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Evaluating particle size of forages and TMRs using the New Penn State Forage Particle Separator

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INTRODUCTION

Having the proper particle size distribution of feeds is an important part of ration formulation. However, until recently, particle size has been difficult to measure on farms. Many dairy nutritionists have developed subjective measures of this aspect of the diet, and most have been quite effective making ration changes with respect to particle size measurements.

The new Penn State Forage Particle Separator provides a tool to quantitatively determine the particle size of forages and total mixed rations (TMRs). The concept of measuring feed particle size using a standard method is not new. The American Society of Agricultural Engineers' (ASAE) standard for particle size analysis and distribution has been available for many years. Unfortunately, the ASAE method is a cumbersome laboratory procedure that is impractical for farm use. The objective of developing the Penn State Forage Particle Separator was to mimic the complex lab method with a simpler, on-farm method.

Management of forage particle size begins with harvesting forages at the proper stage of maturity. Chopping the crop at the proper length produces forages that can be combined to achieve the desired particle length in a TMR.

Measuring the particle length of individual forages is only one part of the solution. In fact, measuring single forages for particle size is similar to analyzing that forage for crude protein. There are recommended ranges for individual forages, but the real value of the particle size measurement is in combining forages to achieve the proper TMR particle size, much like combining feeds to achieve the proper protein level in the ration.

The main goal of analyzing TMR particle size is measuring the distribution of feed and forage particles that the cow actually consumes. Examine not only the particles greater than a particular size, but also the overall distribution of feed particles being consumed by the cow. Measuring TMR samples fresh from the feed bunk and before the cows eat or sort the feed is recommended. Mixing and distribution equipment can reduce particle size of feeds and forages and need to be accounted for when evaluating the actual diet being fed.

An Additional Sieve

The original particle separator, first introduced in 1996, has proven valuable in measuring feed particle size. However, in a survey of 831 TMR samples collected on commercial dairy farms, an average of 58 percent of the material passed through both sieves (0.75 and 0.31 inches). Better characterization of these smaller feed particles requires a more detailed measurement. Thus, a sieve designed to further partition particles less than 0.31 inches should be useful. As a result of this observation, an additional sieve was added to the separator device. A pore size of 0.05 inches was chosen, since feed particles less than this size either are digested rapidly in the rumen or pass rapidly through the rumen. The use of the additional sieve is most applicable when measuring the particle size of a TMR; it is possible that with some forages very few particles will pass through the additional smaller sieve.

GUIDELINES FOR PARTICLE SIZE

Achieving adequate ration particle size requires using recommended guidelines for forages and TMRs (Table 1). Original particle size guidelines were based on field data consisting of a large number of farms. Since that time, three intensive research studies have been conducted at Penn State to further refine these guidelines. The results of forage and TMR particle size distribution can be used in formulating rations and when trouble shooting nutrition problems.

Corn silage

Corn silage can be quite variable, and the required particle size depends largely on the amount fed in the diet. If corn silage is the sole forage, at least 8 percent of the particles should be in the upper sieve of the separator, compared to a minimum of 3 percent when corn silage is not the sole forage.

The chop length of corn silage must balance good packing and fermentation with extremely short, pulverized forage. This means 45 to 65 percent of the silage material should remain on the middle sieve and 30 to 40 percent on the lower sieve of the separator. If the last screen is used for corn silage, no more than 5 percent should be recovered in the bottom pan. As corn silage makes up a greater proportion of the ration, more material should remain in the middle two sieves and less in the top sieve and bottom pan.

Newer systems for harvesting corn silage (chopping and rolling in one process) can create silage with a large percentage of long forage particles without large pieces of whole cobs or stalks. This forage can be excellent quality because it packs and ferments well in the silo.

Typically, when conventional choppers are set to harvest corn silage at a long particle size, forage is predisposed to poor silo compaction and mold formation. The material usually has large pieces of cob, dry stalks and leaves that allow a great deal of sorting and may often be refused by high producing cows.

