagon with a wornout kicker plate; 2 fresh cows in the same pen eating hay or grain in a TMR that was poorly mixed with underprocessed alfalfa hay; the influence of unlevel mixer box (left) and level mixer box (right) on distribution and

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consistency of the TMR; feeder loading corn silage in the front of a dual-auger vertical mixer wagon; overfilled and normal-filled reel-auger mixer; overfilled 4-auger mixer and overfilled dual-auger vertical mixer; an underfilled dual-auger mixer containing close-up dry cow TMR with mineral remaining on the auger; grain mix does not get mixed into the TMR; liquid dispensed through a single pipe in front of the mixer box accompany this article at http://www.vetfood.theclinics.com/

THE TOTAL MIXED RATION AUDIT

The TMR Audit is an on-farm evaluation of the following:

- Silage management
- Distribution and levels of feed and sorting across feed bunks
- Feed center organization and feed mixing equipment flow
- Total mixed ration (TMR) loading and mixing process
- TMR delivery
- Evaluation of the TMR particle size consistency within and across loads of TMR

This article focuses on reducing variation in TMRs with silage face management and with TMR loading and mixing.

REDUCING VARIATION IN CORN SILAGE AND HAYLAGE

A key part of the TMR Audit evaluates the feed out management of silages. Key practices that minimize dry matter (DM) and nutrient variation and silage spoilage are as follows:

- Vertical and smooth faces from where the silage is removed each day
- An adequate depth of silage is removed from the face each day to prevent heating and spoilage
- The leading edge of plastic covering the silage is cut back at least twice weekly to minimize spoilage and weighted with a continuous row of tires to prevent air from traveling across the silo beneath the plastic
- Spoiled silage is removed before facing
- Multiple layers of plastic, and the use of oxygen-limiting plastic, help to reduce spoilage
- The mechanically defaced silage is premixed with the loader bucket or mixer wagon before feeding
- Little to no loose silage should remain after feeding is complete

Significant variation in DM and nutrients often exists across the vertical face of haylage and corn silage stored in bunker silos.[1] Similar variation occurs in forages stored in bags and bales. A key management approach to minimizing this variation, and in making “the paper” ration more similar to the prepared TMR, is to premix forages before they are used to make a load of feed. For example, there was a stepwise reduction in the differences between the high and low content of crude protein (**Figs. 1–3**) in haylage sampled directly from the face (F) of a drive-over pile, from haylage mechanically faced into a windrow (WR) and from mechanically faced haylage after it was pushed and lifted into a conical shaped pile (P) as shown by the video (Video 1). **Fig. 4** shows average content and coefficients of variation of selected nutrients in alfalfa haylage sampled from the F, WR, and P. Pushing and lifting haylage into a pile with the pay loader created a mixing action that reduced the nutrient variation

Fig. 1. The crude protein content expressed on a dry matter basis in 10 samples taken from the face of a haylage drive-over pile.

Fig. 2. The crude protein content expressed on a dry matter basis in 10 samples taken from haylage that was mechanically faced from a drive-over pile.

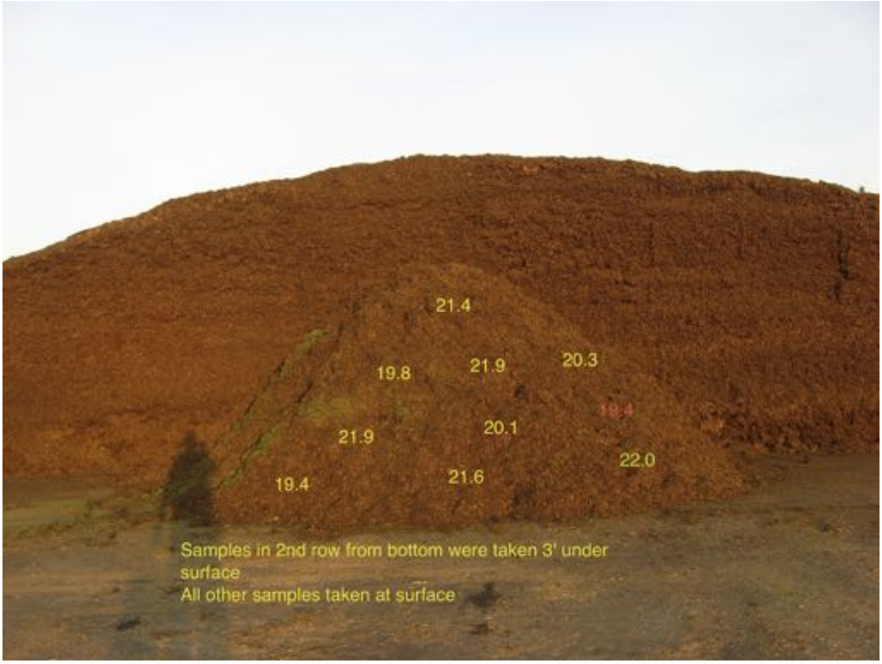
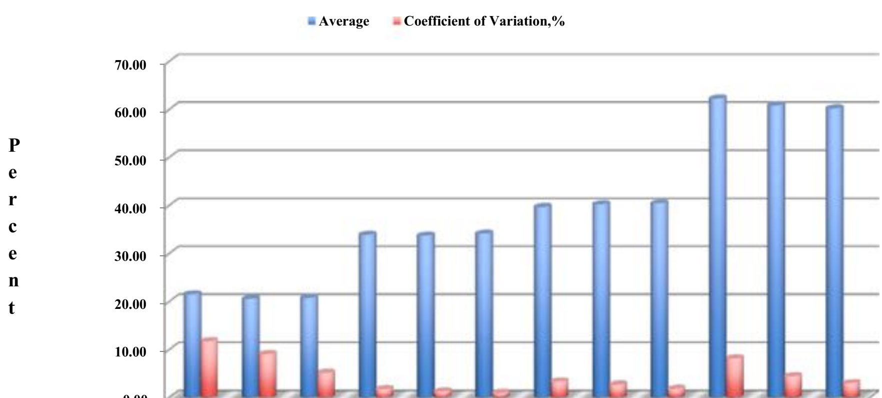


Fig. 3. The crude protein content expressed on a dry matter basis in 10 samples taken from haylage that was mechanically faced and then pushed and lifted into a conical-shaped pile.

in the haylage. This process can be done for corn silage and alfalfa hay bales. Haylage or corn silage stored in bags can vary a lot in moisture and nutrient content as one moves from one end to the other. Video 2 shows how haylage stored in a bag was loaded into a mixer, blended for a short period of time, and then unloaded at the feed center where the loading of TMRs occurred on this particular dairy.



