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*Improving food & health*

# Porosity: The true measure of silage density

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## At a glance

Dry matter density is generally used to calculate feed inventory and to balance rations; however, bulk density or as-fed density is a better metric for on-farm measurement. Packing critical control points for silage harvest are discussed.

Many agricultural crops are harvested each year, stored and subsequently fed. To maximize preservation of the crops' nutrients, we rely on fermentation. This is silage making. But the key to good fermentation is an anaerobic (absence of oxygen) environment.

## Oxygen is the enemy

Oxygen leads to spoilage, where highly digestible nutrients are converted to several undesirable, poorly digestible products and metabolites. This spoilage is costly for two very important reasons: 1) you have already paid to make this feed (seed, fertilizer, herbicide, harvesting, transportation and storage), and 2) it reduces the cow's ability to live up to her genetic potential for making milk (lower digestive efficiency, yeasts, molds, mycotoxins and adverse health events).

Nutrient losses due to spoilage primarily occur at either the initial aerobic phase of ensiling (i.e., when filling the silo), when we are trying to eliminate oxygen from the forage mass, or at the feedout phase when we are trying to minimize the amount of oxygen that infiltrates the stable, fermented forage. Regardless of when they occur, losses can exceed 15 to 30 percent of digestible dry matter.

## The science

When filling the silo, oxygen that remains in the forage mass allows for continued plant cell respiration and for certain microbial spoilage organisms to consume dry matter. During fermentation, oxygen will be consumed and fermentation gasses will fill these pores. At feedout, these gas-filled pores will permit oxygen infiltration into the silage mass, quickly promoting the reanimation of aerobic spoilage micro-organisms, utilizing available carbohydrates and resultant heat.

Improving density of silages is important for a number of reasons; specifically, it: 1) reduces the amount of air (oxygen) in the forage mass, 2) improves fermentation and preservation of nutrients, and 3) allows for storage of more silage in the same footprint without packing forage higher. Higher densities will reduce the annual cost of storage per ton of crop and reduce crop losses during storage.

## Porosity

The primary means by which oxygen is eliminated from the forage mass at ensiling in a horizontal silo (bunker, trench or drive-over pile) happens via packing tractors. The metric by which we evaluate the relative success of packing has always been based on dry matter density because dry matter (DM) is used to calculate feed inventory and to balance rations. However, bulk density or as-fed density is a better metric for two reasons: It is easier to measure bulk density when filling the silo as there is no need to measure moisture content, and as-fed density is more closely related to porosity and silage quality.

Porosity, or gas-filled porosity, is simply the amount of space between the solid and liquid portions of the silage in a given volume of space. Since air is approximately 21 percent oxygen, as gas-filled porosity decreases, the amount of oxygen in the forage mass decreases as well.

Spoilage micro-organisms thrive in the presence of oxygen. Yeasts and molds, as well as other aerobic organisms, convert sugars and organic acids to carbon dioxide, water and heat. The result is dry matter loss. Other indicators of aerobic deterioration include increased fiber content, higher ammonia, elevated pH and potential gray or black color. Therefore, reducing the gas-filled porosity in the forage mass will reduce the quantity of oxygen available for spoilage micro-organisms to proliferate and consume valuable digestible nutrients.

In the example Figures 1 and 2, the syringe was filled with corn silage (35 percent DM), and the resulting calculations provide the basis for discussing gas-filled porosity. Thirty grams of corn silage was placed in the syringe, and the plunger was pushed to 60 cc. Bulk density (as-fed density) is 31.2 pounds per cubic foot, and DM density is 10.9 pounds per cubic foot – not very desirable when our goal for DM density is approximately 15 pounds per cubic foot. In the syringe in Figure 1, the 60 cc volume is 14.9 percent solid (dry matter) and 27.7 percent liquid

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(moisture). The remaining space is gas-filled porosity of 57.4 percent, of which 21 percent is oxygen, thus the syringe holds 12.05 percent oxygen or 7.23 cc of oxygen.

In example Figure 2, the plunger was pushed to 30 cc. No moisture escaped the syringe, and the same quantity of dry matter remained in the syringe; thus the only difference was the absolute quantity and percent of gas-filled porosity.