Haylage

There is a lot of variability with haylage due to the type and use of machinery, sward type and density, and most of all, the dry matter of the crop harvested. Ten to 20 percent of the crop should be in the upper sieve of the particle separator. Particle size recommendations may need to be altered based on silo type. Forages stored in upright, sealed silos would likely fall at the lower end of the range (10 percent). Bunker silos can handle appreciably longer material, up to 20 percent on the upper sieve. The middle sieve should contain 45 to 75 percent of the material and the lower sieve 20 to 30 percent. As with corn silage, no more than 5 percent of the material should be retained on the bottom pan

TMR

Field investigations conducted at Penn State have found considerable variability in overall rations. Feeding management plays an important role in the particle length needs of the cow. Ideally no more than 8 percent of the material should be retained on the upper sieve. Guidelines for TMRs for high producing dairy cows are 2 to 8 percent of the particles in the upper sieve, 30 to 50 percent in the middle and lower sieves, and no more than 20 percent in the bottom pan.

GUIDELINES FOR PARTICLE SIZE (CONTINUED)

Table 1. Forage and TMR particle size recommendations based on three experiments using early lactation cows fed either alfalfa haylage or corn silage with or without cottonseed hulls.

Screen	Pore Size (inches)	Particle Size (inches)	Corn Silage	Haylage	TMR
Upper Sieve	0.75	> 0.75	3 to 8	10 to 20	2 to 8
Middle Sieve	0.31	0.31 to 0.75	45 to 65	45 to 75	30 to 50
Lower Sieve	0.05[a]	0.07 to 0.31	30 to 40	20 to 30	30 to 50
Bottom Pan		< 0.07	< 5	< 5	≤ 20

[a]Pores are square, so largest opening is the diagonal, which is 0.07 inches. This is the reason the largest particles that can pass through the Lower Sieve are 0.07 inches in length.

PARTICLE SEPARATOR INSTRUCTIONS

The Penn State Forage Particle Separator is currently available from Nasco. For their free phone order service, dial 1-800-558-9595. To use the separator an accurate scale is needed to weigh the samples and the boxes. A data sheet and blank lognormal paper are attached to the back of this publication.

A spreadsheet that performs all of the calculations and graphs the results can be downloaded from the Penn State Dairy Cattle Nutrition Website. Visit http://www.das.psu.edu/dcn/catforg/particle and download "particle size.xls."

Using the separator

Stack the four plastic separator boxes on top of each other in the following order: sieve with the largest holes (upper sieve) on top, the medium-sized holes (middle sieve) next, then the smallest holes (lower sieve), and the solid pan on the bottom. Place approximately 3 pints of forage or TMR on the upper sieve. Moisture content may cause small effects on sieving properties, but it is not practical to recommend analysis at a standard moisture content. Very wet samples (less than 45 percent dry matter) may not separate accurately. The separator is designed to describe particle size of the feed offered to the animal. Thus, samples should not be chemically or physically altered from what was fed before sieving.

On a flat surface, shake the sieves in one direction 5 times then rotate the separator box one-quarter turn. There should be no vertical motion during shaking. Repeat this process 7 times, for a total of 8 sets or 40 shakes, rotating the separator after each set of 5 shakes. See the sieve shaking pattern shown in Figure 1.

The force and frequency of shaking must be enough to slide particles over the sieve surface, allowing those smaller than the pore size to fall through. We recommend shaking the particle separator at a frequency of at least 1.1 Hz (approximately 1.1 shake per second) with a stroke length of 7 in (or 17 cm). For best results, calibrate the frequency of movement over a distance of 7 inches for a specified number of times. The number of full movements divided by time in seconds results in a frequency value that can be compared to the 1.1 Hz recommendation.

After shaking is completed, weigh the material on each sieve and on the bottom pan. Note that material on the upper sieve is greater than 0.75 inches long, material on the middle sieve is between 0.31 and 0.75 inches, material on the third sieve is between 0.07 and 0.31 inches, and material in the bottom pan is less than 0.07 inches. See Table 2 for data entry and procedures to compute the percentage under each sieve.

Using Lognormal Paper

There is currently some debate as to the best type of graphing paper to use when plotting particle size results. The size of forage and TMR particles in a sample does not follow a normal distribution pattern, however it can be plotted as a straight-line distribution using lognormal graphing paper. We recommend lognormal paper be used to graph the distribution of forage and TMR particle size as this is the most simple method and it fits most data accurately.