	Crude Protein Face	Crude Protein WR	Crude Protein Pile	ADF Face	ADF WR	ADF Pile	aNDF Face	aNDF WR	aNDF Pile	Protein Sol Face	Protein Sol WR	Protein Sol Pile
Average	21.54	20.58	20.79	33.94	33.74	34.17	39.68	40.27	40.45	62.27	60.86	60.23
Coefficient of Variation,%	11.75	9.07	5.18	1.78	1.31	1.00	3.40	2.71	1.85	8.16	4.48	3.05

Fig. 4. Reducing nutrient variation in alfalfa haylage.

TMR SAMPLING

Ten equally spaced samples of TMR are taken across the feed bunk for each load of TMR that is tested for consistency. Samples are taken immediately after the TMR is delivered and before the cows start eating and disturbing the TMR. Spacing of the samples is determined by counting the number of supporting posts along the feed bunk or along the freestalls and then divide that number by 10 (Fig. 5). A scoop (Fig. 6) is used to collect enough TMR to fill a quart-sized sample bag that can be sealed shut for subsequent analysis. Alternatively, as suggested in Lammers and colleagues,[2] collect a slightly packed sample with a volume of approximately 1.4 L. It is important that the size of all samples is similar to minimize sample-induced variability in the PSPS results. Collected sample sizes should range from 350 to 550 g depending on the TMR. Quart-sized or larger Ziploc bags are labeled (A–J, for example) with a dark-colored Sharpie with "A" representing the beginning (front of the mixer box) and "J" representing the ending of a load (back of the mixer box) of TMR. The detail on knowing front and back of the mixer box helps determine effects of loading position on the mixer box and unlevel mixer boxes on TMR mix quality (discussed later in this article). Note that the effects of loading position and unlevel boxes cannot be evaluated in wagons (usually triple-auger vertical) that unload from the front and back at the same time or when the feeder backs up several times along the bunk to deliver the TMR. However, variation of the TMR can still be evaluated in these situations by taking the 10 samples.

PENN STATE PARTICLE SEPARATOR PROCEDURE AND DATA ANALYSIS

- Arrange samples in order from A to J for each load
- Use the PSPS procedure on each sample, with a consistent sample size and PSPS technique.[2–4]

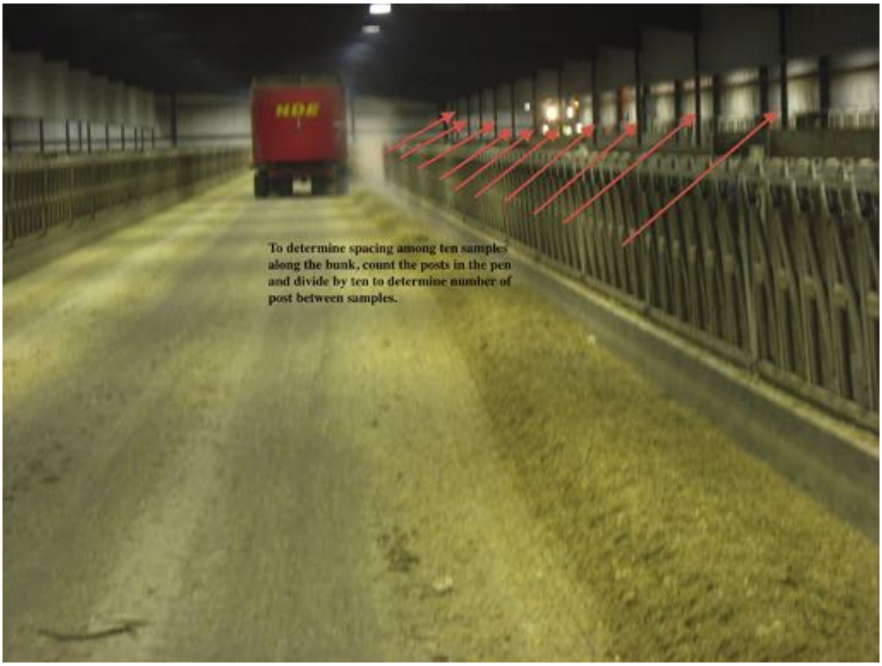


Fig. 5. Counting the posts along the feed bunk help determine the sampling interval.

Fig. 6. Plastic scoop (1-pint) used to take TMR samples.

- Record weights for top, middle, and bottom screens
- Use a spreadsheet software to determine the average and SD. The percent coefficient of variation (CV%) is determined for the top, middle, and bottom screens. The CV% is SD divided by the average times 100. The 4-screen system can be used, but CV artificially increases because percentage levels decrease on the third screen and pan causing the numerator in the CV calculation to become smaller. For the purpose of determining TMR consistency, the 3-screen system works better.
- Use the data from the middle and bottom screens to evaluate particle size consistency of the TMR. The middle and bottom screens are the important screens to use for milking rations.
- Use CV% as the standard for TMR particle size consistency (mix quality) and to test mixer efficiency.[5]
- Goal: 2% CV or less for the middle and bottom screens.
- Plot the data in a line chart and summarize the data as shown in Table 1.

Table 1
Penn State Particle Separator results on a total mixed ration along the length of a feedbunk to assess consistency of mixing

Bunk		Penn State Shaker Box, %		
Location	**Bunk Sample No.**	**Top**	**Middle**	**Bottom**
A Front of load	1	4.5	56.2	39.2
B	2	5.6	55.8	38.6
C	3	5.6	55.5	38.9
D	4	6.8	55.2	38.0
E	5	3.4	57.1	39.5
F	6	3.8	56.6	39.6
G	7	5.0	55.5	39.5
H	8	4.2	55.4	40.4
I	9	2.6	55.9	41.5
J Back of load	10	3.9	54.5	41.5
Average	**Ave**	**4.5**	**55.8**	**39.7**
Coefficient of variation	**% CV**	**26.96**	**1.32**	**2.90**

This procedure was adapted from the feed industry standard of testing mixer performance in feed mills.[5]

THE 9 FACTORS CAUSING TOTAL MIXED RATION VARIATION

The goal of the TMR Audit is to help reduce variation of the major ingredients (corn silage, haylage, and hay). The next part of the audit is to evaluate the TMR mixing process and reduce variation in the critical control points of making a TMR. There are 9 factors or critical control points that can contribute to TMR variation individually or in combination. Each of these is discussed in detail. They are as follows:

1. Worn mixer augers, kicker plates, and knives
2. Mix time after the last added ingredient
3. Unlevel mixers
4. Loading position on the mixer box
5. Load size
6. Hay quality and processing
7. Loading sequence
8. Liquid distribution
9. Vertical mixer auger speed

Worn Mixer Augers, Kicker (Deflector) Plates, and Knives

There are 2 major types of TMR mixers, horizontal and vertical, that can be pulled by tractors, mounted on trucks, or mounted as stationary mixers. There are several types of horizontal wagons:

- 4-augers
- Mono-mixer (1 auger)
- 3-augers
- Reel-auger
- Paddle
- Drum mixers

Figs. 7 and 8 are schematics of a 4-auger and reel-auger, respectively. Drum mixers are usually seen on small dairies that are mixing small batches of TMR or are used in larger feedlot operations to mix mineral and protein premixes. The most common horizontal mixers seen on dairies in the United States are 4-auger and reel-auger mixers. Vertical mixers are replacing the horizontal mixers in both the dairy and beef feedlot industries because they can mix larger volumes of wet feeds without getting overfilled too easily.

