

Dairy Split Sessions

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Current Trends in Forage Preservation and Storage

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Abstract

Improving forage quality to optimize dry matter intake is an important challenge facing progressive dairymen.

Forage quality improvement begins with agronomics, hybrid and variety selection. Eighty percent of preserving quality forage is management practices that are employed to eliminate oxygen from the storage structure as rapidly as possible.

Cutting at optimum maturity and ensiling at proper moisture are important factors. Chopping at the proper length and rapid filling, packing and sealing of the storage structure are all important considerations in eliminating oxygen from the silo.

Silage additives are considered as an important management tool to improve forage quality. Several types of additives are currently available and include acids, enzymes, nutrients and bacterial inoculants.

Bacterial inoculants are the predominant additive being used on ensiled forage in today's progressive operations. It is generally recognized that bacterial inoculants will not make bad silage better, but will improve the quality of well-managed silages.

Certain bacterial inoculants have been shown to improve dry matter recovery, improve protein quality, increase fiber digestibility, improve bunklife and improve animal performance. Bacterial silage inoculants should be considered a routine part of a good silage management program.

Introduction

Maximizing dry matter intake to meet genetic potential for milk yield in the high producing dairy cow is a major challenge currently facing dairymen and veterinarians/nutritionists. Many steps have been taken to meet this challenge including better ration sequencing, quality monitoring of commodities and the feeding of total mixed rations. (TMR)

Different types of ensiled forage and high moisture grains are frequently part of the TMR and the quality and palatability of these forages is often highly variable. Producing, ensiling, storing and feeding forage crops to maintain high intake potential is another challenge facing the dairyman.

Improving forage quality is without a doubt one of the best opportunities available to the progressive dairyman. Improving both the palatability and nutritional quality of home grown or purchased forage can increase dry matter intakes and improve efficiency of production resulting in more profits in today's high producing herds.

Harvest Considerations

Maturity and Moisture

Making high quality silage requires sound management decisions. Maturity at harvest, moisture content, chop length, silage distribution and compaction are all factors that can affect the fermentation process and subsequent nutritional quality of the ensiled feed.

Maturity of the crop to be ensiled is one of the most critical management factors to be addressed when ensiling feed for the high producing dairy cow. Missing the "window of opportunity" for proper maturity will greatly affect the quality of the feed with resultant negative effects on dry matter intake and digestibility.

Cutting at proper maturity assures adequate fermentable sugars for silage bacteria and maximum nutritional value for the cow. Maturity at cutting also determines moisture levels with unwilted forage crops such as whole plant corn silage. Cutting at optimum maturities also provides the cow with forage having acceptable levels of starch and digestible fiber.

Fiber digestibility can vary as much as 30-50% in alfalfa and whole plant corn silage. These variations affect energy content of the ration, microbial protein production and dry matter intake. Rumen fermentation of starch can affect rumen pH, dry matter intake and microbial protein production.¹

Maturity at harvest is the major factor in determining fiber digestibility in alfalfa crops. Advancing maturity increases fiber levels with a resultant loss of

digestibility and reduced intake potential.⁹ The loss of leaves during harvest increases fiber concentrations and reduces neutral detergent fiber digestibility. Excessive wilting time due to rain, cloudy days or excessively high humidities will increase respiration losses, allow leaching of water soluble carbohydrates and increases leaf loss at harvest.

Fiber digestibility in whole plant corn silage is affected by maturity at harvest, genetics and environmental conditions.^{1,10} The effect of genetics on digestibility of corn hybrids is much greater than that of alfalfa varieties. Repeatable differences of over 12% have been demonstrated in recent Michigan studies.¹

Grain and starch content increase in whole plant corn silage with advancing maturity (1/3 milklane through kernel black layer). During this time sugar content of the plant decreases. Whole plant cell wall (NDF) will decrease at 2/3 milklane due to increasing grain content. At black layer the increasing cell wall portion of the stover and reduction in sugar content causes the whole plant NDF to again increase. Rumen fermentability is significantly reduced at each stage of advancing maturity.

It is recommended to harvest whole plant corn silage at 2/3 milklane if it is to be fed with alfalfa or grass forages. If corn silage is to be the only forage source in the ration, harvest at 1/3 to 2/3 milklane to reduce rumen starch load and increase fiber levels in the ration (Table 1).