The cumulative percentage undersized for each sieve is plotted on the graph. Referring to Table 2, value [f] refers to 0.75 inches, value [g] to 0.31 inches, and value [h] to 0.07 inches. These percentages are plotted on lognormal paper and an appropriate line drawn between the three points (best-fit line).

On the graph paper, the horizontal axis represents particle size and the vertical axis represents the cumulative percentage undersized. The axes are not linear. For the example given in Table 2, the following deductions or statements can be made:

- Approximately 5% of the feed is more than 0.75 inches in length.
- Approximately 40% of the feed falls between 0.31 and 0.75 inches in length.
- Approximately 40% of the feed falls between 0.07 and 0.31 inches in length.
- Approximately 15% of the feed is less than 0.07 inches long.

Another interpretation could be:

- Approximately 95% of the feed is less than 0.75 inches in length.
- Approximately 55% of the feed is less than 0.31 inches in length.
- Approximately 15% of the feed is less than 0.07 inches long.

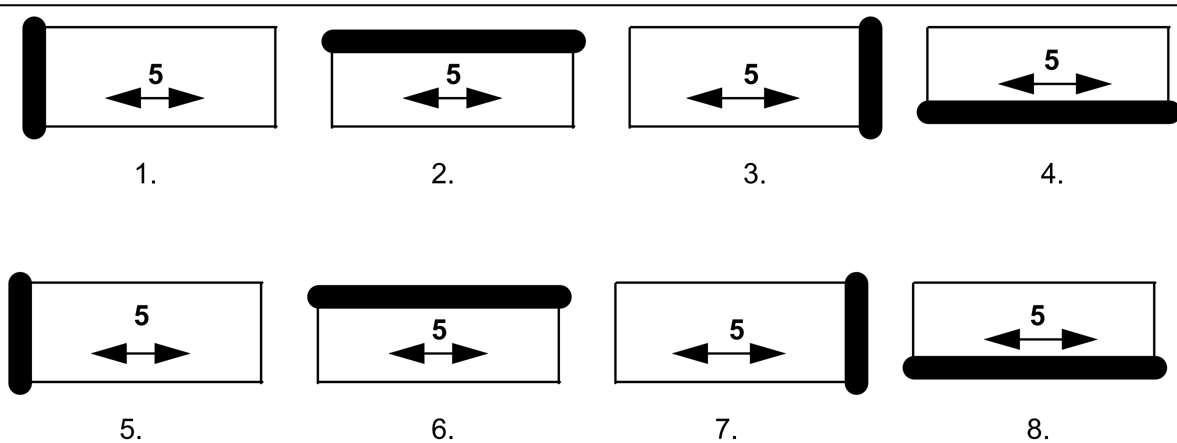


Figure 1. Shaking pattern for particle size separation.

Table 2. Example of the calculation of total weight and cumulative percentages under each sieve.

Record and Calculate Data

Sample	Weight Retained	Proportion Remaining On Each Sieve	
Upper sieve (0.75 inches)	10 grams [a]	a/e * 100	10/200 * 100 = 5%
Middle sieve (0.31 inches)	80 grams [b]	b/e *100	80/200 * 100 = 40%
Lower sieve (0.07 inches)	80 grams [c]	c/e * 100	80/200 * 100 = 40%
Bottom pan (< 0.07 inches)	30 grams [d]	d/e * 100	30/200 * 100 = 15%
Sum of Weights	**200 grams [e]**		

Compute Cumulative Percentage Undersized[1]

% Under upper sieve	f = 100 – (a/e *100)	100 – 5 = 95% undersized
% Under middle sieve	g = f – (b/e*100)	95 – 40 = 55% undersized
% Under lower sieve	h = g – (c/e*100)	55 – 40 = 15% undersized

[1] Cumulative percentage undersized refers to the proportion of particles smaller than a given size. For example, on average, 95% of feed is smaller than 0.75 inches, 55% of feed is smaller than 0.31 inches and 0.15% of feed is smaller than 0.07 inches.