The vertical mixers are defined as follows:

- Single auger
- Dual auger
- Triple auger

Fig. 9 is a schematic of a dual-auger vertical mixer. Most types and brands of mixers can mix a high-quality TMR if the feeder follows the proper procedures for all 9 critical control areas. However, TMR particle size consistency, as well as moisture and nutrient consistency along the feed bunk (TMR mix quality), can decrease significantly with worn blades, kicker plates, and augers.

Worn augers

Mixers are factory set with specific agitator clearances of 0.3 to 0.9 cm.[6] As these clearances increase because of wear, mixer efficiency is impaired.[6] The easiest way

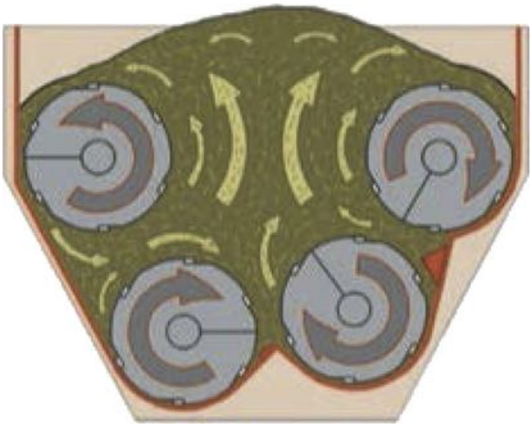


Fig. 7. A 4-auger horizontal mixer. (*Courtesy of* Kuhn North America, Inc., Brodhead, WI; with permission. Available at: http://www.kuhnnorthamerica.com/us/product-tips-tmr-mixer-guide.html.)

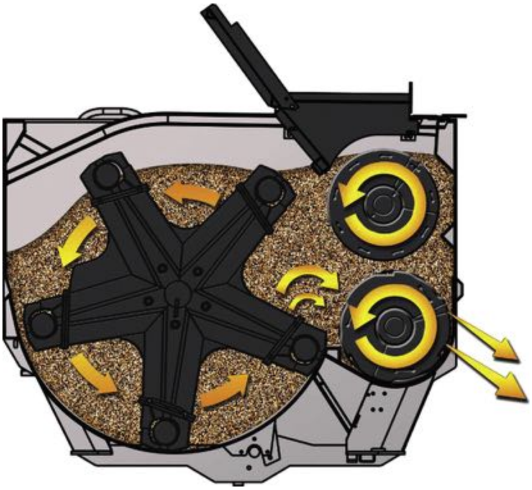


Fig. 8. A reel-auger horizontal mixer. (*Courtesy of* Kuhn North America, Inc., Brodhead, WI; with permission. Available at: http://www.kuhnnorthamerica.com/us/product-tips-tmr-mixer-guide.html.)

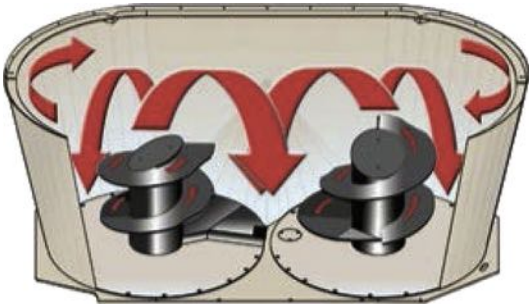


Fig. 9. A dual-auger vertical mixer. (*Courtesy of* Kuhn North America, Inc., Brodhead, WI; with permission. Available at: http://www.kuhnnorthamerica.com/us/product-tips-tmr-mixer-guide.html.)

to evaluate wear on augers is to look for feed under horizontal augers or reels (Figs. 10 and 11) and to look for the feed ring inside vertical mixers (Fig. 12). Fig. 13 shows the changes in the levels of TMR in middle and bottom screens of the PSPS from the front (samples 1–5) to the back (samples 6–10) of the reel mixer shown in Fig. 11. These changes resulted in significant variation in the TMR particle size due to the malfunctioning part of the reel.

Worn kicker plates

Kicker plates or shoes are welded or bolted to the top and at the leading corner of the bottom piece of flighting on vertical augers. Some brands of mixers will bend part of the leading edge of the bottom flighting down toward the floor of the wagon to create a deflector. When the auger rotates, these devices lift the TMR upward to create a hole or space for the TMR to fall into. Also, these devices direct the feed toward the center of the auger so that the feed can be lifted and dropped into the holes. This action mixes the TMR. Video 3 (left video) is correct mixing action in a new mixer wagon and Video 3 (right video) is poor mixing action in a vertical wagon with a worn kicker plate. Notice in the video (see Video 3, left) how the TMR comes up through the top of the augers and then rolls toward and down the sides of the mixer box. Contrast to the video on the right where there is very little movement of the TMR because of the worn kicker plate. As a result, the TMR will be inconsistent in particle size distribution and chemical analysis. Inconsistent particle size maybe clumps of unprocessed hay, or clumps of haylage, or streaks of grain and/or protein concentrate in the TMR along the bunk. There also can be differences in moisture and nutrients in the TMR along the bunk. In addition to worn augers and kicker plates, rotational speed (rpm) of the auger can also affect movement of the TMR. Slow auger speed will make the TMR move up and down with no rolling action. This type of action will decrease mix quality, which is discussed in the section "Vertical Speed Auger Mixer."

Fig. 14, left, shows a well-conditioned kicker plate and Fig. 14, right, is a photo of a worn out kicker plate in Peecon mixer boxes. The arrow in the picture on the left shows a metal plate on top of the metal wedge welded to the flighting, whereas the arrow in the picture on the right shows the metal plate missing. The best way to determine what the kicker plate should look like is to download a photo of the new kicker plate from the Web site of the manufacturer and compare. Fig. 15 is a photo of a worn deflector in a Trioliet mixer box resulting in feed lying on the floor of the mixer box.

Fig. 10. TMRs under the augers indicate excessive wear, which decreases auger diameter and mixing ability.

Fig. 11. TMR under the front part of the mixer rail indicating a bent or worn rail.

Fig. 12. TMR ring between augers and mixer wall suggests worn kicker plate and/or augers.

