

Fermentation Characteristics of Round-Bale Silages

R.E. Muck

USDA, Agricultural Research Service

US Dairy Forage Research Center, Madison, WI 53706

Introduction

Making round-bale silage is an attractive option for many producers. From one relatively inexpensive harvesting machine one can make either hay or silage, depending on weather or need. It provides a means of making a silage that is transportable and saleable while maintaining an anaerobic environment in the process of transferring that silage to the buyer. So the potential exists for selling silage over a greater hauling distance than is possible for silage from other silo types. A further advantage of round-bale silage is that it is easy for the producer to create an inventory by field or harvest, setting aside for example the highest quality bales for the livestock that can best utilize that quality.

While there are a lot of advantages, a major concern is the quality of fermentation that one gets from baled silage. There certainly is anecdotal evidence of fermentation problems: clostridial or butyric acid silages, moldy bales and even contamination with listeria. Are these the result of ensiling long forage particles at low densities? Do the layers of plastic film used affect these problems? Will the use of stationary knives at the baler pickup to cut the forage in smaller pieces improve density and fermentation? This paper will review the literature to attempt to answer these questions and provide some practical recommendations to help ensure a good fermentation in round-bale silage.

Ensiling Basics

Preservation by ensiling depends on three factors: anaerobic (oxygen-free) environment, fermentation acids (lactic and acetic acids), and low pH. Failure to achieve one or more of these factors may compromise silage quality.

An anaerobic environment is the most essential element for silage preservation. It is created by sealing the crop and allowing plant respiration to remove any oxygen trapped within the crop. This usually occurs within a few hours of a bale being wrapped. There are two main reasons why an oxygen-free environment is important. One, many aerobic spoilage microorganisms (particularly molds and yeasts) can grow at low pH (< 4.0) so that a good fermentation can slow down but not stop the growth of molds. Two, an anaerobic environment is also critical for the efficient growth of the lactic acid bacteria (LAB) that ferment the crop.

Lactic acid bacteria typically account for just a small percentage of the microorganisms on the crop when bales are wrapped. However, once the crop becomes anaerobic, the lactic acid bacteria are extremely good competitors and will usually become the dominant microorganisms within hours or days depending on moisture content. The LAB grow on plant sugars, producing primarily lactic acid as well as acetic acid, ethanol and other products. Lactic acid is a good inhibitor of the bacteria that cause listeriosis (*Listeria monocytogenes*). Acetic acid is a good

inhibitor of yeasts and molds. However, concentrations of acetic acid are rarely high enough to prevent mold growth.

The production of lactic and acetic acids lowers crop pH. A low pH reduces the activity of plant enzymes and inhibits growth of undesirable anaerobic bacteria. The most important of these are the clostridia. These bacteria produce butyric acid and amines from fermentation of sugars or lactic acid and amino acids, respectively. Such fermentations cause losses of dry matter (DM) and reduce silage intake by ruminants. In addition, low pH makes lactic and acetic acids more inhibitory to sensitive microorganisms, for example increasing the effect of acetic acid on mold growth.

Keys to Dealing with Detrimental Microorganisms

Clostridia. Clostridial bacteria are anaerobic bacteria like the lactic acid bacteria. However, they are typically slower than the LAB and cannot grow at as low a pH as LAB. So the key to controlling these bacteria is to drop the pH sufficiently. The critical pH to reach is a function of the crop and its DM content (Fig. 1). At the same DM content, a lower pH is needed to prevent clostridial growth in grasses than in legumes. A crop like whole-plant corn has abundant sugars for fermentation, and pH is usually below 4.0, which is why corn silage rarely has butyric acid. Grasses and legumes have highly variable sugar contents dependent on stage of growth, weather, and harvest conditions. Because of this, field wilting prior to making silage is the common means in the U.S. for preventing clostridial fermentation. If the crop has a low sugar content, then the crop has to be drier to prevent clostridial activity.

Yeasts and molds. Some yeasts grow anaerobically, producing ethanol, but these yeasts are not usually a major concern. The biggest concern is aerobic spoilage caused by yeasts that grow aerobically on lactic acid and by molds. When silage is exposed to air, yeasts that consume lactic acid are generally the first aerobic microorganisms to grow, using up lactic acid, raising silage pH, and then allowing all of the other spoilage microorganisms to grow. While molds can grow at low pH, they are much slower than other aerobic microorganisms so that when you see molds on the silage surface, it indicates that oxygen has been present for some time. Because many yeasts and molds can grow at low pH, the key to stopping them is keeping oxygen out. In practical terms, that means doing a good job of wrapping, handling wrapped bales carefully, and routinely monitoring and patching wrapped bales.

