

Packing Bunker and Pile Silos to Minimize Porosity

by Brian J. Holmes and Richard E. Muck

Why is silage density important when packing bunkers and piles?

Attaining a high silage density is important for two primary reasons. Most importantly, density and dry matter content determine the porosity of the silage. Porosity, in turn, sets the rate at which air moves into the silo and subsequently the amount of spoilage which occurs during storage and feedout. Ruppel (1992) measured dry matter loss for alfalfa silage and developed an equation to relate the loss to density. Table 1 summarizes those results. The higher the density, the greater is the capacity of the silo. Thus, higher densities generally reduce the annual cost of storage per ton of crop by both increasing the amount of crop entering the silo and reducing crop losses during storage.

TABLE 1. Dry matter loss as influenced by silage density – Ruppel (1992)

Dry Matter Density (lbs DM/ft ³)	DM Loss, 180 days (%)
10	20.2
14	16.8
15	15.9
16	15.1
18	13.4
22	10.0

So, what is porosity and why is it important?

Porosity is a measure of the voids between the solid particles of a material. Pore space can be filled with fluids including gas and/or water in silage. The “gas filled” porosity allows gases to move within the material. For gases to move throughout the material, the pores must be continuous. Closed pores do not contribute to gas flow. The preferred gas in stored silage is carbon dioxide. In high concentration, it

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displaces oxygen which contributes to aerobic microbial activity. Aerobic microbial activity decomposes available carbohydrates with resultant dry matter loss. Evidence that aerobic activity is occurring is heating silage. Evidence that aerobic activity has occurred for some time is increased fiber and crude protein contents and in extreme cases moldy gray to black colored silage.

How does gas flow through porous silage?

There are several forces which can cause gas to move through the pores of silage. The first is diffusion through the exterior surfaces. For example, at the feed out face, the oxygen content of the air is about 20% and deep in the silage mass it is 0%. Thus oxygen moves from high concentration to low by diffusion through the open pores. This process occurs in all feed out faces independent of orientation (vertical or horizontal). The higher the porosity, the faster the oxygen flow rate. This process also occurs at the top, sides or walls. The lower the porosity of the wall or cover, the lower the oxygen diffusion rate.

Gravity can move fluids through porous materials. A common example of this is water moving through the soil profile. A similar process occurs with gases. Carbon dioxide, which is heavier than air, settles through silage and emerges from the bottom of the vertical feed out face of a horizontal silo. The carbon dioxide is replaced by air drawn into the top portion of the feed out face. This air containing oxygen supports the spoilage organisms. They release carbon dioxide as they decompose the carbohydrates and the cycle continues.

Finally wind impacting the silage surface can result in gases being displaced by oxygen bearing air. Walls and roofs of tower silos help protect the feed out face from wind. Walls of bunker silo provide some wind protection.

How is porosity measured?

Porosity is difficult to measure in the laboratory and probably impossible to measure in the field. An equation developed by Richard et al (2004) relates porosity to bulk density (as fed density) of organic materials. This equation was used to develop Figure 1. From this graph, porosity is most influenced by bulk density over the range of dry matter contents

recommended (0.30-0.40) for ensiling in bunkers, bags and piles.

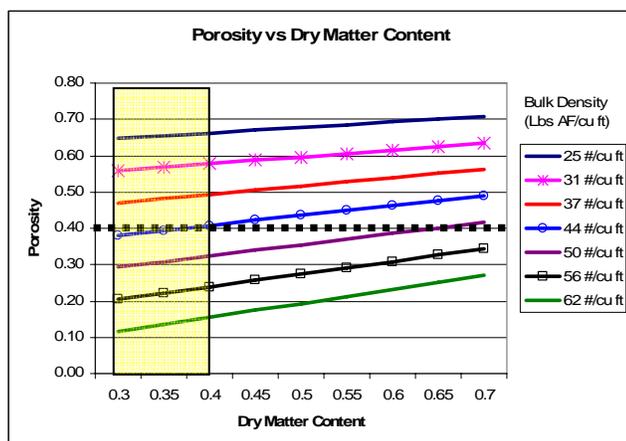


Figure 1. Graph of porosity (decimal) vs. dry matter content (decimal) for various bulk densities

Holmes and Muck (2004) have recommended a minimum dry matter density of 15 lbs DM/ft³ as a reasonably attainable density and to avoid excessive dry matter loss. From Table 2 it is apparent the porosity varies quite widely (~20 - 60%) for the combinations of dry matter content and bulk density that produce a dry matter density of 15 lbs DM/ft³ (note bold values for DM density meet or exceed 15 lbs DM/ft³). That being the case, it may be better to recommend a maximum porosity in the range of 30-40%. However, because porosity is relatively constant for a given bulk density over a typical range of ensiling DM contents and because bulk density is more readily measured than porosity, it may be better to

recommend a minimum bulk density. A minimum bulk density of 44 lbs AF/ft³ keeps porosity below 40% within the recommended range of DM content. An example may be useful here. If one wants to achieve a bulk density of 50 lbs AF/ft³, what dry matter density must be achieved? From Table 2, forage at 30% dry matter can be packed to 15 lbs DM/ft³ to give the desired bulk density, but dryer material at say 40% dry matter must be packed to 20 lbs DM/ft³ a much more difficult task. In both cases, the porosity is close to 30%.