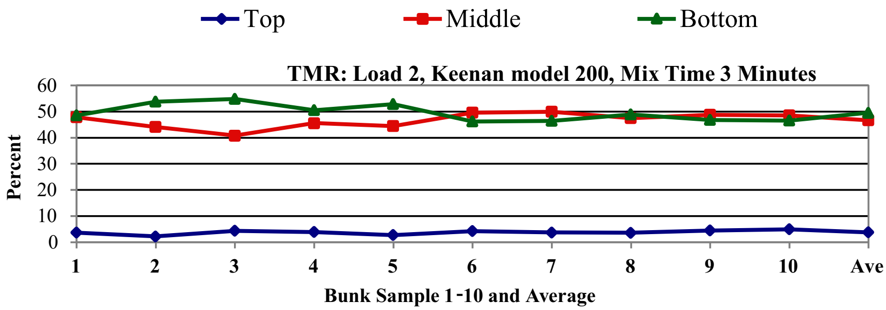


Fig. 13. The effect of a bent mixer reel on the levels of TMR in the middle and bottom screens of the PSPS.

Worn knives

Fig. 16, left, is a photo of a mixer box with sharp knives and Fig. 16, right, shows dull knives. Dull knives do not process alfalfa hay or baleage or straw very well, resulting in extra-long pieces or clumps of hay (shown in Fig. 17) that are easily sorted against and not eaten by cows. Video 4 is a video of 2 fresh cows eating the same ration at the same time; however, one is eating hay while the other is eating the grain because the forage was not well processed and the TMR not well mixed.

The degree and speed of wear on the augers, kicker plates, and knives depends on the size of the herd, and the amounts of hay, baleage, or straw fed. Routine replacement of blades, kicker plates, and augers is required to keep TMRs consistent. Feed managers should have maintenance programs in which these critical parts are inspected at least monthly.

Mix Time After the Last Added Ingredient

Several investigators have cited mixing time as a critical element to obtain consistent mixes.[6–8] Groesbeck and colleagues[5] showed that the amount of mix time after the last ingredient was added to a swine diet in a horizontal ribbon mixer was important in reducing the variation in the concentration of salt. Salt is an essential nutrient added to the diet and is often used in the feed industry as a marker to measure mixer efficiency.[5]

Fig. 14. A good conditioned (new) kicker plate (left photo) and a worn out kicker plate (right photo) in Peecon vertical mixer boxes.

Fig. 15. The deflecting edge is worn off, allowing feed to build up on the floor of this Trioliet mixer box.

Mixer efficiency is defined as the amount of time needed to reach 10% CV or less among 10 samples.[5] One of the most common mistakes in TMR mixing is lack of mix time after the last added ingredient (usually corn silage or liquid supplement). With inadequate mix times, often the corn silage at the top of the load does not get mixed and is delivered toward the end of the load as pure corn silage. This is even more prevalent as mixer boxes are overfilled. Suggested mix times after the last ingredient with tractors/trucks at nearly full power (1700–2000 rpm engine speed) are as follows:

- Horizontal auger mixers: 5 minutes
- Horizontal reel-augers and verticals: 3–5 minutes

Inadequate mix times result in inconsistent TMRs, as shown in **Table 2** comparing 3.5 versus 5.0 minutes of mix time in a 4-auger horizontal mixer on CVs.

Unlevel Mixers

Video 5 is a video of a dual-auger vertical mixer on the left that has an improper hitch mount causing the wagon to be lower in front than in back. As a result, whole

Fig. 16. Sharp knives in a vertical mixer box (left photo), and a vertical mixer with completely worn out knives (right photo).

Fig. 17. Clumps of alfalfa hay from a round bale that did not get processed in a vertical mixer with dull knives.

cottonseed builds up at the front of the wagon due to poor distribution. The video on the right shows the very same mixer with the hitch adjusted to make it level. There is even distribution of ingredients, including whole cottonseed. Fig. 18 shows the TMR from the unlevel load (left) and level load (right), respectively. The unlevel load of TMR was very inconsistent due to the grain-concentrate and whole cottonseed migrating to the lower part of the wagon during loading and mixing. Fig. 19 shows PSPS analysis of 10 samples taken from a triple-auger vertical that was parked in a ramp that was too short. This caused the grain-concentrate portion of the TMR to migrate to the lower part of the wagon, which was the back end in this case. Notice how the amount of relatively more dense material in the bottom screen increases from sample 1 (front) to sample 10 (back), and the opposite trend is observed for the middle screen. The middle screen typically contains less dense feedstuffs, such

Table 2
Influence of mix time after the last added ingredient on total mixed ration mix quality (percent coefficient of variation [CV%])

	Penn State Shaker Box Results					
	3.5 min			5 min		
Bunk Sample No.	**Top**	**Middle**	**Bottom**	**Top**	**Middle**	**Bottom**
1 Front	10.9	38.2	50.8	14.9	38.8	46.3
2	8.6	38.8	52.6	12.6	41.5	45.9
3	11.6	38.4	50.0	12.5	40.0	47.5
4	15.6	37.8	46.7	14.3	39.3	46.5
5	13.9	39.1	47.0	13.1	39.8	47.1
6	10.8	38.2	51.0	11.7	39.5	48.8
7	9.2	39.1	51.7	12.6	38.8	48.6
8	12.2	41.7	46.0	12.4	38.7	48.9
9	14.1	38.1	47.7	13.0	40.2	46.9
10 Back	11.6	37.3	51.1	11.4	39.3	49.3
Average, %	**11.8**	**38.7**	**49.5**	**12.8**	**39.6**	**47.6**
CV%	**18.52**	**3.11**	**4.81**	**8.15**	**2.12**	**2.56**

Fig. 18. The influence of unlevel mixer box (left photo) and of a level mixer box (right photo) on TMR consistency at the feed bunk.

as haylage and corn silage and small particles of hay. This is a typical pattern in the PSPS analysis for both unlevel mixer boxes and for improper loading position on vertical wagons.