Listeria. *Listeria monocytogenes* has been isolated from wrapped round-bale silages. Most reported cases have been in cool-season grass silages in northern Europe. However, that may be more a function of the number of scientists there who have looked for listeria. I do expect that listeria can be present in our bale silages. Listeria are aerobic bacteria and do not grow below pH 4.5 to 5.0. Listeria generally are found in spoiled silage where oxygen has been present and pH is high. This is another good reason not to feed spoiled silage. Like the situation with yeasts and molds, the key is keeping oxygen out. If there are no visible molds, the likelihood of a significant listeria population is greatly reduced.

How Does Fermentation in Round-Bale Silage Compare with That in Other Silo Types?

There are several reasons why one might expect a poorer fermentation in round-bale silage relative to silage from other silo types. Lactic acid bacteria are on the outside of plant particles and do not have a means for moving around. The sugars that they grow on must diffuse from the inside of plant cells to them. Therefore one might expect that access to sugars may be more limited in round-bale silage compared with other silo types where the crop is finely chopped. Expected densities in bale silage typically range from 10 to 14 lbs. DM/ft³. These densities are similar to those in bag silos, but below those in tower silos and well-packed bunkers or piles. A lower density might also contribute to few sugars diffusing to the LAB. Finally, wrapped bales have the largest surface to volume ratio of all silo types. This makes wrapped round-bale silage potentially most susceptible to oxygen getting into the silage during storage, negatively affecting preservation.

A number of studies have compared wrapped bale silage with silage from another silo type. Nicholson et al. (1991) ensiled alfalfa (average DM content of 39%) from the same fields into wrapped bales (4 layers of film) or a bag silo. Core samples found a more rapid and extensive fermentation in the bag silage as indicated, for example, by pH (Fig. 2). At 60 d, there were more water-soluble carbohydrates (WSC) in the bale silage (6.6 vs. 4.4% DM) than the bag silage. The differences in remaining sugars and degrees of fermentation suggest that a significant portion of the WSC was not available to the LAB. In a subsequent study (Nicholson et al., 1992), alfalfa was harvested at two DM contents (27 and 40%) in bales and bags. Again, fermentation was faster and attained a lower pH in the bag silage. At the end of 60 d, butyric acid was beginning to accumulate in the bale silage at both DM contents.

Other studies have shown smaller differences than the two Canadian studies above. For example, McCormick et al. (1998) in Louisiana compared the ensiling of annual ryegrass using wrapped bales (4 layers of film) with bag silos. Alternate windrows were ensiled for each silage type. Over two years, DM contents were similar, 34 vs. 36%, respectively. The average pH was higher in the bale silage (4.80 vs. 4.53). Concentrations of various fermentation products were not significantly different; however, there was a trend for the bale silage to be lower in lactic acid and higher in acetic acid.

The somewhat higher pHs in baled silage suggest that greater wilting may be necessary to avoid clostridial fermentation. Huhnke et al. (1997) sampled bales from four different Oklahoma farms ensiled at a wide range of moisture contents. The forage was primarily annual ryegrass with varying amounts of legume (1 to 50%). The pH values from that study are shown in Fig. 3. The high pHs generally are from outer cores with spoilage present. Only six samples had significant levels of butyric acid. There is a trend with the well-fermented silages of increasing pH (or less fermentation) in drier bales as would be expected. Superimposed on the data in Fig. 3 is the line from Fig. 1 for grasses, indicating the critical pH to avoid clostridial activity. For moisture contents below 60% (or DM > 40%), pH values are generally below the line, indicating a clostridial fermentation would be unlikely. Under wetter conditions most of the points are above the line. While few samples had butyric acid, the level of fermentation in annual ryegrass at DM < 40% under Oklahoma conditions appears to be insufficient to prevent clostridial activity.

In Wisconsin, alfalfa is the dominant forage ensiled in wrapped bales. For other silo types, clostridial fermentation is unlikely in our alfalfa silages when the crop is wilted to 35% DM or higher. However, our typical recommendations are to wilt to 40% DM or higher in making wrapped bale silage to avoid clostridial activity based on experience. So a reasonable rule of thumb for the minimum DM content to ensile wrapped bales of a particular forage would be to add at least 5 percentage units to the minimum DM content to prevent clostridial silage in other silo types.

