SCIENTIFIC ASPECTS OF SILAGE MAKING

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ABSTRACT

Silage is a common way of storing and feeding forage in the United States. There are 4 phases (aerobic, anaerobic, stable, and feedout) that silage undergoes. The most critical phases to manage to minimize nutritive losses are when the silage is going from an aerobic to an anaerobic environment and at feedout. The first important step in achieving silage of high nutritive value is to harvest at the proper maturity and moisture level. Alfalfa should be harvested between mid bud and one-tenth bloom, and corn should be harvested between one-half and two-thirds milkline. The type of silo (pile, bunker, bag, or upright) has an impact on silage DM lost during storage. Bunker silos and piles usually have higher silage DM loss than bag and upright silos primarily because there is a greater amount of surface area exposed to oxygen. Limited research suggests that the nutritive value of high DM corn silage (~38%) can be preserved better (increased milk production) in a bagged silo system compared to a bunker silo. Filling bunker silos rapidly using the progressive wedge technique has been shown to improve the nutritive value of silage. Covering bunker silos with polyethylene plastic also improves the amount of silage DM recovered and the nutritive value of both hay crop and corn silage. During the feedout phase it is important to feed approximately 5 inches or more from the silo face each day to minimize losses in quality that occur when silage is exposed to oxygen.

Key Words: fermentation, management, harvest, silo type, silo covering, feedout

INTRODUCTION

Silage is the endproduct of fermenting low dry matter forages (typically grass, alfalfa, and corn) in an anaerobic environment. It is usually stored in a silo of various designs (upright, bunker, bag, or pile), and fed to animals throughout the year. Silage has been a popular option for preserving the nutritive value of forages in the United States (~39 million tons of DM; Wilkerson et al., unpublished). Some advantages to storing forage as silage include: 1) do not need as ideal of weather conditions for ensiling forage as is required for hay and grain production, 2) with annual crops (corn, sorghum small grains), there is a higher yield of nutrients per acre than grain, and 3) flexibility in harvest dates. Some disadvantages to storing forage as silage include: 1) silage has a higher moisture content and lower nutrient density than many other feeds, 2) need more sophisticated storage systems to ensure an anaerobic environment, 3) the moisture content and nutrient density limit feasibility of transport (produced and stored close to home), and 4) high initial investment in facilities and equipment. There are many management practices that can be employed by farmers and custom operators that will ensure a high quality wet forage is preserved and fed. Management of silages can be broken down into 4 categories: 1) harvest, 2)

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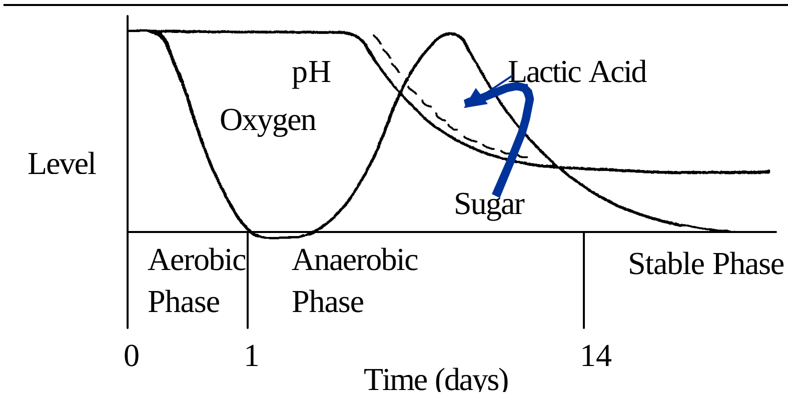
silo type, 3) covering/filling, and 4) feedout. All of these management practices can have an impact on the economics of feeding silage.