Table 1. Whole Plant Corn Silage Chemical Composition at Different Harvest Maturities+

	1/3 rd Kernel Milklane	2/3 rd Kernel Milklane	Kernel Black Layer
Dry Matter (%)	31.7 ^e	39.1 ^f	45.4 ^g
Grain Content (%)	32.4 ^e	41.8 ^f	46.1 ^g
Ear Content (%)	40.9 ^e	49.8 ^f	54.3 ^g
Stover Content (%)	59.1 ^e	50.2 ^f	45.8 ^g
ADF (%)	27.0 ^e	25.3 ^f	25.5 ^g
NDF (%)	46.3 ^{ea}	43.8 ^f	44.5 ^{fb}
Total Sugars (%)	9.8 ^e	7.1 ^f	6.6 ^f
Starch (%)	22.1 ^e	28.4 ^f	31.0 ^g
TDN (%)	66.2 ^e	68.4 ^f	68.2 ^f
Instu (24 hr)			
Dry Matter Disappearance (%)	60.3 ^{ea}	58.9 ^{ea}	56.4 ^f
Tons/Acre++	34.46 ^g	38.07 ^g	37.49 ^{xy}
Tons of TDN/Acre*	7.45 ^e	8.10 ^f	8.12 ^e

+ Pooled data from six genetically diverse Pioneer hybrids (maturity to black layer ranged from 2658-2792 GDUs) researched at two locations (Modesto, CA and Nampa, ID) in 1986. Adapted from Hunt *et al.*¹⁰

++ Adjusted to 70% moisture

* 100% Dry Matter Basis

efg means within a column with different superscripts differ (P<.01)

xy means within a column with different superscripts differ (P<.05)

Harvesting at proper moisture levels varies with different types of forage crops (Table 2). Proper moisture aids in silage compaction and the rapid, efficient removal of oxygen from the silage mass. Moisture levels below those recommended can lead to the entrapment of air in the silo which allows growth of spoilage organisms such as yeast, molds and aerobic bacteria. Moisture levels higher than those recommended can lead to extended fermentation times with high acid levels. Excessive moisture in alfalfa and grass silage can also trigger a clostridial fermentation which results in excessive protein loss and poor quality feed.

Table 2. Harvest Maturity and Moisture Recommendations

Crop	Maturity	SILO TYPE			Length of cut - inches -
		Bunker	Stave - % moisture -	Sealed	
Corn Silage	milk line 1/2-2/3 down kernel	67-72	63-68	50-60	3/8-1/2
Alfalfa	mid-bud to 1/10 bloom wilt to...	65-70	60-65	50-60	1/4-3/8
Cereal Silage	milk-soft dough, wilt to...	67-72	63-68	50-60	1/4-3/8
Grasses	stems first head out, wilt to...	67-72	63-68	50-60	1/4-3/8
Clover	1/4-1/2 bloom, wilt to...	67-72	63-68	50-60	1/4-3/8
Forage Sorghum	medium-hard grain or leaves begin to loose color	70-75	65-70	50-60	3/8-1/2
Sorghum-Sudan-grass	3-4 ft high	70-75	65-70	50-60	3/8-1/2
Whole plant Grain Sorghum	medium-hard dough grain	67-72	63-68	50-60	3/8-1/2
Ground Ear Corn	full dent	34-40	32-38	28-34	-----
Cracked Shelled Corn	full dent	26-32	26-32	-----	-----
Whole Shelled Corn	full dent	-----	-----	22-28	-----
Rolled Ground Sorghum Grain	medium-hard dough	26-32	26-32	-----	-----
Whole Sorghum Grain	medium-hard dough	-----	-----	22-26	-----

Chop Length

To optimize rumen fermentation yet allow for maintenance of rumen health, a chop length of between 1/4" and 1/2" theoretical length of cut (TLC) is recommended (Table 2). These chop lengths also promote oxygen exclusion from the silage mass, allow for ease in unloading tower structures and will provide adequate effective fiber to meet rumen function demands. This is essential to reduce chances for indigestion, milk fat depression and displacement of the abomasum.

Whole plant corn silage should be chopped from 3/8" to 1/2" TLC. Longer chop length can result in poor packing, improper functioning of silo unloaders, more whole kernels passing through the cow undigested and sorting of stover and cob fractions in the total mixed ration (TMR).

Chopping shorter than $\frac{3}{8}$ " will help packing in dry conditions. It does, however, require more power and may slow harvesting of the crop.

