

# Are Forage Inoculants Cost Effective?

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## Introduction

Forage preservation has been a fundamental aspect of livestock production for thousands of years. With any forage preservation technique, the quantity and quality of material available at the end of storage are always less than the original. Thus, the primary goal of forage preservation is to minimize spoilage and losses of dry matter (DM). This is accomplished by minimizing the effects of plant enzymes and microorganisms either through drying (hay production) or through controlled fermentation (silage production). The choice between silage and hay production depends on climate and properties of a given crop. In wetter regions of the world, silage production dominates. For example, in Western Europe, where most silage is made from grasses, about 50% more forage dry matter is stored as silage than as hay. However, in regions where hay production is feasible, it has been the preferred method. In 1999, Kentuckians produced approximately 1.7 million tons of corn silage and 4.8 million tons of hay.

Over the last 30 years, our understanding of the processes of stored forage deterioration has improved considerably. This, and the development of many technologies, has resulted in an increase in the production of silage in developed countries, often at the expense of hay production (Wilkinson and Stark, 1992). One such development has been the commercial availability of a number of microbial inoculants that can be used to 'direct' microbial growth in stored forages. The objective of this paper is to give a general overview of the science behind forage inoculants and to review the available research to determine whether or not forage inoculants are cost effective.

## Silage

The ensiling process can be divided into four phases: 1) aerobic, 2) fermentation, 3) stable, and 4) feedout. Understanding the role of inoculants requires an understanding of each of these phases.

***Aerobic phase.*** From the time silage is cut, plant enzymes are responsible for two major processes that deteriorate silage quality – respiration and proteolysis. Respiration is the conversion of plant sugars to carbon dioxide, water, and heat. The loss of these sugars is important, because they serve as the primary substrate for lactic acid bacteria to produce the acids to preserve the crop. Excessive heating from this process (temperatures over 110 °F) will result in non-enzymatic (Maillard) reactions, which reduce the availability of proteins that are not broken down. Also, any loss of energy as heat represents energy that will never be available to animals. Respiration requires oxygen, and thus can be minimized by shutting down the oxygen supply. In proteolysis, plant proteins are broken down, primarily to amino acids and ammonia. Low pH will shut down proteolytic enzymes. Thus, rapid acidification (from the lactic acid bacteria) is desirable to minimize protein degradation.

**Fermentation phase.** Packing and sealing are essential to exclude oxygen from the ensiled forage. Certain bacteria (facultative anaerobes) are responsible for 'scavenging' what oxygen remains, allowing anaerobic microorganisms to flourish. Several groups of microorganisms exist in silage. The primary groups are the lactic acid bacteria, enterobacteriaceae, clostridia, yeast, and molds. Of these, only the lactic acid bacteria are desirable because their endproduct, lactic acid, is essential for the proper preservation of silage. All of the other groups will compete with the lactic acid bacteria for nutrients (esp. fermentable carbohydrates) and produce end-products that decrease the quality of the silage. Acidification will halt the growth of the enterobacteriaceae (below pH 5.0) and clostridia (below pH 4.6). Lactic acid bacteria will tolerate pH as low as 4.0. Thus, active fermentation typically continues for a period of 7 to 21 days, at which time it is discontinued as a consequence of either low pH, or the depletion of sugars for fermentation. The proliferation of lactic acid bacteria and the subsequent rate of pH decline are related to a number of factors: 1) levels of naturally occurring (epiphytic) microorganisms, 2) dry matter content of material, 3) levels of fermentable carbohydrate, 4) buffering capacity of material, 5) efficiency of oxygen exclusion.

**Stable phase.** With proper oxygen exclusion and low pH, little activity exists in silage following the active growth of lactic acid bacteria. Some of the fibrous components (hemicellulose) may break down at a slow rate. If fermentation ceased because of a lack of carbohydrate, fiber degradation could provide substrate to the lactic acid bacteria, leading to a continued, but slow decrease in pH. Provided oxygen is not allowed to leak in, properly preserved silages should remain in the stable phase indefinitely.

**Feedout phase.** Once the silo is opened, and through feeding, portions of the silage are exposed to oxygen. Aerobic microorganisms, primarily yeast and molds, will grow, consume dry matter, and cause heating. The time required for heating to occur depends on 1) numbers of aerobic microorganisms in the silage, 2) time exposed to oxygen before feeding, 3) silage fermentation characteristics, and 4) ambient temperature. Minimizing dry matter losses during this phase is primarily a function of silage management practices. For example, rapid filling, adequate packing, and tight sealing of silo can minimize numbers of aerobic organisms; and feeding rate, exposed surface area, and silage density can affect exposure time to oxygen before feeding.