SILAGE FERMENTATION

Forage is fermented in an anaerobic environment to enhance acid production by microbes naturally present on the forage crop or by added bacterial inoculants. The acid reduces the pH of the forage crop, and in an oxygen free environment, the forage will remain stable until it is fed to animals. There are 4 phases associated with silage fermentation (Figure 1). The aerobic phase happens at the beginning of fermentation when the pH is high. During this phase, oxygen is consumed by the microbes that are present in the forage. The fermentation phase is the second phase. During the fermentation phase the microbial population increases. The microbes consume the soluble sugars present in the forage and produce acid. The majority of the soluble sugars eventually get consumed by the microbes, and the acid concentration in the forage gets to a level that inhibits proliferation of microbes and the bacteria die. This is the beginning of the stable phase (3rd phase) that has minimal biological activity. The forage will remain in the stable phase until there is exposure to oxygen. The fourth phase is referred to as the feedout phase. The silo is opened and oxygen infiltrates through the face of the silo. This allows for growth of microorganisms that thrive in an aerobic environment (yeast, molds, acetic acid bacteria, and bacilli). These organisms are known to decrease the nutritive value of silage. The main goal when making silage is to get from the aerobic phase to the stable phase as quickly and efficiently as possible, and minimize aerobic exposure at feedout. Therefore, many of the important silage management factors focus on reducing the time between the aerobic and stable phases, and limiting oxygen exposure at feedout.

Figure 1. Phases of Silage Fermentation.



Source: Allen et al., 1995.

SILAGE MANAGEMENT

Harvest

Many factors affect the quality of forage at harvest. However, the two factors that are commonly used to determine when to harvest forages for silage are stage of maturity and DM content. The

DM content of forages tends to increase as maturity advances. The quality of grass, alfalfa, and corn all tend to decline rapidly after a certain maturity level is obtained. To maximize quality it is recommended that alfalfa be harvested at mid bud to 1/10 bloom and wilted to a DM of 30 to 35% (Table 1). Recommendations for unprocessed corn silage include harvesting between one-half and two-thirds milkline when the DM content is between 30 to 35% (Table 1).

Table 1. Recommended harvest maturity, DM content, and nutrient composition of forages commonly fed as silage in the United States.

	Grass Silage	Alfalfa Silage	Corn Silage
Stage of Maturity	Boot	Bud	½ to 2/3 Milkline
DM, %	30-35	30-35	30-35
pH	4.5-5	4-5	3.5-4
Lactate, %	3-4.5	4.3-5.3	4-6
CP, %	18-20	20-25	8-10
NDF, %	50-55	36-42	36-45

In recent years two practices that differ from the traditional method of harvesting corn silage have gained popularity. The first practice is to harvest corn silage at higher cutting heights. This forage is often referred to as 'super' or 'hi-chop' silage. The second practice is to mechanically process corn silage during harvest with an on-board kernel processing unit. This unit contains two counter rotating rolls that operate at differential speed that are located between the cutting knives and the blower spout.

At a given maturity, the nutritive value of corn silage can be changed by altering the cutting height of the silage. As much as 20 inches of the lower portion of the stover has been left unharvested (Quaife, 2000). This management technique results in silage that has lower fiber content and higher starch than conventionally harvested corn silage. While a more digestible forage is harvested, there is also a loss in yield of harvested forage (Table 2).

Table 2. Effect of cutting height on quality and yield of corn silage.

Cutting Height (inches)	Yield (tons/acre 30% DM)	Acid Detergent Fiber, %	Starch Content %	Estimated Milk Produced per Ton of Corn Silage DM (lbs)
4	29.8	22.1	28.4	2,452
8	28.4	21.6	29.3	2,500
20	26.6	20.6	31.1	2,646

Mechanically processing also alters the nutritive value of corn silage. Typically, the nutritive value (measured via energy content) of unprocessed corn silage increases as maturity advances to approximately two-thirds milkline (Figure 3; solid line). This is primarily related to 2 factors:

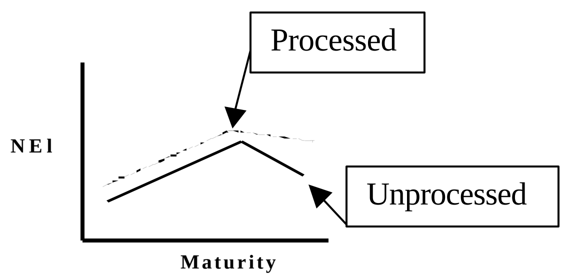
1) The fiber digestibility being high in the stover portion of the plant
2) An increase in the highly digestible starch content as the corn grain develops in the ear