Layers of Plastic

Several factors may be causing the reduced fermentation observed in wrapped round-bale silage: the numbers of layers of plastic film, chop length and density. A greater number of layers would be expected to keep the silage more anaerobic leading to a more efficient fermentation and reduced visual evidence of molds.

Hancock and Collins (2006) compared 2, 4 and 6 layers of film in two trials with alfalfa in Kentucky. There were two DM contents in the first trial (50 and 63%) and one in the second (39% DM). After 5 mo storage, there were few significant differences in fermentation. The pH was higher under the 2 layer treatment (5.81) at 63% DM compared with the other two treatments (4.79). Differences in fermentation products were few and did not follow any consistent increasing or decreasing pattern with the number of layers. However, there was evidence of greater oxygen transfer across the plastic in the 2 layer treatments. Bale temperatures were higher in the 2 layer treatments during storage, and NDFs were significantly higher in the 2 layer treatments in two of the three DM contents. Hancock and Collins concluded that 2 layers were inadequate for preservation of alfalfa wrapped bale silage for 5 mo storage whereas 4 and 6 layers were similarly effective.

This work confirms a number of studies in northern Europe and Japan in more moderate climates (Muck and O'Kiely, 2002). In longer term studies (9 to 11 mo) in these areas of the world, increasing the number of layers from 2 to 4 layers substantially reduced losses and incidence of visible mold whereas increasing from 4 to 6 layers had little effect on quality. For example, Forristal et al. (1999) found in Irish conditions with a 9-mo storage that the average area of visible mold declined from 21.5% to 1.7% to 0.7% with 2, 4 and 6 layers respectively.

A concern about applying these results to the Southeast is the effect of your climate on plastic integrity. The higher temperatures and intensity of solar radiation could reduce the effectiveness of the polyethylene film. Paillat and Gaillard (2001) found that the service life of polyethylene stretch film in a tropical climate (Reunion Island, 21° S latitude) was reduced on average 30% to 50% (dependent on the stretch rate, altitude) compared to that in a temperate climate (France), and thus additional layers may be necessary for good preservation.

Overall, it would appear that the number of layers of polyethylene film has a relatively small effect on fermentation. However, the number of layers does affect the amount of oxygen that diffuses into the bale during storage and consequently the amount of spoilage and visible molding that occurs. Two layers of film are inadequate for preservation. Four and six layers have

performed similarly in temperate climates, but it would seem prudent to use six layers for long-term (> 9 mo) storage in the Southeast.

Chop Length

Cutting systems have become available on round balers, typically consisting of stationary knives that provide a theoretical length of cut between 1.5 to 6 in. depending on the model. These systems could potentially improve fermentation by the shorter particle sizes and by increasing density.

There are relatively few studies on these systems. Han et al. (2006) studied the effect of bale chamber pressure and chop length on the ensiling of pearl millet in wrapped round bales in two trials (23 and 42% DM) in Kentucky. Long forage was compared with a 6 in. chop length. The chopped forage produced heavier bales (7 to 11%), but DM densities were not significantly different. Fermentation was only marginally affected by chop length across the two trials after 8-mo storage. The pH values were not statistically different ($P > 0.05$) in either trial. Lactic acid in the trial with a wetter crop was the only fermentation product with a significant difference in the two trials, being higher in the shorter chop length. The chopped pearl millet silage did have less WSC remaining in the silage, suggesting more of the sugars were available to the lactic acid bacteria.

Borreani and Tabacco (2006) in Italy compared a 3.7 in. chop length with long alfalfa in three trials, one with two different DM contents. Chopping increased density in a fixed chamber baler by approximately 4% across all trials. In the wetter trials (35 and 38% DM), chopping did not affect the rate of decline or final (140 d) pH values of the silages. At 49% DM, the rate but not final pH was improved by chopping. The greatest effects on pH occurred at 61% DM with a 0.3 pH unit reduction in the final silage from chopping. Lactic acid was reduced by chopping in the wettest silage and acetic acid increased by chopping in the driest silage. Otherwise there were no significant effects of chopping on these principal fermentation products. In the two wettest silages, dry matter recovery was increased from chopping by approximately 1 percentage unit.

These limited results suggest that chopping is not having a large effect on fermentation. The biggest effects appear to be under dry conditions (> 50% DM), permitting a more extensive fermentation.

Density

A higher density might be expected to improve fermentation by increasing the contact between forage particles and helping to express plant juices, making plant sugars more readily available to the lactic acid bacteria. Again, research in this area is limited.