**The role of inoculants.** The lactic acid bacteria that exist naturally on forages are a rather diverse group, including at least 6 different genera (Table 1). One important classification is whether the particular bacteria is homofermentative (producing only lactic acid) or heterofermentative (producing lactic acid along with other organic acids, ethanol, CO<sub>2</sub>, etc.). In general, because we are interested in lactic acid production for proper silage preservation, homofermentative species are preferable to heterofermentative species. Additional characteristics that have been identified as desirable for species to be used as silage inoculants include rapid growth rate (to compete with other microorganisms), tolerance of low pH, ability to reduce pH to around 4.0 quickly, ability to ferment a wide variety of sugars, absence of action on organic acids, ability to tolerate wide temperature range, ability to grow in high DM materials, absence of proteolytic activity, ability to hydrolyze starch. Early studies indicated that a very small percentage of bacterial strains possessed all of the characteristics desirable for silage inoculants. Research over the last 30 years has

indicated that *Lactobacillus plantarum* is one of the best suited lactic acid bacteria. Thus, single or multiple strains of *L. plantarum* are included in most commercial inoculants available today. However, some strains of *L. plantarum* are slow to produce lactic acid until the pH drops below 5.0. Therefore, many commercial inoculants also contain strains of *Pediococcus* and/or *Enterococcus* which are active when pH is between 5.0 and 6.5, and will dominate the early fermentation to establish an environment conducive to the growth of *L. plantarum*.

**Responses to inoculants.** Silage inoculants have been the focus of a tremendous amount of research over the last 20 years and several reviews have been published. Fermentation characteristics are generally improved with inoculation. Bolsen et al. (1990) reported that inoculation improved fermentation characteristics in over 90% of 300 silages, including alfalfa, wheat, corn, and forage sorghum silages. In over 250 studies reviewed by Muck (1993), inoculation enhanced silage fermentation 75% of the time with alfalfa, 77% of the time with grass silages, but only 40% of the time with corn silages. A number of reviews indicate that improvements in dry matter recovery (tons silage DM fed/tons DM ensiled) on the order of 2 to 3 percentage units can be expected in 75% of the cases when inoculants are used. The number of studies which have evaluated animal responses to inoculated silages is considerably smaller than the number which have evaluated fermentation responses. However, work reported by Muck (1993) indicates that increases in dry matter intake averaging 11% can be expected in 25% of the cases, increases in daily gain averaging 11% can be expected in 25% of the cases, increases in feed efficiency averaging 9% can be expected in 50% of the cases, and increases in milk production by dairy cows averaging 5% can be expected in 40% of the cases. Interestingly, increases in animal performance are not always explained by improvements in fermentation characteristics. It has been hypothesized that some as-yet unidentified components of inoculated silages may be responsible for such effects.

**Table 1. Lactic acid bacteria important in silage preservation<sup>a</sup>.**

Genus	Species	Fermentation type <sup>b</sup>
<i>Lactobacillus</i>	<i>acidophilus, casei, coryniformis, curvatus, plantarum, salivarius</i>	Homofermentative
	<i>brevis, buchneri, fermentum, viridescens</i>	Heterofermentative
<i>Pediococcus</i>	<i>acidilactici, cerevisiae, pentosaceus</i>	Homofermentative
<i>Enterococcus</i>	<i>faecalis, faecium</i>	Homofermentative
<i>Lactococcus</i>	<i>lactis</i>	Homofermentative
<i>Streptococcus</i>	<i>bovis</i>	Homofermentative
<i>Leuconostoc</i>	<i>mesenteroides</i>	Heterofermentative

<sup>a</sup>From McDonald et al. (1991)

<sup>b</sup>Homofermentative – produce primarily lactic acid; heterofermentative – produce lactic acid plus other organic acids or ethanol.

Obviously, there is some variability in response to inoculants. Much of this variation is explained by known factors. For example, effects of inoculants are expected to be more common with legume and

grass silages than for corn silage. This is believed to be due to the fact that corn typically has high numbers of naturally-occurring, epiphytic microorganisms with which inoculated bacteria must compete. Also, corn silage generally has high amounts of fermentable carbohydrate, allowing existing bacteria to generate a reasonably rapid pH decline. Other factors affecting response to inoculation include the particular species and strains of bacteria present in inoculants, the application rate and viability of the bacteria at application time, and the dry matter percentage of the ensiled crop.