Loading Position on the Mixer Box

Loading position refers to the location on the mixer box where the feeder is dumping ingredients. Improper loading position on the mixer box will create a poorly mixed TMR. The correct loading positions on mixer boxes are as follows:

- Reel with a horizontal auger should to be loaded over the augers in the center of the wagon
- Single-auger, dual-auger, triple-auger, and 4-auger horizontal mixers need to be loaded in the center of the box
- Single-auger verticals can be loaded from either side of the box
- Dual-auger verticals need to be loaded between the augers and can be loaded from either side
- Triple-auger verticals need to be loaded over the middle auger and can be loaded from either side
- One exception to loading position on the verticals is that the feeder needs to drop large round or square bales of forage directly on top and center of the augers to avoid bending the auger flighting

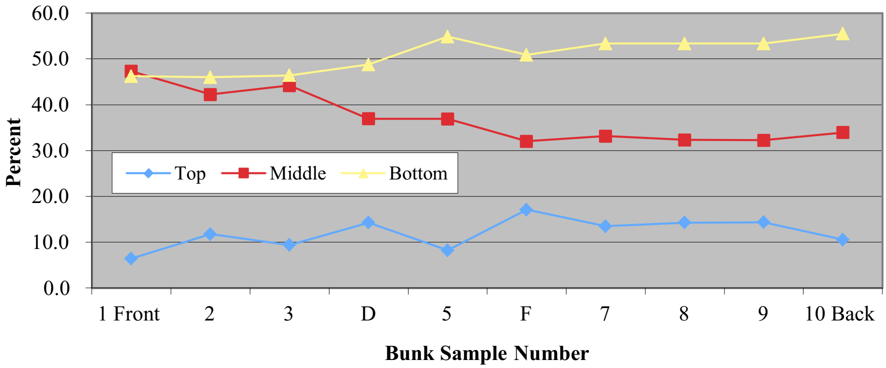


Fig. 19. Influence of unlevel mixer box on TMR particle size distribution on the PSPS screens.

Fig. 20 shows a feeder loading out of position on a dual-auger vertical mixer. This particular brand of mixer has placed a red dot on the side of the mixer denoting the proper loading spot. Fig. 21 shows the influence of loading liquid in the front versus the middle of a dual-auger vertical mixer on TMR distribution in the middle and bottom screens of the PSPS. The liquid was a whey product that bound more of the small feed particles in the bottom screen to the larger particles in the middle screen at the front of the wagon. There was a continuous increase in the amount in the bottom screen as the load was discharged and more of the feed came from the back of the wagon. The opposite trend was seen for the middle screen. The mixer was moved ahead approximately 4 feet so that the liquid whey could be loaded between both augers or in the center of the mixer box. This resulted in the very consistent TMR shown by the dotted lines (see Fig. 21). Fig. 22 shows the influence of loading a liquid protein supplement in the back of a dual-auger vertical wagon on moisture and protein content in the TMR. Both moisture and protein increase linearly as you move from the front to back of the wagon. This resulted in a very inconsistent TMR along the feed bunk. Because cows are quite territorial within the pen, an inconsistent TMR like this will result in cows consuming variable diets. This potentially leads to differences in rumen health and digestion, rumination patterns, and manure consistency among cows within the pen fed this ration. Video 6 shows a feeder dumping corn silage over the front auger of a dual-auger mixer wagon and Fig. 23 shows the increased particle distribution in the middle screen of the PSPS for samples representing the front part of the wagon. As the amount of corn silage decreased on the middle screen, the particle amount in the top screen increased as the load was discharged from the front to the back of the wagon. Most dual-auger and triple-auger vertical wagons move feed back and forth in the wagon, but it takes time. These results show that feed dumped in either end of these wagons does not completely mix during routine mixing. If mixing time is increased so that the TMR is completely mixed, then there is increased risk of decreasing effective particle size in the TMR. The increased mixing time would also increase fuel and labor cost. Load all mixers at the proper position as designated by the manufacturer for best performance. Most of the examples on loading position were vertical wagons. However, the same effects of loading position (especially liquid supplements) on TMR mix quality have been observed in horizontal wagons.

Fig. 20. Improper loading position on a dual-auger vertical mixer.

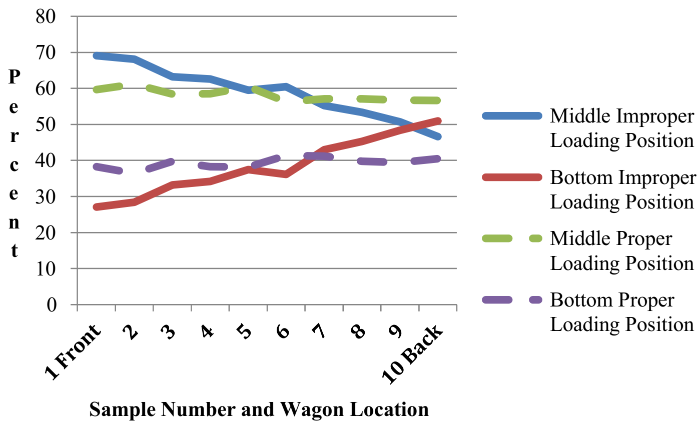


Fig. 21. The influence of loading liquid whey in the front versus center of a dual-auger vertical mixer on levels of TMR in the middle and bottom screens of the PSPS.

Load Size

Overfilling of mixer wagons

Load capacity can be exceeded on all types of mixer wagons, resulting in a poorly mixed load of feed. This is a common TMR mixing error on many dairies and feedlots. Overfilling is a key cause of shrink during TMR loading and mixing. Shrink from overfilling is the loss of feed spilled on the ground. Overfilling occurs for several reasons:

- Undersizing the mixer box for the dairy
- Inaccurate pen counts
- Changes in forage moisture levels (ie, drier silages take up more space)
- Too large of an increase in bunk calls where the mixer box is already at full capacity

The videos in Video 7 show an overfilled reel-auger (left video) and one that is not overfilled (right video). Video 8 shows an overfilled horizontal mono-mixer (left video) and an overfilled dual-auger vertical (right video). Reducing the load size in the mono-mixer shown in Video 8 by 5000 pounds effectively decreased the CV

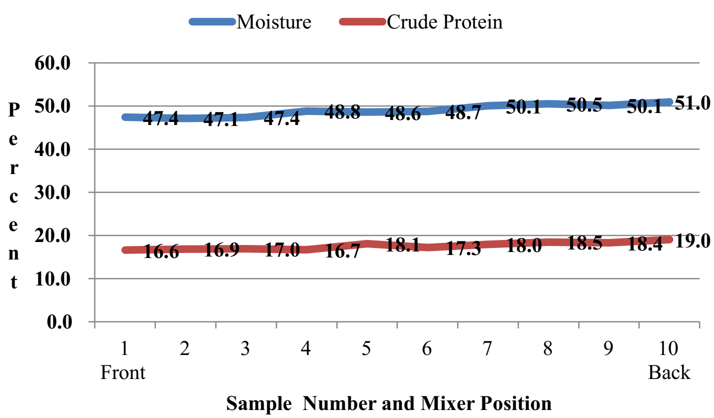


Fig. 22. The influence of loading a liquid protein supplement in the back of a dual-auger wagon on moisture and crude protein levels in the TMR.