Alfalfa haylage should be chopped at $\frac{3}{8}$ " TLC. At this length 15-20% of the forage particles will be over $1\frac{1}{2}$ " long. In alfalfa based diets this chop length will allow the dairyman to feed enough effective fiber without adding long stem hay to the ration. If chopping at less than $\frac{3}{8}$ " TLC consider adding long stem hay at up to 25% of the ration dry matter.

Filling, Packing and Sealing of the Silo

The crop should be harvested and placed in the storage structure as rapidly as possible. Slow filling results in increased dry matter losses due to plant respiration. When using a bunker or trench for storage, packing should begin immediately. A wheeled tractor is preferred over tracked vehicles for packing because they provide greater weight per unit of surface area.

After packing is complete, the silo should be sealed with an air-tight cover to minimize dry matter loss due to air penetration and water damage. Use a 4-6 mil plastic cover, seal the edges and place tires edge to edge to hold down the plastic.^{14,22} Cutting tires in half and tying them together with twine to form a "hairnet" like cover appears to be an effective method to reduce surface losses to a minimum.

Research has shown a net return of up to 2:1 for covering whole plant corn silage and up to 4:1 for alfalfa haylage.²⁰

Fermentation of the Forage

Aerobic Phase

Fermentation actually begins with aerobic respiration immediately upon the cutting of the plant. During this phase water soluble carbohydrates (WSC), which are primarily plant sugars are converted to water, CO₂ and heat. This conversion is accomplished by both plant cells and by indigenous aerobic organisms (epiphytes). Aerobic respiration continues until the oxygen in the structure is depleted or until the water soluble carbohydrates are gone.

Plant enzymes other than those involved in respiration also remain active as the crop is ensiled. Other enzymes facilitate the hydrolysis of starch and hemicellulose to monosaccharides. This hydrolysis provides additional sugars for the ensuing lactic acid fermentation.¹⁸

Under ideal management conditions the respiratory phase should last only a few hours.³² It is important to minimize the length of this phase for several reasons. When respiration is extended, there is excessive loss of plant sugars which could be used by later by lactic acid bacteria or by the animal. Production of excess heat also

occurs which can lead to protein damage in the stored material.

Although the negatives of the aerobic phase of fermentation have been noted there are some potential benefits. Respiration depletes oxygen trapped in the structure thus hastening the onset of anaerobic fermentation. Also, certain of these organisms produce biochemical antimycotic compounds that may improve the aerobic stability of the silage during feedout.

Anaerobic Phase

When trapped oxygen has been depleted, anaerobic fermentation begins in the storage structure. The first organisms to grow are the heat and acetate tolerant enterobacteria and several other strains of heterofermentative lactic acid bacteria. These organisms produce acetic acid, ethanol, lactic acid and CO₂ from the fermentation of five and six carbon sugars. As the pH in the silage mass falls below five, heterofermenters decrease in numbers due to acid conditions that inhibit their growth. This early anaerobic phase usually lasts from 24-72 hours.

As the pH continues to decline, there is a shift towards increased populations of efficient, homofermentative lactic acid bacteria (LAB) which allow a more rapid reduction in silage pH. The pH decline begins when there are approximately 100 million (10⁸) lactic acid bacteria per gram of wet forage. Silage temperatures will stabilize as the homofermentative LAB population ferments WSC to acids. More WSC, peptides and amino acids are conserved in the silage when the fermentation is rapidly completed. Varying amounts of volatile fatty acid (VFA) such as acetic, propionic, butyric, lactic and isoacids are produced during this phase of fermentation (Table 3). Lactic acid is the strongest, most effective silage acid for rapidly reducing pH and maintaining aerobic stability in the silo and the feedbunk. The best quality silage has lactate as the dominant acid at levels of near 6-8% of the silage dry matter. This is usually greater than 60% of the total organic acids (Table 3).

The anaerobic phase is the longest phase in the ensiling process and continues until the pH of the forage is sufficiently low to inhibit the growth of all organisms in the silage mass. Natural fermentation, accomplished solely by epiphytic organisms and unassisted by any type of silage additive, will take 10 days to 3 weeks for completion. The total time to reach terminal pH depends on crop type, buffering capacity, moisture level and the maturity of material going into the structure.

The extent of final pH drop in the ensiled material depends largely on the moisture level and type of crop being ensiled. Legumes with a lower WSC count and higher buffering capacity will reach a terminal pH of around 4.5. Corn silage with higher WSC and lower

buffering capacity will reach a pH of near 4.0. Less mature, higher moisture silages have a higher buffering capacity, ferment longer and require higher WSC levels and a lower pH for stability. When the final pH is achieved, the silage is considered to be in a "preserved" state. It is important to realize, however, that pH alone is not a good indicator of the rate or quality of the fermentation. Other measures such as VFA and protein profiles are needed for such a determination.