The numbers above, however, will allow us to estimate the economic value of silage inoculants. Values in Table 2 represent a conservative estimate, based on increased DM recovery of 1.3 percentage units and increased milk yield of 0.2 lb/d, although research shows that responses considerably greater than this are possible. Even with no effect on milk production, increases in DM recovery alone will result in a NET increase in silage value on the order of \$5.00 per ton ensiled. With higher levels of milk production, and with greater responses in milk production due to silage inoculation, increases in net value will be greater. For example, gaining 0.5 lb milk per day, well within the range of reported responses, would result in increased silage value of about \$10.00 per ton.

**Table 2. Estimated effect of corn silage inoculation on economic returns with dairy cattle milking an average of 17,000 lb/yr<sup>a,b</sup>.**

	Without Inoculant	With Inoculant
Dry matter recovery, %	90.0	91.3
Dry matter recovered per ton wet feed ensiled, lb <sup>c</sup>	585.0	593.5
Amount fed daily, lb DM <sup>d</sup>	7.6	7.6
Cow days per ton ensiled	77.3	78.4
Milk gained per ton ensiled, lb		62.2
Milk value gained from increased DM recovery per ton ensiled		<b>\$ 8.40</b>
Increased milk yield per cow per day, lb		0.2
Increased milk yield per ton ensiled, lb		15.7
Milk value gained from increased milk yield per ton ensiled		<b>\$ 2.12</b>
<b>Total increase in value</b>		<b>\$10.52</b>
Cost for other feed for extra 1.1 days of silage per ton ensiled		<b>\$ 2.68</b>
Inoculation costs per ton ensiled		<b>\$ 1.00</b>
<b>Total costs per ton ensiled</b>		<b>\$ 3.68</b>
<b>Net increase in value per ton ensiled</b>		<b>\$ 6.84</b>
<b>Net increase per cow per year</b>		<b>\$26.60</b>

<sup>a</sup>Adapted from Bolsen et al., [http://www.oznet.ksu.edu/pr\\_silage/bunker\\_silo\\_mgmt.htm](http://www.oznet.ksu.edu/pr_silage/bunker_silo_mgmt.htm)

<sup>b</sup>Calculated for milk value of \$13.50/cwt.

<sup>c</sup>Assuming silage DM content of 32.5%.

<sup>d</sup>For diet comprised of 20% corn silage (DM basis) fed at approx. 40 lb of DM/day, to meet needs for 17,000 lb milk/year.

Economic responses with beef cattle are not quite as dramatic. However, calculations indicate that net increases in value of silage would be expected. Using a similar approach as in Table 2, and using beef steers growing at 2.3 lb/d without inoculant and 2.35 lb/d with inoculant (a 2.5% increase in gain), with steer prices at \$0.75/lb, net increases in silage value of about \$2.50 per ton would be realized. This value would be expected to be greater when applying inoculants to forages such as legume haylage, in which opportunities for improved performance are greater than with corn silage.

The above results apply especially to inoculants containing homofermentative species of bacteria. More recently, inoculant research has been geared toward examining certain strains of heterofermentative bacteria. Results to date indicate that some of these strains, particularly those producing acetic and/or propionic acid, may substantially enhance the aerobic stability of silages during feed-out. Increases in aerobic stability will add to the economic value of silage inoculants.

Although the research data indicates that silage inoculants are cost effective in most circumstances, it is important to note that inoculants will not overcome poor silage management. Key management factors to consider to ensure quality silage include: determining proper silo dimensions, harvesting the crop at a proper maturity and moisture level, chopping to proper length, ensiling rapidly, ensuring adequate packing, covering silage securely, and using the proper rate and method of feedout.

### **Which Inoculant to Use**

Several commercial inoculants are available and selecting the appropriate inoculant can be difficult. Thus, a few helpful pointers are given. Inoculants should provide at least 100,000 (i.e.,  $10^5$ ) colony forming units (cfu) of lactic acid bacteria per gram of forage. The lactic acid bacteria should dominate the fermentation, be homofermentative (although addition of heterofermentative strains may help improve aerobic stability), grow across a wide range of temperatures and moisture levels, and ferment a wide range of plant sugars. The product should be purchased from a reputable company that can provide quality assurance as well as research results from independent, unbiased sources to document the effectiveness of the product in the crop of interest.