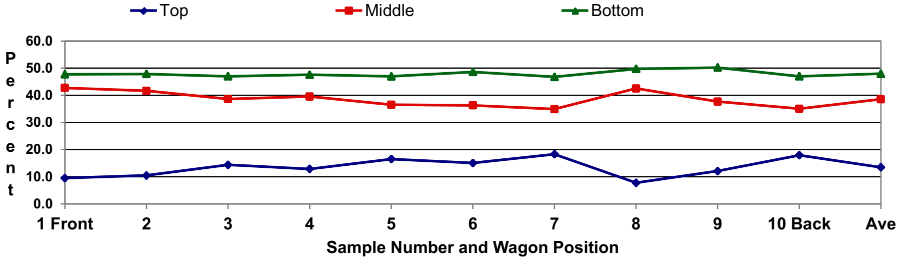


Fig. 23. Influence of loading corn silage in the front of a dual-auger vertical mixer wagon on the level of TMR in the middle and top screens of the PSPS.

(Table 3) for TMR particle size distribution in all 3 PSPS trays and improved TMR mix quality. Recommendations for filling mixer boxes are as follows:

- Reel-auger: allow 4 to 6 inches between the TMR and the rails on the reel (see Video 7 on the right)
- 3-auger and 4-auger horizontal: top of the metal side walls or where you can see good movement of the TMR
- Mono-mixer horizontal: where you can see good movement of the TMR and below the top of the metal side walls
- Vertical mixers: a good rule of thumb is 2 feet above the top of the augers for most brands and types of augers.

Underfilling vertical mixers

Underfilling of vertical mixers occurs when the TMR does not reach the top of the augers so that all of the ingredients are pushed off the augers and mixed. This happens often on smaller dairies that mix rations for smaller pens, such as fresh cow and close-

Table 3
Influence of load size in a mono-mixer horizontal mixer on total mixed ration mix quality (percent coefficient of variation [CV%])

	Penn State Shaker Box Results					
	Overfilled[a]			Normal Filled[b]		
Bunk Sample No.	**Top**	**Middle**	**Bottom**	**Top**	**Middle**	**Bottom**
1 Front	4.9	45.9	49.2	5.6	44.8	49.6
2	2.9	46.3	50.7	6.0	46.0	48.0
3	2.3	44.2	53.5	4.7	46.2	49.1
4	3.8	44.0	52.2	7.4	45.9	46.7
5	4.8	43.8	51.4	5.5	44.5	50.0
6	3.4	47.7	48.9	8.8	42.8	48.5
7	4.3	44.6	51.1	7.0	46.5	46.5
8	3.8	44.2	51.9	8.1	44.1	47.8
9	7.0	37.3	55.7	7.2	43.9	48.9
10 Back	3.6	38.8	57.6	5.9	44.1	50.0
Average, %	**4.1**	**43.7**	**52.2**	**6.6**	**44.9**	**48.5**
CV%	**31.58**	**7.39**	**5.22**	**19.35**	**2.72**	**2.58**

[a] Total mixed ration was overflowing the sides of the mixer box and falling onto the ground.
[b] Load size was reduced by 5000 lb so that feed would not flow out of the mixer. The top of the feed was approximately 2 feet below the top of mixer box.

up dry cow pens. Video 9 shows a dual-auger mixer with close-up dry cow mineral remaining on the auger after loading is complete. Sometimes smaller loads like this can still mix properly if the augers are run at a higher speed.

Hay Quality and Processing

Most nutritionists and dairy producers prefer to have alfalfa hay in the TMR processed so that the maximum length is 3 to 4 inches. Straw should be processed shorter, with few particles longer than 2 inches. These particle lengths are recommended to provide good mixing and to prevent cattle from sorting against the forage. Sorting is a major problem on many dairies throughout the United States. Forage processing is best achieved with commercial grinders that are fitted with screens of defined pore sizes depending on whether alfalfa hay, grass hay, or straw is being ground. The screens used to grind alfalfa hay, grass hay, and straw usually have pore size diameters of 8, 6, and 4 inches, respectively, to grind these forages to desired length. Oftentimes, the same screen is used to process hay and straw by changing the rotational speed of the grinder. Slower speeds are used to process alfalfa hay and higher speeds are used to process straw. The nutritionist often works with the dairy to get the desired length of chop on the forages by experimenting with the grinder pore sizes and rotational speed on the grinder. However, many smaller dairies in United States process hay and straw through mixer wagons equipped with knives. The quality of the forage processing in mixer wagons is highly dependent on the number of knives, auger speed, and condition of the knives (see section on worn mixers, augers, and knives). If clumps of hay or long pieces of hay or straw are observed in the TMR, it usually means dull mixer knives or an inadequate amount of time that the forage was processed in the mixer. It could also be an ingredient mix order problem in which the forage was added later in the mix and was not given enough time to process. Poor hay quality and inadequate processing make TMRs very inconsistent and can affect both variation and level of milk components in a herd (**Fig. 24**).

Loading Sequence

Several investigators have addressed loading sequence as a factor contributing to TMR mix quality.[6–9] The loading sequence will depend on:

- Mixer wagon type (auger-reel vs 4-auger or vertical)
- Ingredient type (density, particle size, and shape and moisture level and flowability)

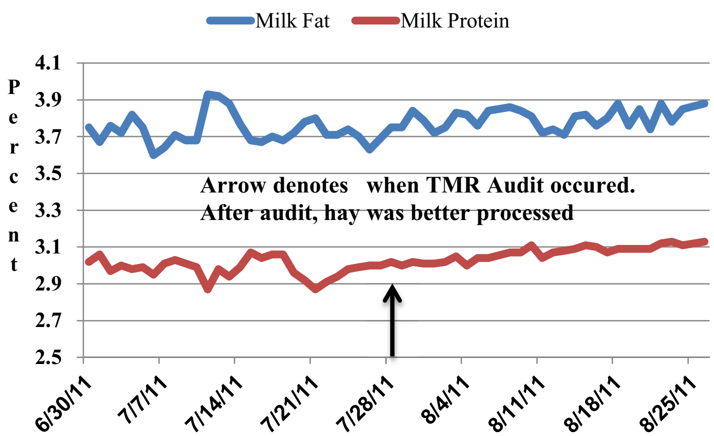


Fig. 24. Milk fat and protein levels in the bulk tank before and after a TMR Audit.

- Inclusion level[6]
- Convenience of loading based on where ingredients are stored at the feed center and time available to the feeder (not the most ideal situation on many dairies)

Generally, lower density and large particle feeds are loaded first, followed by dry more dense feeds followed by wet feeds and last with liquid. With the dry feeds of higher densities, the lower inclusion-level feeds are added first so that they can be blended properly.[6] Use the ratio of 50:1 to blend lower inclusion dry feeds, such as rumen bypass fats and vitamin/mineral premixes. Example, if 50 lb of rumen bypass fat is being added, then the load size should be no more than 2500 lb. The mixer should be running to allow the lower inclusion feed to mix.