What is the minimum recommended density when packing bunker or pile silos?

To keep porosity below 40%, a minimum bulk density of 44 lbs AF/ft³ is needed (see Figure 1).

References

Holmes, B. J. and R. E. Muck. 2004. Managing and designing bunker and trench silos (AED-43). MidWest Plan Service. Ames, IA.
 Richard, T. L., A. H. M. Veeken, V. de Wilde and H. V. M. Hamelers. 2004. Air-filled porosity and permeability relationships during solid-state fermentation. *Biotechnology Progress*. 20 (1372-1381)
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Table 2. Porosity and Dry Matter Density as a Function of Bulk Density and Dry Matter Content

Bulk Density (lb AF/ft ³)			30	35	40	45	50	55
Dry Matter (decimal)	Max. DM Density (lb DM/ft ³)	Max. Bulk Density (lb AF/ft ³)	Porosity(%) (DM Density, lb DM/ft ³)					
0.25	17.0	68.1	55.9 (7.5)	48.6 (8.8)	41.3 (10.0)	33.9 (11.3)	26.6 (12.5)	19.2 (13.8)
0.30	20.8	69.3	56.7 (9.0)	49.5 (10.5)	42.3 (12.0)	35.1 (13.5)	27.9 (15.0)	20.7 (16.5)
0.35	24.7	70.6	57.5 (10.5)	50.5 (12.3)	43.4 (14.0)	36.3 (15.8)	29.2 (17.5)	22.2 (19.3)
0.40	28.8	72.0	58.3 (12.0)	51.4 (14.0)	44.5 (16.0)	37.5 (18.0)	30.6 (20.0)	23.6 (22.0)
0.45	30.0	73.4	59.1 (13.5)	52.3 (15.8)	45.5 (18.0)	38.7 (20.3)	31.9 (22.5)	25.1 (24.8)
0.50	37.4	74.9	59.9 (15.0)	53.3 (17.5)	46.6 (20.0)	39.9 (22.5)	33.3 (25.0)	26.6 (27.5)

Packing bunkers and piles properly is also essential. Unloading Cost. This is a source of major cost that most people do not realize. Operating costs on a tractor can be anywhere from \$8-\$50/hour⁴. If an hour a day is spent unloading from a bunker, pile or bags with a \$15/hour tractor, the yearly cost of unloading is \$5,475.00. The following are approximate costs for each type of silo to be used in the following spreadsheets. For exact costs, contact your local silo construction company. This spreadsheet compares and tallies the cost involved in tower and bunker storage. Spreadsheet is in Microsoft Excel format. Click here to view In addition, the International Silo Association has available on request a form that, when completed, will give you a complete analysis of your feed storage situation. What is the minimum recommended density when packing bunker or pile silos? To keep porosity below 40%, a minimum bulk density of 44 lbs AF/ft³ is needed (see Figure 1). This article was contributed by the University of Wisconsin Forage Team; Brian J. Holmes and Richard E. Muck. Pile On The Safety When Packing Bunkers. Don't allow people on foot in or closely near a bunker or pile. Especially during filling or feed-out. Mark where new silage is added to old silage (if it applies) as the joining area can be unstable during silage removal and collapse without warning. Use proper unloading technique that includes shaving silage down the feed-out face. Never dig the bucket into the bottom of the silage. Pile height should not exceed the reach of the unloading equipment. Most bunker silos and silage piles are packed to a density between 40 to 48 pounds per cubic foot on an as fed (moisture included) basis. Do the math. A silage avalanche involving 2 cubic yards of silage packed at a density of 44 pounds per cubic foot weighs 2376 pounds, over a ton. That weight falling from a 20 foot tall silage face versus a 10 foot silage face represents a significant increase in force. The goal is minimize the penetration of air into the new silo face as silage is removed so equipment that allows a smooth face to be maintained is preferred. Silage face shavers (or defacers) and silage rakes are designed for this purpose. Digging into the face of the silage should be minimized because that usually creates a rough, uneven face with more potential for silage avalanches.