The nutritive value (energy content) of the unprocessed corn silage starts to decline as maturity advances from two-thirds milkline to blackline (Figure 3; solid line). This occurs primarily due to 3 factors:

1) The outer covering of the corn kernel becomes difficult for rumen microbes to penetrate, therefore it is more difficult to digest starch in the inner portion of the corn kernel
2) There is an increase in the less digestible form of starch (vitreous starch) in the corn grain
3) Fiber digestibility in the stover portion of the plant declines.

However, processing corn silage tends to increase the nutritive value (energy content) of corn silage at all maturities (Figure 3; dashed line). At the early maturities, the improvement is primarily because of an increase in fiber digestibility due to the shearing action that occurs to the plant as it passes through the rollers on the forage harvester. At advanced maturities, the improvement is primarily due to an increase in starch digestibility because processing cracks the corn kernels and alters the starch matrix in the kernel.

Figure 3. Energy content of corn silage.



Silo Type

There are four silo types that are commonly used throughout the United States. They include bunker, pile, bags, and upright silos. Higher losses of silage DM usually occur in a pile or bunker silo compared to bags and upright silos. The increase in DM loss is associated with the increased amount of surface area that has the potential to be exposed to oxygen. When all the costs for forage harvest and storage are considered on an annual basis, the bagging system usually is the least cost alternative when compared to upright, bunker or pile systems (Holmes, 1998). These evaluations only consider input costs and recovery of silage from storage since limited data exists where the nutritive value of forage stored in alternative silos (side by side comparison) has been evaluated (Harrison et al., 2001).

In 1999 and 2000 we conducted two experiments to evaluate the nutritive value of corn silage that was stored in either bunker or Ag Bag silos. The study design involved the ensiling of corn silage at the same time into the two types of silos to minimize the impact of field variation and weather. In the first study (Harrison et al., 2001) the corn silage had a DM of ~38% and was mechanically processed. With this drier silage we noted an increase in milk production of 2.7 pounds of 3.5% FCM (Table 3). In the second study, we harvested corn silage that was ~28% DM and mechanically processed. Cows fed the bagged silage produced 0.7 pounds more milk (not statistically different – 114.4 vs 113.7 pounds milk) when compared to cows fed the bunker stored silage. The difference between trial 1 and trial 2 is likely related to the amount of corn silage fed in the ration and the DM content of the forage at ensiling. In both trials we observed that the bagged silage was cooler during the ensiling period of ~6 months. This difference in temperature was also observed in the face of the bunker and bagged silage during the feedout period.

Table 3. Effect of silo type on milk production.

Silo	Milk lbs	Milk fat %	3.5% FCM	Milk Protein %	Milk Protein lb
Ag Bag	83.8	3.80	86.7	2.89	2.38
Bunker	82.7	3.61	84.0	2.86	2.35
P value	0.17	0.05	0.06	0.17	NS

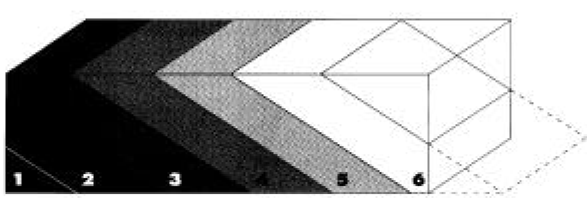
Silo Filling/Covering

It is an accepted fact that rapid filling of the silo at harvest time maximizes silage quality. Limiting the amount of time that the cut forage is exposed to oxygen lowers levels of bound protein, creates smaller increases in fiber (ADF), lowers final pH, and improves feed bunk life. Research by Ruppel (1993) demonstrated that reducing the number of days to fill the silo from 11.3 to 5 reduced ADIN (acid detergent insoluble nitrogen also referred to as 'bound protein') by 5.28 percentage units. Bound protein usually occurs when the forage is subjected to high temperatures, and the protein undergoes a chemical reaction (Maillard reaction) that renders the protein undigestible to the cow. Therefore, these results suggest that rapid filling limits oxygen exposure which reduces the opportunity for a rise in temperature due to increased plant respiration.