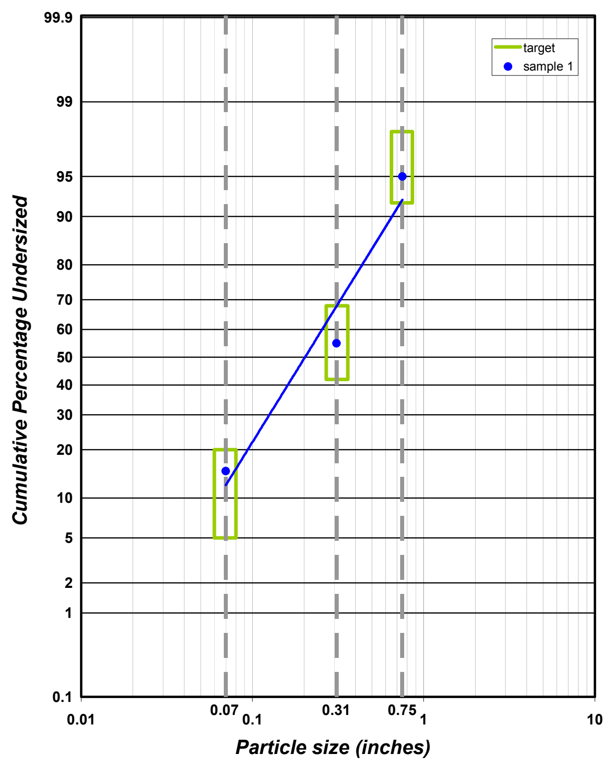


Figure 2. Data from example in Table 2 plotted on lognormal paper.

PARTICLE SIZE EFFECTS ON THE DAIRY COW

The dairy cow's need for increasingly higher levels of energy have led to diets relatively high in concentrates. However, cows still require adequate fiber in the ration to function properly. When the minimum fiber levels are not met, cows may show one or more of the following disorders: reduced milk fat percentage, displaced abomasum, and/or an increase in the incidence of rumen parakeratosis, laminitis, or rumen acidosis. Cows consuming sufficient NDF with severely reduced forage particle size may exhibit the same metabolic disorders as cows fed a diet deficient in fiber.

Adequate forage particle length is necessary for proper rumen function. Reduced forage particle size has been shown to decrease the time spent chewing and cause a trend toward decreased rumen pH. When cows spend less time chewing, they produce less saliva, which is needed to buffer the rumen. In comparison, when feed particles are too long, animals are more likely to sort the ration, and ultimately the diet consumed is very different than the one originally formulated.

If rations or forages are too fine, feeding a small amount of long hay or balage can improve the average ration particle size. Farms feeding 5 or more pounds of long hay per cow daily would not likely have problems with overall particle size. Many farms, however, do not have long hay as an option. In these situations, the distribution of particle size in the total ration is likely more important than the proportion of particles greater than a certain length.

In addition to analysis of both forage and TMR particle size, the particle separator may also be used to monitor the possibility of feed bunk sorting and may aid in trouble shooting feeding, metabolic, or production problems. To evaluate sorting, measure the TMR remaining in the bunk several times throughout the day (e.g. 4, 8, 12, and 48 hours after feeding). The resulting particle size distribution should not differ more than 3 to 5 percent from the original TMR. If cows are sorting throughout the day, pH may fluctuate more than expected and may affect intake, rumen fermentation, or overall digestion. Problems may be more pronounced if bunks are overcrowded or if first-calf heifers are grouped with older cows. In these situations more aggressive animals may preferentially consume grain and other more palatable, readily fermentable feeds leaving high fiber, poorly digestible feeds for the other animals.

Feeding a ration containing extremely fine or coarse particle size is not recommended. Diets on either end of the spectrum can predispose cows to rumen acidosis and other associated problems and should be avoided. Particle size analysis is not a crystal ball for determining ration problems. However, the Penn State Particle Separator does provide an objective measurement of particle size, and it can be a useful tool to improve the overall nutrition of the dairy cow.

RECOMMENDED FIBER INTAKES

Adequate NDF intake by the dairy cow is necessary for normal rumen function, production, and health. A majority of the NDF in the ration must be in the form of forage NDF along with sufficient ration particle size to maintain a healthy rumen environment. Under conditions of marginal particle size, special attention must be paid to maintaining adequate levels of total NDF and forage NDF intakes (Tables 3 and 4).