Han et al. (2004) carried out two trials (41 and 48% DM) on alfalfa in Kentucky comparing densities of approximately 12.5 vs. 10.5 lbs. DM/ft³ by varying baler chamber pressure. In the wetter trial, there was a trend toward lower pH, higher lactic acid and lower acetic acid in the high density treatment, but the effects were not significant ($P > 0.05$). In the drier silage, pH was significantly lower (4.8 vs. 5.1) and acetic acid significantly higher (3.3 vs. 2.0% DM) in the

high density treatment. Other factors such as temperature during storage, DM recovery and mold score were unaffected by density.

More recent work from the same group (Han et al., 2006) studied bale chamber pressure on pearl millet silage at two DM contents (23 and 42%). In the wetter silage, pH was reduced by high density (8.7 vs. 5.4 lbs. DM/ft³), but in the drier silage the effect of density (11.9 vs. 9.0 lbs. DM/ft³) was not significant. Lactic acid was increased by high density in the wetter silage but there was no effect in the drier silage. Acetic acid was not affected by density in either trial. The lack of fermentation effects in the drier trial may have been due to the excellent fermentations that occurred (average pH 4.15; lactic acid, 6.4% DM; acetic acid, 0.8% DM), precluding an effect of density.

Overall, it appears that increasing density modestly improves silage fermentation but not consistently. This inconsistency may be due to the supply of sugars for the lactic acid bacteria. Where sugar concentrations limit fermentation, increasing density may allow for more sugars to reach the lactic acid bacteria, improving fermentation. If the crop has abundant sugars, increasing density appears to have no effect on fermentation.

Summary

High quality silage can be made with wrapped round bales, but fermentation is somewhat restricted relative to fermentation in other silo types. Research on the number of layers of plastic, chopping the forage at baling, and bale density suggests that each factor can play a minor role in affecting fermentation. However, no one factor stands out as being solely responsible for reduced fermentation in wrapped bale silage. The practical effect of the more restricted fermentation in bale silage is that crops should be ensiled at least 5 percentage units drier than recommended for ensiling in bag, pile or bunker silos to avoid clostridial fermentation.

References

- Borreani, G., Tabacco, E. 2006. The effect of a baler chopping system on fermentation and losses of wrapped big bales of alfalfa. *Agronomy Journal* 98(1):1-7.
- Forristal, P.D., O'Kiely, P., Lenehan, J.J. 1999. The influence of the number of layers of film cover on silage preservation, gas composition and mould growth on baled silage. In: Pauly T. (ed) *Conference Proceedings of the XIIth International Silage Conference*, pp. 305-306. Uppsala, Sweden: Swedish University of Agricultural Sciences.
- Han, K.J., Collins, M., Newman, M.C., Dougherty, C.T. 2006. Effects of forage length and bale chamber pressure on pearl millet silage. *Crop Science* 46(1):337-344.
- Han, K.J., Collins, M., Vanzant, E.S., Dougherty, C.T. 2004. Bale density and moisture effects on alfalfa round bale silage. *Crop Science* 44(3):914-919.
- Hancock, D.W., Collins, M. 2006. Forage preservation method influences alfalfa nutritive value and feeding characteristics. *Crop Science* 46(2):688-694.
- Huhnke, R.L., Muck, R.E., Payton, M.E. 1997. Round bale silage storage losses of ryegrass and legume-grass forages. *Applied Engineering in Agriculture* 13(4):451-457.
- Leibensperger, R.Y., Pitt, R.E. 1987. A model of clostridial dominance in ensilage. *Grass and Forage Science* 42:297-317.

- McCormick, M.E., Cuomo, G.J., Blouin, D.C. 1998. Annual ryegrass stored as Balage, haylage or hay for lactating dairy cows. *Journal of Production Agriculture* 11(3):293-300.
- Muck, R.E., O'Kiely, P. 2002. New technologies for ensiling. In: Gechie, L.M., Thomas, C., editors. *The XIIIth International Silage Conference*, 11-13 September 2002, Auchincruive, Scotland. p. 334-343.
- Nicholson, J.W.G., Charmley, E., Bush, R.S. 1992. Effect of moisture level on ensiling characteristics of alfalfa in big bales or chopped and compacted in plastic tubes. *Canadian Journal of Animal Science* 72(2):347-357.
- Nicholson, J.W.G., McQueen, R.E., Charmley, E., Bush, R.S. 1991. Forage conservation in round bales or silage bags: effect on ensiling characteristics and animal performance. *Canadian Journal of Animal Science* 71(4):1167-1180.
- Paillat, J.M., Gaillard, F. 2001. Air-tightness of wrapped bales and resistance of polythene stretch film under tropical and temperate conditions. *Journal of Agricultural Engineering Research* 79(1):15-22.