In a bunker silo, filling method has an affect on forage quality. Ruppel (1993) demonstrated that carbohydrate digestibility was greater when a progressive wedge (Figure 4) method of filling was used versus full height before adding to length and full length before increasing height methods were used. The concentration of ADF was 3.3 percentage units lower and the concentration of NSC (% CHO) was about 8 percentage units greater for silos filled using the progressive wedge versus the other filling methods (Ruppel, 1993). The improvement in carbohydrate digestibility was attributed to an improvement in packing and more efficient burial of previously harvested forages (Ruppel, 1993).

Pack density of forage in the silo affects the feedbunk life (aerobic stability) of silage. Silage density increases with increased packing. The increased packing limits the amount of oxygen present in the silo. Less oxygen will lower the amount of aerobic microorganisms present in the forage. This in turn will lengthen the amount of time it will take for the forage to increase in temperature once the forage is re-exposed to oxygen at the time of feedout.

Figure 4. Progressive wedge method of filling silo.



Source: Corn silage production, management, and feeding bulletin. 1995.

The amount of time spent packing has a greater affect on density than initial NDF content of the hay crop or particle length (Ruppel, 1993). The NDF content of silage in one silo was ~60%, however it had the highest density of all the silos in the study because the amount of time spent packing (measured as hr-lbs/as-fed ton and hr-lbs/ft^2 top surface) the silo was greatest (Ruppel, 1993).

It has been reported that a minimum pack density of 14 lbs/ft^3 on a DM basis needs to be achieved to minimize the amount of detrimental aerobic microorganisms present that can spoil the forage (Muck and Holmes, 1999). To achieve this level of pack density it is necessary to have a minimum of 625 hr-lbs per wet ton of forage based on Equation 1. The amount of hr-lbs is calculated using Equation 2. Other research has demonstrated that packing at a rate of 800 to 1000 hour-pounds per ton has been shown to result in better aerobic stability in hay crops (Ruppel, 1997). Two equations (Equations 3 and 4) demonstrate: 1) how to calculate the tons of forage that can be harvested per hour based on the packing tractors weight and/or 2) the amount of packing tractors need (based on weight of packing tractors) based on the number of tons of forage that can be harvested in an hour.

Equation 1: pack density (lbs/ft3) = 12.1 + 0.00304 hr-lbs/wet ton
Equation 2: [tractor weight (lbs) * packing hours (hr)] / tons of forage harvested (as-fed basis)
Equation 3: filling rate (tons per hour) = packing vehicle(s) weight / 800
Equation 4: packing vehicle(s) weight = filling rate (tons per hour) * 800

Along with proper filling and packing techniques, it is also equally as important to properly cover a bunker silo. Research has demonstrated that the quality and recovery of silage is compromised if horizontal silos (bunkers, trenches, and stacks) are not covered with polyethylene plastic (Bolsen, 1997). Dry matter content in the top 30 inches tends to be lower in unsealed versus sealed silos because the unsealed silos are exposed to all forms of precipitation. Recovery of both alfalfa and corn silage DM is also greatly reduced in the top 10 to 30 inches of the silo (Bolsen, 1997; Table 4). A large percentage of the silage mass can be within the top 3 feet depending on silo size and depth. The low DM recoveries in the top 30 inches of the unsealed silos measured in this study indicate that there is significant loss of forage DM when horizontal silos are not covered (Table 4).

Along with a reduction in DM content and yield of silage there is also deterioration in quality. The concentration of lactic acid tends to be lower in the top 30 inches of the silo, and pH levels tend to be higher in the top 10 inches of the silo for corn silage (Bolsen, 1997; Table 4). The reduction in quality as indicated by pH and lactic acid concentration is verified by in situ DM digestibility data. Both alfalfa and corn silage were incubated for 72 hours in steers, and the DM digestibilities tended to be lower for forages within the top 30 inches stored in unsealed silos compared to sealed silos (Bolsen, 1997; Table 4).