It is wrong to assume that once final pH is attained that no further changes occur in the silage mass. Conversely, the silage is a dynamic mass and changes can occur during storage. The changes that occur depend upon the amount of air penetration into the mass, remaining levels of fermentable substrate, numbers and types of spoilage organisms (yeasts, molds and aerobic bacteria) on the crop at the time of ensiling, levels and types of fermentation acids present in the silage and the management of the surface or face of the silo during unloading for feeding.

Table 3. Goals for Stable Silage

- (1) **pH 4.0-4.5**
 - upper range for legume silages
 - lower range grass, corn and cereal silages
 - higher range for wilted vs direct-cut silages
- (2) **Fermentation Acids (% dry matter (DM) basis)**
 - a) Lactic Acid 6-8% - wet silages (>65% moisture)
3-4% - wilted silage (<55% moisture)
1-3% - high moisture grains
 - b) Acetic Acid <2% - forage silages
<.1% - high moisture grains
 - c) Butyric Acid <.1%
 - d) Propionic Acid 0-1%
- 3) **Water Soluble Carbohydrates (6-carbon reducing sugars, DM basis)**
 - 1-4% - high moisture grains, upper level if cob included
 - 4-6% - legumes and grasses
 - 6-8% - corn silage
- 4) **Protein Parameters**
 - a) Ammonia Nitrogen (NH₃-N, % of Total Nitrogen)
<5% Corn & Cereals, <10-15% Grass/Legumes
 - b) Heat damage (bound or unavailable protein)
 1. If the ratio of bound protein (BP)/crude protein (CP) is <12%, fermentation proceeded normally. Use CP values of balance rations.
 2. If the ratio of BP/CP is >15%, considerable heat damage has occurred. Use available CP values to balance ration.
- 5) **Silage Temperature**
 - No greater than 15-20°F above ambient temperature at ensiling
- 6) **Microbial Analysis (Colony-Forming Units/gram of silage, as fed basis)**
 - a) Total Aerobes: <100,000 (10⁵) cfu/gram of silage
Example: Bacillus species
 - b) Molds: <100,000 (10⁵) cfu/gram of silage
Example: Species of Fusarium, Gibberella, Aspergillus and Penicillium species
 - c) Yeast: <100,000 (10⁵) cfu/gram of silage
Example: Acid-metabolizing species Candida and Hansenula are more concern than fermentative species like Saccharomyces and Torulopsis

Potential Problems During Fermentation

Heat Damaged Proteins

Crude protein in fresh forage is composed of 60-70% true available protein. The remainder of crude protein is 20-30% non-protein nitrogen (nitrates and non-specific amino acids) and 4-15% unavailable nitrogen found in the acid detergent insoluble nitrogen (ADIN) fraction.²⁹ All ensiled forages have some level of unavailable protein as a result of both physiology of the plant and the fermentation process (Table 3).

During a normal fermentation the temperature of the silage does not normally rise more than 15 to 20 degrees F. above ambient, however, silages that experience temperatures in excess of 120 degrees F. are likely to contain more bound protein than normal. These forages may appear dark in color and smell like tobacco. This heating is caused by a prolonged aerobic phase due to excess oxygen trapped in the silage mass. This may be caused by slow filling, low moisture, overly mature crops, long chop length or by poor distribution and compaction.

Heat damaged silages have a lowered protein availability as a result of the Maillard chemical reaction which binds proteins to the carbohydrate fraction of the forage. Ruminants lack the enzymes necessary to digest this nutrient complex.

Heating on the surface of the silage during feedout does not normally contribute to the bound protein fraction. Surface heating occurs when oxygen penetrates the surface and allows for the growth of aerobic spoilage organisms. This heat is not readily retained by the silage mass and thus does not contribute to bound protein.

A brownish discoloration is often observed in high moisture shelled corn. This is likely due to a non-enzymatic chemical reaction that has been well documented in the food industry. It occurs most commonly in corn that was ensiled in the 25-28% moisture range at near 98 degrees F. This browning is not indicative of reduced protein availability in high moisture corn.²⁷

Protein Degradation in the Silo

Proteolytic plant enzymes can also lower the feeding value of the forage crop by hydrolyzing proteins and effectively increasing the NPN level of ammonia, nitrates, nitrites, free amino acids, amines, amides and peptides.²¹ The reduction to ammonia and amines is largely due to microbial activity.¹⁸ Up to 50% of the total plant protein may be degraded by these pathways. In grass and alfalfa silages greater than 70% moisture, proteolytic clostridial organisms can also contribute greatly to protein degradation with a further loss of energy that might have been available for the rumen bacteria.