Bulk density is 62.4 pounds per cubic foot, and dry matter density is 21.8 pounds per cubic foot – exactly twice as much as seen in Figure 1, as we have the same quantity of corn silage in half the volume. This would be considered excellent packing density.

In the syringe in Figure 2, the 30 cc volume is 29.8 percent solid (dry matter) and 55.3 percent liquid (moisture). The remaining space is gas-filled porosity of 14.9 percent, of which 21 percent is oxygen, thus the syringe holds 3.13 percent oxygen or 0.94 cc of oxygen.

By increasing packing density, specifically by minimizing gas-filled porosity, we have significantly reduced exposure of the corn silage to oxygen and allowed for significantly more corn silage to be stored in the same original 60 cc of space.

### Packing critical control points

• Match delivery rate to packing tractor weight to exceed “the rule of 800.” (Packing tractor weight needed = 800 multiplied by tons of forage delivered per hour, or packing tractor weight available divided by 800 = maximum tons of forage delivered per hour.)

• Thin layers (about 4 inches thick) spread and packed in a progressive wedge configuration will facilitate achievement of higher-density bunkers and piles.

• For bunker silos, alternate dumping, pushup and packing from left side to right side and vice versa achieves uniform layer thickness, optimal packing time and overall efficiency. Alternating dumping, pushup and packing will reduce the likelihood of “crowned” or “cupped” filling and the resulting variations in DM density across the face of the bunker.

• The ideal packing tractor speed is 1.5 to 2.5 mph. Do not turn around on the pile. Make sure one set of wheels comes off the pile when changing direction in order to minimize loss of traction.

• In order to store more feed in the same area (volume) of storage, increase as-fed packing density. Increasing as-fed packing density from 45 to 51 pounds as-fed per cubic foot increases storage capacity by 13.3 percent. If you routinely store 6,000 tons of DM, you could now store 6,800 tons of DM in the same area.

• Packing is complete when every square foot of top layer has tire tracks; having been run over twice and is smooth. There is no advantage to more than 30 minutes of packing after the final load has been spread.

• Bottom line: The most skilled tractor operator should be in the ‘push’ tractor. The people operating the ‘push’ and ‘pack’ tractors could be the most valuable (and often most overlooked) team members in the entire process, as oxygen is the enemy.

### Take-home message

Fortunately, gas-filled porosity is closely related to as-fed density and allows for practical measurement on-farm. It is the true metric of silage density, and ultimately silage quality, due to the significance of reducing or eliminating oxygen in the silo.

**Figure 1: Example of gas-filled porosity for 30 g of corn silage (35 percent DM) in syringe at 60 cc.**

| | Units | Actual | Example | Targets |
|---|---|---|---|---|
| Plunger depth | ml | 60.0 | 30.0 | |
| Corn silage, fresh weight | g | 30.0 | 35.0 | |
| Bulk density | lbs AF/cu ft | 31.2 | | >47.5 |
| Dry matter | % | 0.35 | 0.35 | 30-45 |
| Dry matter density | lbs DM/cu ft | | 10.9 | >17 |
| Maximum achievable bulk density | lbs AF/cu ft | 73.3 | | |
| Bulk density, % maximum | % | | 42.6 | >65 |
| Gas-filled porosity | % | 57.4 | | <35 |
| | Solid (%) | 14.9 | | |
| | Liquid (%) | 27.7 | | |
| | Gas (%) | 57.4 | | |

**Figure 2: Example of gas-filled porosity for 30 g of corn silage (35 percent DM) in syringe compressed to 30 cc.**

| | Units | Actual | Example | Targets |
|---|---|---|---|---|
| Plunger depth | ml | 30.0 | 30.0 | |
| Corn silage, fresh weight | g | 30.0 | 35.0 | |
| Bulk density | lbs AF/cu ft | 62.4 | | >47.5 |
| Dry matter | % | 0.35 | 0.35 | 30-45 |
| Dry matter density | lbs DM/cu ft | | 21.8 | >17 |
| Maximum achievable bulk density | lbs AF/cu ft | 73.3 | | |
| Bulk density, % maximum | % | | 85.1 | >65 |
| Gas-filled porosity | % | 14.9 | | <35 |
| | Solid (%) | 29.8 | | |
| | Liquid (%) | 55.3 | | |
| | Gas (%) | 14.9 | | |