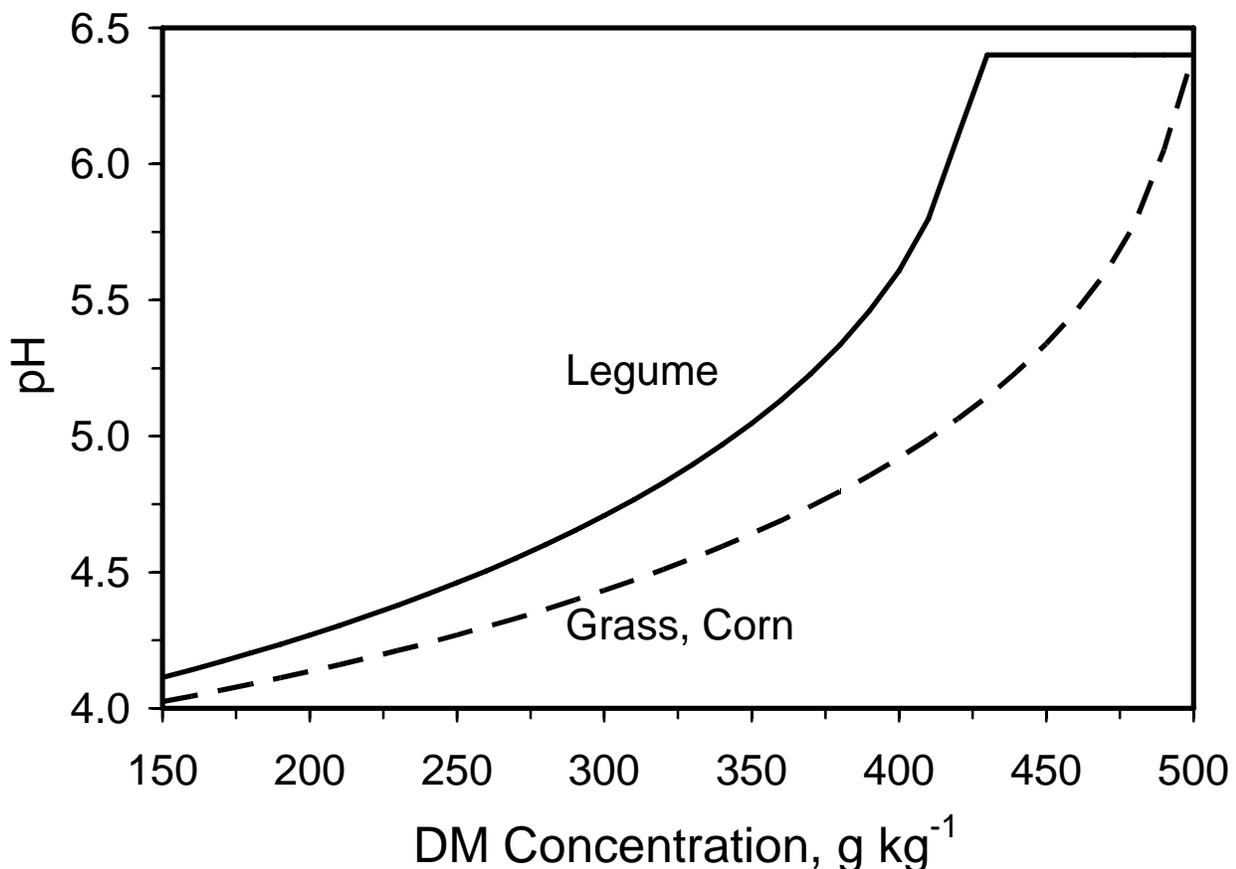


Figure 1. The pH below which the growth of *Clostridium tyrobutyricum* ceases as a function of the DM content of the crop (based on Leibensperger and Pitt, 1987).