Suggested ranges for total NDF are at least 1.10 to 1.20 percent of body weight. Forage NDF intake can range from 0.75 to 1.10 percent of body weight. However, if the forage or TMR particle length is too fine, then a higher minimum (less than 0.85 percent of body weight) should be used.

Table 3. Guidelines for forage NDF intake.

Forage NDF as % of body weight[1]	Intake level
0.75%[2]	Minimum if ration provides 1.30 to 1.40% total NDF by use of byproduct feeds.
0.85%[2]	Minimum if ration provides 1.00 to 1.20% total NDF by use of grains or starchy feeds.
0.90%	Moderately low
0.95%	Average
1.00%	Moderately low
1.10%	Maximum

[1]Forage dry matter intake should range between 1.40% and 2.40% of body weight, regardless of forage NDF intake parameters.
[2]Higher minimum may be necessary if forage is chopped too fine.

Table 4. Guidelines for total NDF and forage NDF intakes as a percent of the total ration dry matter when feeding concentrates with low NDF.

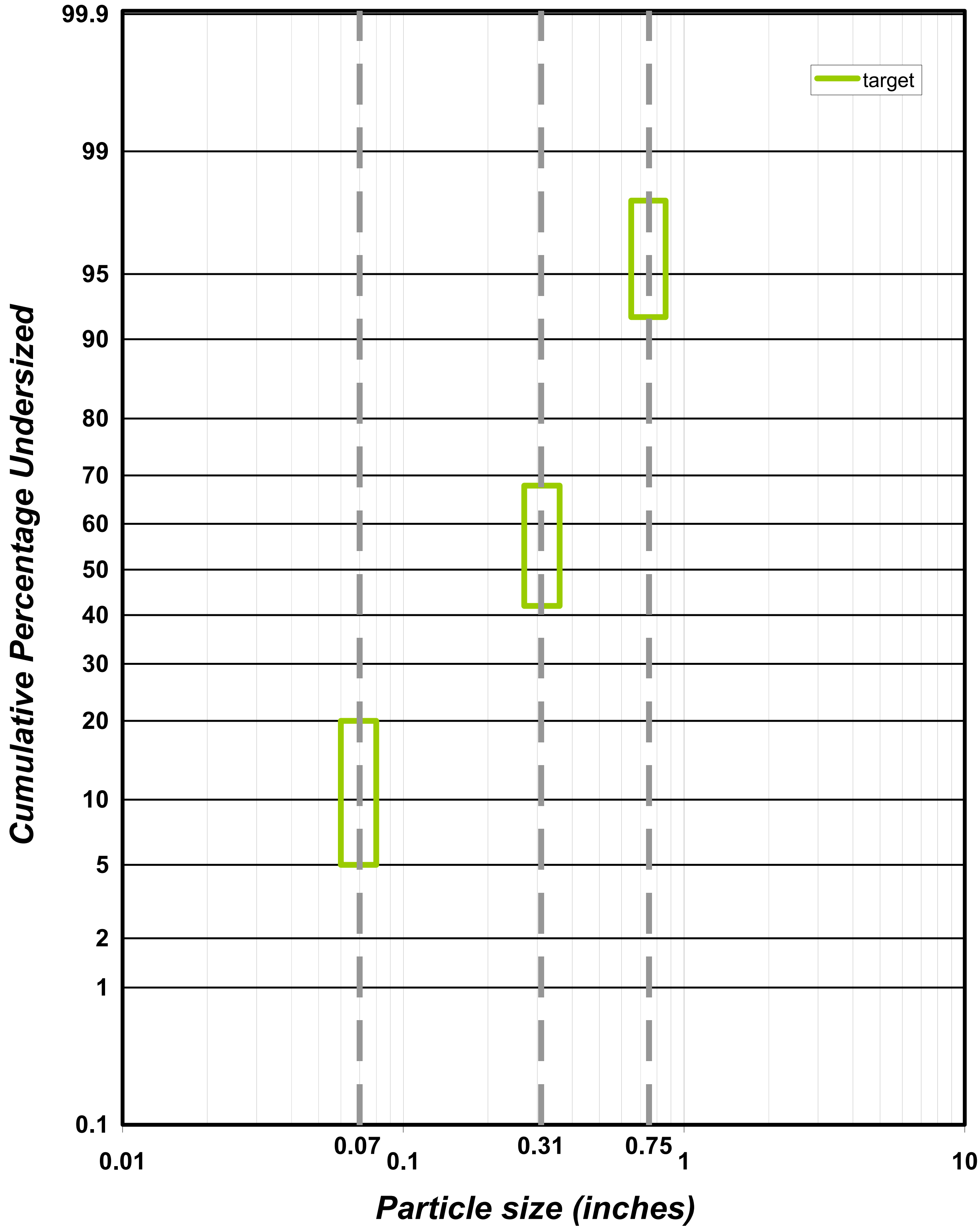
Milk production	Total NDF intake	Forage NDF intake
High (> 80 pounds)	28-32%	21-27%
Medium (60-80 pounds)	33-37%	25-32%
Low (< 60 pounds)	38-42%	29-36%