### **Hay**

Hay production as a means of forage conservation depends on drying forage sufficiently to minimize microbial growth. Field and harvest losses of dry matter are substantial with hay production (Fig. 1), mainly because of loss of leaves during harvest. Baling hay at higher moistures can decrease DM losses and increase quality because more leaves, with proportionately higher nutrient concentrations than stems, will be retained and chances for losses due to weathering can be minimized. However, several problems are inherent when attempting to conserve wet hay. First, wet conditions are a breeding ground for bacteria, yeast, and molds. As in silage, rapid growth of these microorganisms will cause heating, ultimately decreasing the available protein in the forage, and in severe cases, combustion may ensue. Additionally, aerobic deterioration can result in large losses in dry matter. Mold growth can cause additional difficulties through production of mycotoxins and by creating respiratory problems in both animals and humans.

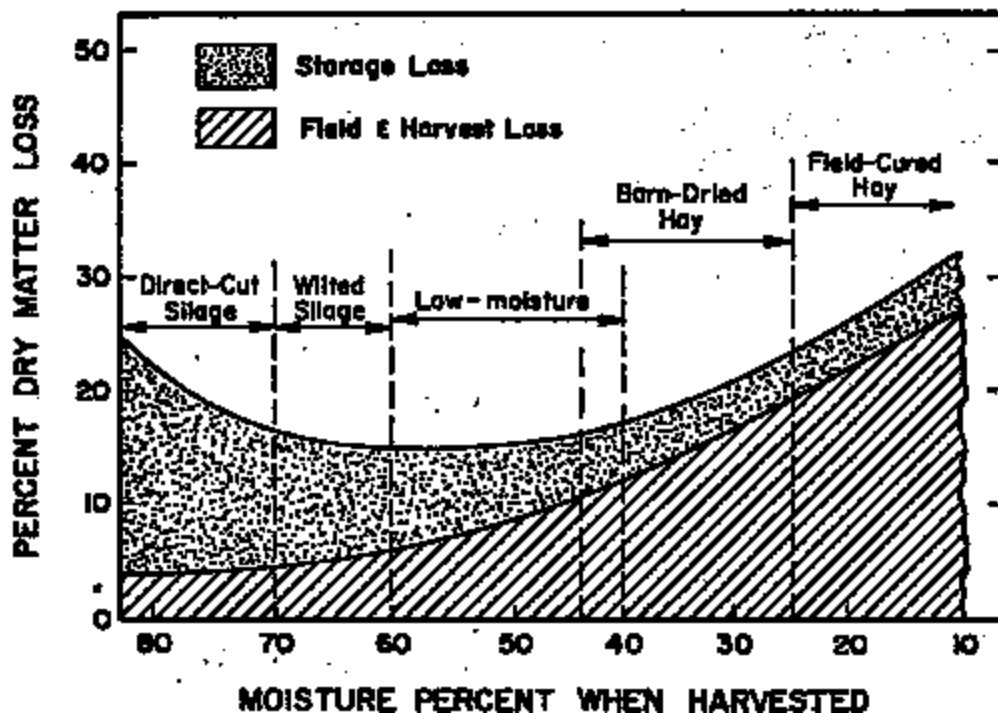


Figure 1. Influence of harvest moisture content on dry matter losses in forages. From Hoglund, 1964, Michigan State Univ., Ag. Econ. Pub. #947.

Thus, inoculants have been evaluated for their ability to decrease spoilage (storage) losses with production of wet hay. Most work has been done with heterofermentative species, because of the apparent need to produce acetic and/or propionic acid to minimize growth of unwanted aerobic organisms, especially yeasts and molds. Research results to date are somewhat inconclusive. This is likely because of the inherent difficulties in establishing populations of beneficial organisms in a partially aerobic environment. With continued research and development of new technologies, it is likely that within a few years, microbial hay inoculants will be commonplace.

### Conclusions

Are forage inoculants cost effective? When appropriate inoculants are applied to *ensiled forages*, they are cost effective. Several factors influence the degree of response from inoculants, but on average, net returns increase when inoculants are used on silages. At present, responses to *hay* inoculants are quite variable. Additional research and development is necessary before hay inoculants offer the degree of economic benefit noted for silage inoculants.