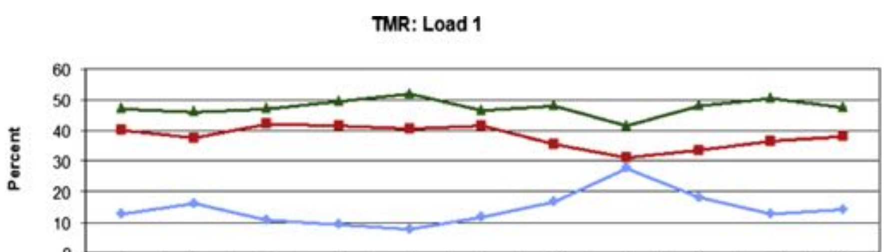
An example of a dairy lactation TMR loading sequence in vertical and 4-auger mixers would be as follows:

1. Long-stem or chopped hay or straw
2. Dry grain (use as a carrier for blending low-inclusion dry feeds)
3. Low-inclusion dry ingredients
4. Protein mix
5. Wet by-products
6. Haylage
7. Corn silage
8. Liquid

If loading a reel-auger mixer, grain has to be added before hay or straw to prevent breaking or bending of the reel. Then follow the rest of the sequence shown previously. Sometimes, the order has to be adjusted to get a better TMR mix quality. An example is loading wet alfalfa haylage first or second so as to break down chunks of the haylage that may be frozen or simply clumped together.

Figs. 25 and 26 show the results of the PSPS on a lactating cow TMR with haylage added second to last and second, respectively, in a 4-auger horizontal mixer. Loading the haylage second behind the alfalfa hay with this particle type of wagon allowed the haylage and hay to blend and break down the forage chunks. The CVs for the middle and bottom screens decreased on an average from 7.8% to 1.8% with the change in mix order.

Fig. 27 is another example in which TMR mix quality was improved dramatically by increasing mix time from 2 to 4 minutes after the last added ingredient and then changing mix order to further improve the mix quality. This TMR was mixed with a dual-auger



	1	2	3	4	5	6	7	8	9	10	Ave
Top	12.7	16.4	11.0	9.3	7.7	11.9	16.8	27.5	18.2	13.0	14.5
Middle	40.2	37.5	42.1	41.4	40.6	41.6	35.5	31.2	33.8	36.8	38.1
Bottom	47.1	46.1	46.9	49.4	51.7	46.5	47.7	41.3	48.1	50.2	47.5

Bunk Sample 1-10 and Average

Fig. 25. PSPS results of a lactation TMR in which haylage was added second to last in a 4-auger horizontal mixer wagon.

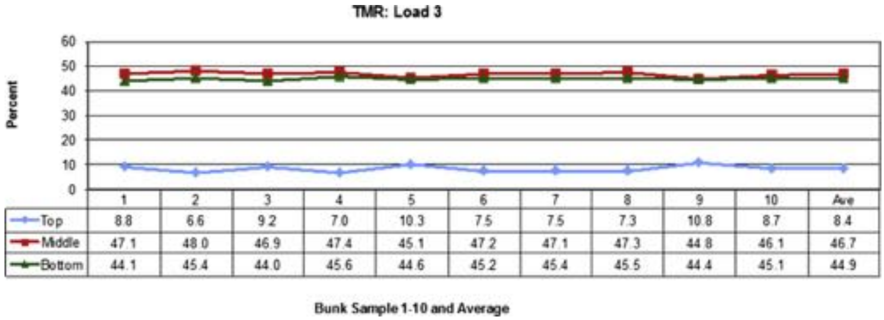


Fig. 26. PSPS results of a lactation TMR in which haylage was added second behind alfalfa hay in a 4-auger horizontal mixer.

vertical that was in excellent condition, was level, was not overfilled, the hay was well processed, and the liquid was well distributed.

Many farms load ingredients out of the proper order because of the daily routine of mixing and the convenience of where ingredients are stored on the dairy. Video 10 shows how the grain mix does not get mixed into the TMR when added last in combination with a worn out mixer. It is clearly evident that the grain does not mix appropriately.

Liquid Distribution

Liquids, such as water, whey, and cane molasses, are routinely added to the TMR to add moisture, sugar, or are used as a carrier for micro-ingredients as in the case for some commercial supplements of cane molasses. Another important reason liquids are added to the TMR is to help reduce sorting by cattle. The liquids, especially cane molasses and liquid whey, are sticky and they help bind the smaller particles to the larger forage particles. As a result, the levels on the bottom pan of the PSPS will shift to the middle and top screens by as much 5% to 7% units depending on type and level of liquid added directly to the TMR.

It is usually best to add the liquid last to the TMR to prevent any balling or clumping of the drier ingredients.[6] There are 2 challenges of adding liquid directly to the TMR: time and distribution. Depending on the amount of liquid added to the TMR and the sizes of the pumps and pipes to load the liquid, the amount of time it takes to add liquid can range from 2 to 10 minutes per load and sometimes even longer. This can create a

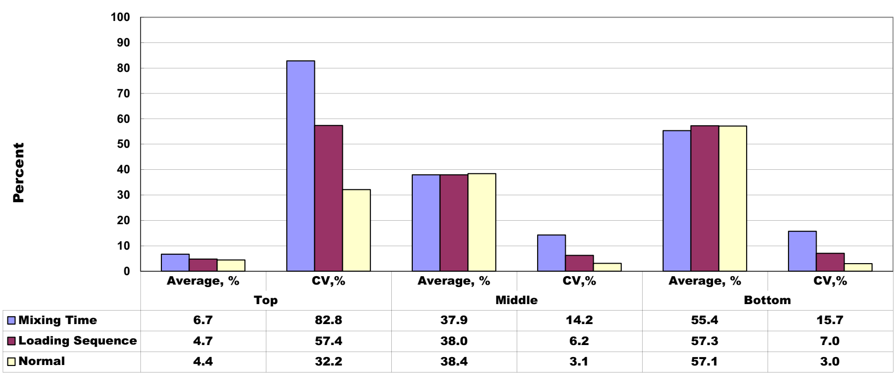


Fig. 27. Influencing of mixing time after the last added ingredient and loading sequence on TMR variation.

bottleneck in getting cattle fed on time for larger operations. Many dairy operations are adding the liquid to the on-farm commodity blend. The on-farm commodity blend is often a mixture of alfalfa hay and/or straw, protein, dry by-product feeds, and grain. The key advantages of the on-farm blend are *reduced feed shrink* and *less time to load the TMR*. It is best to make the blend fresh each day after all the cattle are all fed so that there is no interference with the feeding schedule.