Protein degradation during fermentation increases the levels of soluble intake protein and degraded intake protein. At the same time undegraded intake protein levels decline. All these variations must be taken into consideration when balancing rations containing a high proportion of fermented feeds (Table 4).

Good quality silages are low in ammonia-nitrogen and have higher levels of amino acids and peptides in the NPN fraction (Table 3). A controlled, efficient fermentation has been shown to markedly reduce the production of ammonia-nitrogen while sparing peptides and amino acids.³⁰ The increased level of peptides may stimulate the growth of starch digesting bacteria.²³

Ammonia and amine compounds are end products of fermentation that have been linked to marked reductions in feed intake. It appears that ammonia may only be a marker for other NPN factors such as increased amines which are the actual compounds that depress intake.⁵

Any process that shortens fermentation, denatures proteolytic enzymes or reduces proteolytic bacterial activity will reduce silage protein degradation. Wilted silages undergo a shorter fermentation with less protein degradation and less acid production, both of which may stimulate intakes. However, the producer must only wilt the forage to a moisture level which will insure adequate compaction and elimination of oxygen from the storage structure.

Rapid exclusion of oxygen, which hastens the onset of anaerobic fermentation, is also important because a rapid acidification of the silage mass will more quickly denature proteases and reduce their negative effect on the protein fraction of the silage.

Clostridial Fermentation

Alfalfa, grass and some cereal forages ensiled at moisture levels greater than 70% may undergo an undesirable type of fermentation. At these extreme moisture levels large populations of clostridial organisms may dominate the fermentation.

Clostridial organisms are anaerobes that degrade sugars and lactic acid to butyric acid, carbon dioxide and hydrogen gas. They also degrade amino acids to acetate and ammonia.¹² The result is a silage that has a high pH, sour smell and poor protein quality. These silages tend to be aerobically stable but are relatively unpalatable thus making this a very undesirable fermentation.

The pH at which clostridial activity stops is dependent upon the water activity, which is related to the moisture content of the silage mass. Unwilted silages may need to reach a terminal pH in the low 4's to completely stop clostridial growth.¹⁸ When management allows, it is advisable to wilt forages to less than 70% moisture before ensiling. It also should be noted that whole plant corn silage rarely undergoes a clostridial fermentation, most likely due to high sugar levels and low buffering capacity, which usually result in rapid pH drops to near 4.0.

Silage Management Post-Ensiling

Storage and Feedout

Research shows that up to 50% of silage dry matter losses occur due to aerobic spoilage on the surface of the silage when it is re-exposed to air during storage and feedout.⁷ Conditions which can predispose silage to aerobic stability problems include high background populations of potential spoilage organisms (yeasts, molds or aerobic bacteria), unfermented WSC still present in the silage, crops that have been exposed to environmental stress prior to harvest, high manure applications that may have inoculated the crop with mold spores and yeasts and crop contamination with soilborne organisms.

To minimize the potential for surface losses, storage structures must be sized to fit the size of the feeding operation. A common problem is to build bunkers that are too wide and towers that have too large a diameter.

To keep surface losses at the lowest possible level, plan to remove at least 2" per day from tower structures in the winter and at least 4" per day in the summer. In bunker and trench silos it is important to remove at least 4-6" per day from the entire face of the silo. Bunker faces that are exposed for 3-4 days can undergo extensive dry matter losses (Table 6).

Another point to consider is that the dry matter losses that occur during storage and feedout are the highly digestible WSC and not the fiber portion of the

Table 4. Examples of Changes in Forage Composition Occurring During Ensiling*

Silage Parameter	Fresh grass-legume	Grass-legume silage	Fresh alfalfa	Alfalfa haylage	Whole corn plant	Corn silage
Dry matter %	20.9	25.8	35.4	35.0	29.4	30.0
pH	--	4.62	5.56	4.52	5.20	3.91
Crude Protein %	17.9	19.6	20.2	20.9	8.2	8.0
Ammonia N (% of total N)	2.9	8.0	3.0	11.9	5.5	8.0
Acid detergent fiber %	34.0	40.4	34.2	36.4	24.5	24.5
Neutral detergent fiber %	45.3	52.8	44.0	43.1	45.5	45.3
Sugars %	5.1	.6	6.4	1.4	10.8	1.6
Lactic acid %	----	6.6	----	7.4	----	4.6
Total organic acids %	----	11.2	----	11.7	----	6.7

* Adapted from Erdman⁵

Table 6. Dry Matter Losses from Trench Silages with Different Face Characteristics.