Table 4. Effect of sealing treatment and depth on DM content and nutritive value of corn and alfalfa silage.

Sealing Treatment	Depth	DM	DM Rec.	In situ DMD	pH	Lactic Acid	Acetic Acid
	Inches	%	%	%		%	%
			Corn Silage				
	9.8	15.6	24.9	37.1	7.11	0.07	0.13
Unsealed	19.7	23.2	75.0	63.1	3.84	0.97	3.21
	29.5	24.4	76.7	65.7	3.86	5.21	4.22
	9.8	32.4	90.0	72.4	3.92	2.16	1.01
Sealed	19.7	33.6	92.4	71.2	3.79	4.23	1.48
	29.5	32.8	93.6	71.9	3.88	4.31	1.60
			Alfalfa Silage				
	4.9	65.4	66.4	54.3	8.21	. . .	. . .
Unsealed	9.8	45.2	47.6	59.4	8.68	. . .	. . .
	11.6	35.5	90.6	74.9	4.85	. . .	. . .
	4.9	52.9	90.7	74.7	5.23	. . .	. . .
Sealed	9.8	52.7	91.1	76.8	5.28	. . .	. . .
	11.6	47.2	89.5	75.4	5.20	. . .	. . .

Adapted from: Bolsen (1997)

The amount of tires placed on top of the polyethylene plastic also has an affect on silage yield and quality. In a study reported by Ruppel (1993) there was a reduction in the temperature and improved protein availability of hay crop silage when the amount of tires per square foot increased. The loss of DM in the top surface of silage was also reduced as the amount of tires per square foot increased. Based on this research it is suggested that there should be 0.2 to 0.25 tires per square foot (0.25 tires per square foot approaches “tire to tire” placement).

Silo Feedout

There is a great opportunity for silage quality to deteriorate during feedout from a silo because the silage face is exposed to oxygen for long periods of time. In the presence of oxygen, yeast and mold spores that had remained dormant in the anaerobic environment can become active. Yeast and molds that are growing in the silage are the primary cause of ensiling losses at feedout.

Four key steps to reducing DM losses and quality of silage at feedout include:

1) Capitalize on proper harvesting and storage techniques (described above).
2) Feed approximately 5 inches of silage per day from the silo face.
3) Do not leave loose silage on the floor of the silo.
4) Scrape silage face downward.

Ruppel (1995) demonstrated that DM losses of hay crop silage can be up to 10% lower in bunker silos that feed greater than 5 inches of silage per day from the silage face. Below is an equation (Equation 5) to calculate the width of the silo that is needed in order to feed 5 inches a day. This type of calculation will be beneficial to producers that are considering building a bunker silo, or producers that would like to restructure existing silos to improve silage quality during feedout. An easy way to monitor how much silage is being removed each day is to make a mark on the silo once per week and measure the distance between marks over time.

Equation 5: Width (ft) = (12 x Amount Fed) / (Silo Height (ft) x Silage Density x 5)

Silage density varies depending on packing. Some average DM densities reported by Ruppel (1997) are: 1) hay crop silage = 14.8 lbs DM/ft^3 and 2) corn silage = 17.7 lbs DM/ft^3

CONCLUSION

Silage quality is dependent on many factors. Some key factors to minimize loss of silage DM and maximize nutritive value include; 1) harvesting at the correct maturity (alfalfa = mid bud to 1/10 bloom and corn = one-half to two-thirds milkline), 2) fill the silo rapidly, 3) pack forage densely in the silo (minimum of 625 hr-lbs per wet ton of forage), 4) cover bunker silos with polyethylene plastic and tires, and 5) feed silage out of the silo at a rate of at least 5 inches per day. Alternative silage management items to consider include; 1) silo type (bag vs bunker) and 2) corn silage harvesting techniques ('hi chop' silage or mechanical processing).

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