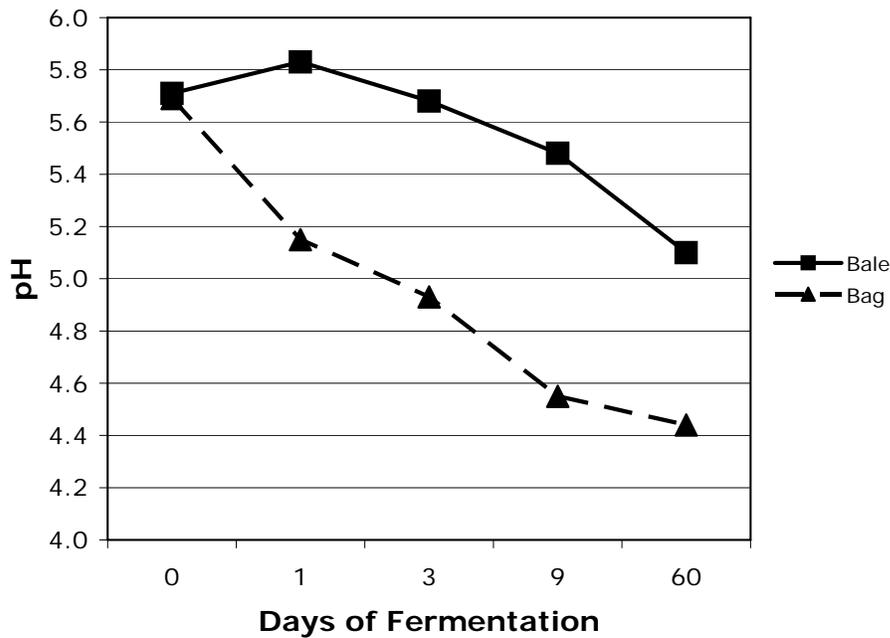


Figure 2. The pH of alfalfa-grass silage made by wrapped round bales or bag silo (Nicholson et al. (1991).

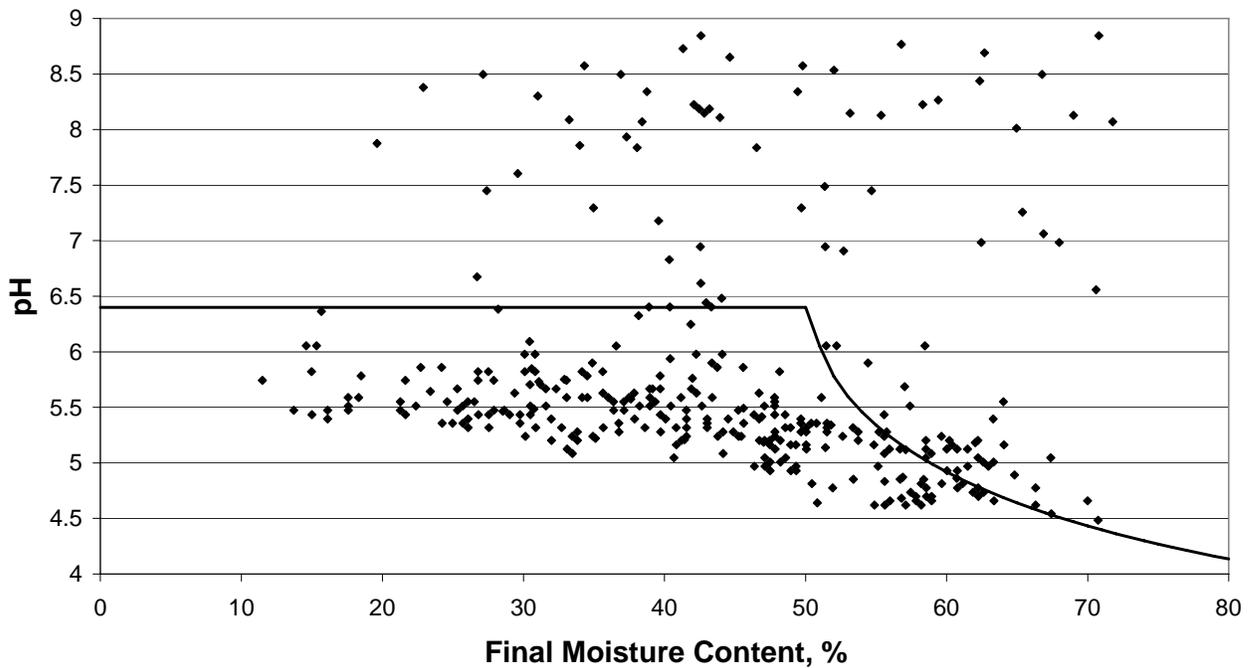


Figure 3. The pH values of wrapped bale silage (annual ryegrass with varying amount of legume) sampled at four Oklahoma farms as related to bale moisture content (Huhnke et al., 1997). The line is the critical pH for clostridial growth on grass silage, taken from Fig. 1.