Data Sheet For Forage and TMR Particle Size Analysis

	Weight of Material Retained		
Upper (a)			
Middle (b)			
Lower (c)			
Bottom Pan (d)			
Sum of Weights (e)			
	Calculations for percentage retained on each sieve		
Upper [= a/e *100]			
Middle [= b/e *100]			
Lower [= c/e *100]			
Bottom Pan [= d/e *100]			
	Calculations for percentage under each sieve		
Total Weight [e = a+b+c+d]			
Upper Sieve [f = 100 – a/e*100)]			
Middle Sieve [g = f – (b/e*100)]			
Lower Sieve [h = g – (c/e*100)]			

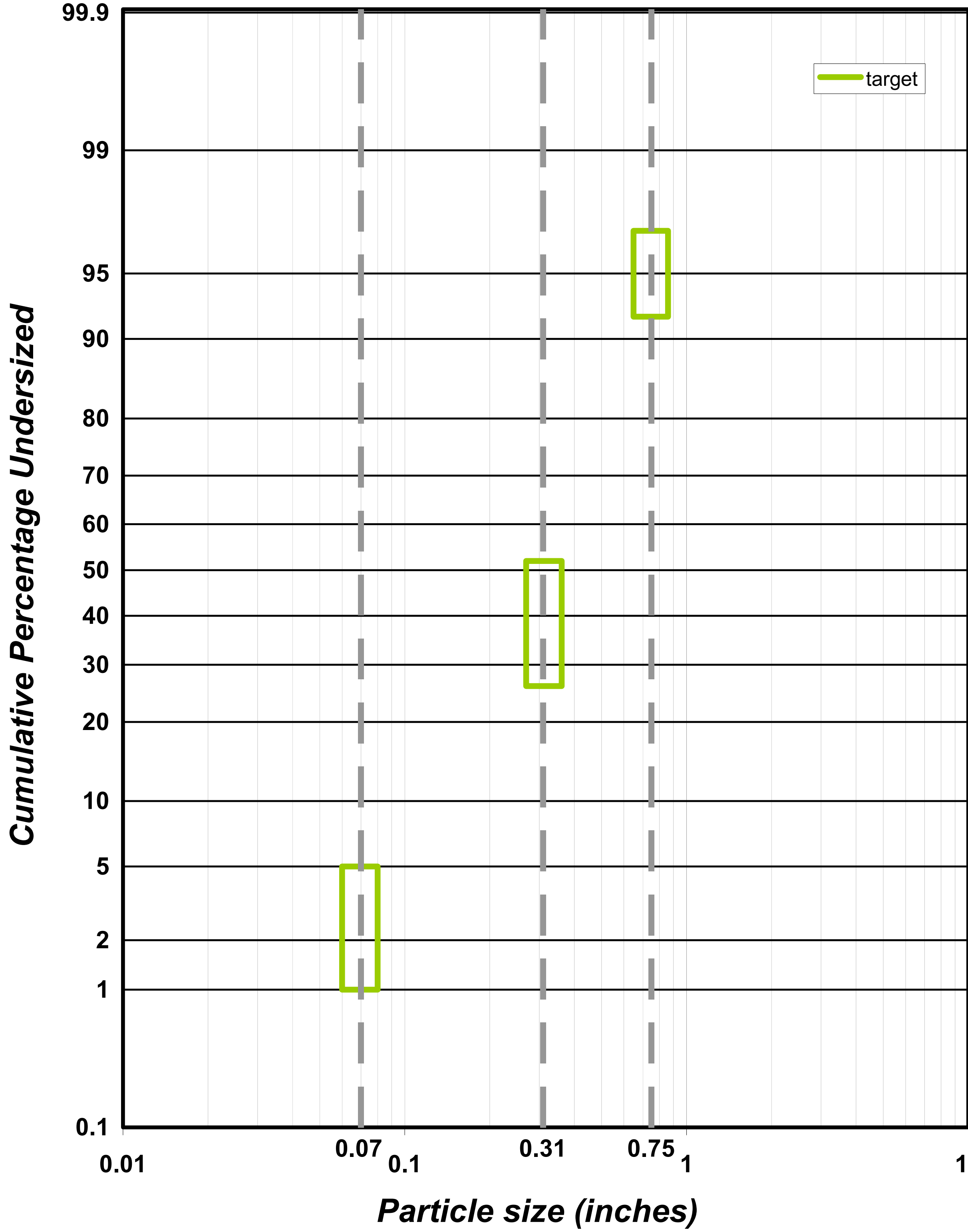
TMR Particle Size Analysis

For:



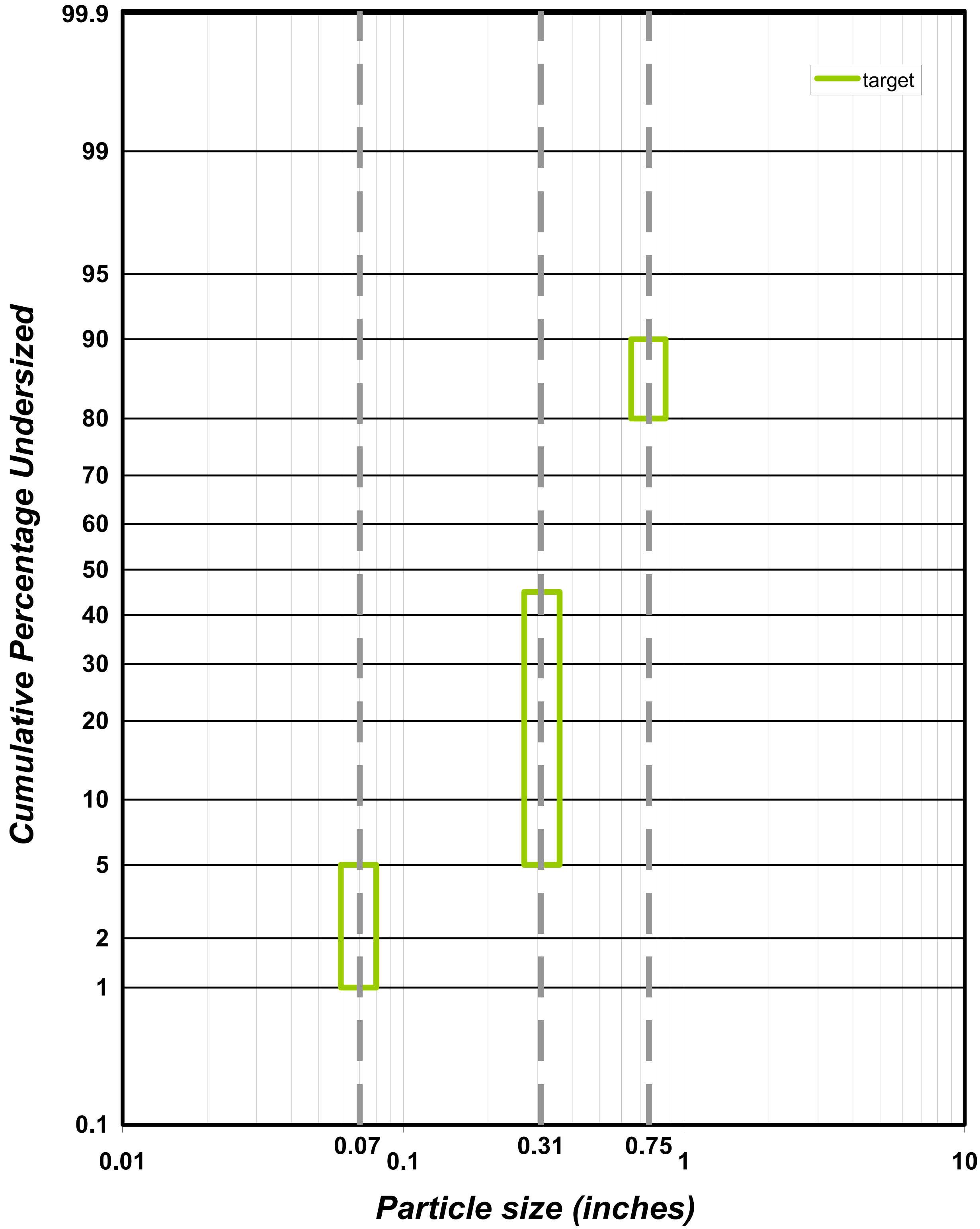
Corn Silage Particle Size Analysis

For:



Haylage Particle Size Analysis

For:



Appendix. Particle Size Spreadsheet, Instructions

Particle Size Analysis

http://www.das.psu.edu/dcn/catforg/particle/

Instructions

Summary: Enter the weight of particles on each sieve on the "Data" tab. The distribution will be calculated and shown below your entries. View a graph of the results by clicking on the "Graph" tab. See the explanation below for more details.

Entering Sample Data

1. Click on the "Data" tab below.
2. Enter information in cells with blue text; always replace or delete the example text.
3. Be sure to enter the type of sample. Target ranges on the graph are based on sample type.
   Use the following numeric code to identify the sample type:
   TMR = 1 Corn silage = 2 Haylage = 3
4. Enter the sample name and the weight of particles left on each sieve.
   If only one sample is analyzed, delete the example data for "Sample 2".

Reading the Output

1. The output from your measurements has two forms.
   The "Output" section on the "Data" tab below.
   A graph of your results on the "Graph" tab below.
2. The "Output" section
   Percentage of particles on each sieve
   Cummulative percent undersized, which is the amount under each sieve
   Average length of particles in the sample
   Standard deviation for length of particles in the sample
   Recommended particle size distribution for your sample type
3. The Graph
   Blue and orange points plot the cummulative percent undersized
   Blue and orange lines show the "line of best fit" for the sample (regression)