Adding the liquid directly to the on-farm blend instead of the TMR decreases TMR loading time and helps feeders stay on time with respect to feeding pens of cows. Instead of loading 8 to 12 ingredients per load of TMR, the on-farm blend can reduce the number ingredients to 4, (example: on-farm blend, wet by-product, haylage, and corn silage).

Improper distribution of the liquid can make the TMR very inconsistent along the feed bunk. Video 11 shows liquid dispensed through a single pipe in front of the mixer box. Notice the difference in the distance from the top of the TMR and the top of the wagon between the front where the liquid is loading and the back of the wagon where there is no liquid. There is no mixing action between the wetter and drier TMR in this video because of poor distribution of the applied liquid. **Fig. 28** (photo) is a great example of how liquid should be added to a TMR or to an on-farm commodity blend.

Vertical Mixer Auger Speed

Vertical mixer augers lift feed upward from the bottom of the mixer to the top of the auger and then the feed rolls away from the top of the auger toward the mixer walls. As the feed approaches the walls, it falls to the bottom of the mixer to repeat the mixing process. Each revolution of the auger lifts the feed several inches and the amount of lift depends on the type of auger and brand of mixer box. The speed at which the auger rotates is critical to getting good mixing action, good clean out, and smooth delivery of the TMR along the feed bunk.

The following discussion is a case study on the apparent effects of vertical auger rotational speed on TMR mix quality and milk production for a large dairy herd. The mixer was a triple-auger mixer box with an initial auger speed of 42 rpm. The dairy replaced the 2-speed gearbox with a 3-speed gearbox for maintenance purposes. The feeder continued to mix in the lowest gear with the new gear box generating only 28 rpm on auger speed. There was a decrease in TMR mix quality with the lower

Fig. 28. A spray system to properly load liquid into a TMR or an on-farm commodity blend.

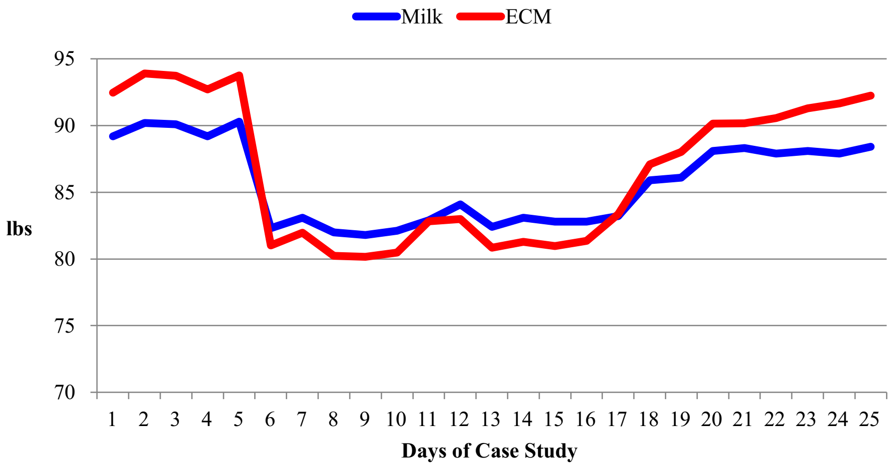


Fig. 29. Influence of vertical mixer auger speed on TMR mix quality and milk and energy corrected milk production.

auger speed and at the same time there were substantial decreases in energy-corrected milk (Fig. 29), fat and protein percentages, and a large increase in milk urea nitrogen (Fig. 30). Changing to second gear in the new gearbox increased auger speed to 38 rpm, improved TMR mix quality back to its original level, and improved milk production and components within 1 to 2 days after the change.

Table 4 is a list of several brands of vertical mixers with CVs of TMR mixed at low and higher auger speeds. The data in Table 4 show better mix quality with higher auger speeds. Most brands of vertical mixers can make very uniform TMRs with coefficients of variation approaching 2% for averages observed on the middle and bottom screens of the PSPS.

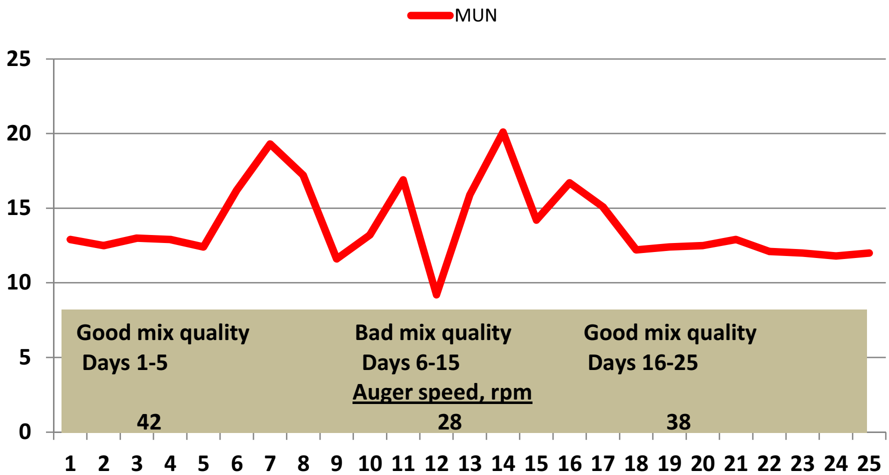


Fig. 30. Influence of vertical mixer auger speed on TMR mix quality and milk urea nitrogen.

Table 4
A summary of different brands of vertical mixers with slow and fast auger speeds on the average percent coefficient of variation of shaker box levels in the middle and bottom screens for lactation total mixed rations

	Auger Speed	
Vertical Mixer	**Slow**	**Fast**
Kuhn VTC 1100, dual auger (Kuhn North America, Brohead, WI)	3.50	2.00
Peecon, 3-auger (Peeters Landbouwmachines, The Netherlands)	5.00	1.78
Penta 1420 HD, dual auger (Penta TMR Inc, Canada)	6.13	2.19
Roto Mix 1355, dual auger (Roto-Mix, Dodge City, KS, USA)	5.00	3.24
Supreme 1600 with Forage Auger, dual auger (Supreme International Ltd, Canada)	8.53	2.45
Supreme with Feedlot Auger 1200T, dual auger (Supreme International Ltd, Canada)	—	2.11
Trioliet (Trioliet, The Netherlands)	4.83	2.81
Average	**5.50**	**2.37**

SUMMARY

A system to test TMR consistency along the feed bunk and to evaluate mixer performance has been developed. Implementation of this system has improved TMR consistency on many dairies across the United States. The standard for TMR particle size consistency determined on 10 samples is 2% or less CV for the average levels on middle and bottom screens of the PSPS.

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SUPPLEMENTARY DATA

Supplementary data related to this article can be found online at http://dx.doi.org/10.1016/j.cvfa.2014.08.003.

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