   Green boxes indicate a recommended target range for your sample type

Unless you are interested in the math and equations behind these calculations, you will not need to use the "Calculations" tab below.

Developed by Coleen Jones, Paul Kononoff, and Jud Heinrichs

Questions?
If they concern using this spreadsheet, contact Coleen Jones at cjones@psu.edu
If you are interested in particle size and target ranges, contact Jud Heinrichs at ajh@psu.edu

Appendix. Particle Size Spreadsheet, Data

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Particle Size Analysis Datasheet

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Farm Name	Maximum Milk Makers	**Sample Date**	7/15/2002
Address	658 Dairy Lane	**Sample Type**	1
	Anytown, PA 17956		1 = TMR, 2 = Corn silage, 3 = Haylage

INPUT

Seive	**Sample 1:** High Group TMR Weight (grams)	**Sample 2:** Low Group TMR Weight (grams)
Upper	40.0	50.0
Middle	310.0	275.0
Lower	330.0	235.0
Bottom Pan	120.0	90.0
Total	800.0	650.0

OUTPUT

Section 1. Distribution of Particles

	Sample 1: High Group TMR		Sample 2: Low Group TMR	
Seive	**Particles Remaining (% of total)**	**Cumulative Particles (% under each sieve)**	**Particles Remaining (% of total)**	**Cumulative Particles (% under each sieve)**
Upper	5	95	8	92
Middle	39	56	42	50
Lower	41	15	36	14
Bottom Pan	15		14	

Section 2. Sample Parameters

	Sample 1	**Sample 2**
Average Particle Size (in)	0.21	0.23
Standard Deviation (in)	0.11	0.11

Section 3. Recommended Distribution of Particles **Sample Type:** TMR

Seive	Particles Remaining (% of total)
Upper	2 to 8
Middle	30 to 50
Lower	30 to 50
Bottom Pan	20 or less

Appendix. Particle Size Spreadsheet, Graph