Face	Days of Exposure			
	1	2	3	4
	----- % DM loss -----			
Firm	.3	1.5	3.5	6.0
Loose	.7	3.0	6.9	11.2
Completely loose	2.0	7.0	12.0	15.0

Source: Zublena *et al.* (1987)

feed. When calculating the dry matter loss from a storage structure, remember that the nutrient with the highest value is lost and will have to be replaced when balancing the ration.

Silages that heat and spoil in the feedbunk can have a negative effect on dry matter intakes. This is especially critical in the summer months when dry matter intakes are already reduced due to high temperature/humidity indices.

Minimizing losses in the feedbunk can best be accomplished by following good management procedures for ensiling and then further minimizing exposure to air once the feed is in the bunk. This means feeding more than once a day, especially during warm weather and making sure most of the feed is cleaned up between feedings.

By knowing what to expect and planning ahead the dairyman can further reduce feedout losses. For example, when ensiling mature grasses and cereals, pay very close attention to moisture and chop since these crops have hollow stems which carry air into the silage mass and contribute to compaction difficulties.

It is common to have bunklife problems with ensiled forages that have been rained on after cutting. Rain can splash soilborne bacteria and molds onto the crop which may make the resulting silage more prone to aerobic spoilage. Crops stressed by drought, insect damage or hail damage will usually have higher mold counts which makes them more susceptible to aerobic spoilage as well.

Management is critical with whole plant corn silage and high moisture grains, both of which are quite susceptible to aerobic spoilage. In corn silage, aerobic deterioration is often initiated by *Bacillus* organisms followed by yeasts and molds. Yeasts of the species *Candida* and *Hanensula* cause special problems because they can metabolize lactic acid in the silage resulting in an elevation of silage pH (Table 3). Sediment type yeasts such as *Saccharomyces* and *Torulopsis* are of less concern since they have a low capacity to metabolize lactate and do not raise pH. Usually yeasts by themselves do not

compromise intakes. However, once the pH is elevated above 5.0, the conditions are suitable for the growth of molds and other spoilage organisms if they are present. Continued growth of these types of organisms can negatively affect palatability and increase the losses of valuable nutrients.

Silage Additives - The Final Step In Forage Management

General Considerations

The production and utilization of high quality silage from forage crops requires strict adherence to all of the management principles already discussed in this paper. Only when these management practices are closely followed should the dairyman consider the use of a silage additive. In other words, a quality silage additive will make good silage better but a silage additive will not make bad silage good. Silage additives, when properly used, are a value added product and should be considered as an integral part of a good forage management program.

Choosing a silage additive can be a confusing and difficult undertaking. Currently the silage additive industry in the United States is essentially a non-regulated industry. This means that just about anyone can attempt to manufacture and sell just about anything to the dairyman. There are at least 200 different silage additive products from which to choose.² There are four broad categories under which these various products fall and include acids, enzymes, nutrients (including non-protein nitrogen) and bacterial inoculants. Some products are presented as various combinations of the four general categories.

How does the dairyman make a decision with all there is to choose from? First of all, the producer should demand data that supports an economic return from the use of the additive. This is especially important since visual differences between the performance of the various products is often difficult to ascertain. This data should be from reputable universities as well as from the manufacturer.

What kinds of performance parameters should the dairyman be looking for? Most important, is to look for products that have been shown to do more than affect only the "front end" of the fermentation process. Rapid and extensive pH drop is not the only important criteria. The producer should look for additives that go beyond "preservation". There are additives available that, in addition to efficiently controlling the fermentation, also improve protein quality, improve fiber digestibility improve aerobic stability and have been shown in feeding trials to improve the efficiency of animal production. Obviously, an additive that can improve forage quality in all areas, has a much better probability of providing an economic return for the dairyman.

A final factor that should be considered before deciding on an additive is what kind of support can be expected from the manufacturer of the product. In the making of quality silage the producer is dealing with a biological system that is highly variable. Results are not the same each time a crop is ensiled and having expertise available to guide the producer can lead to increased profitability.

Acids

The use of acids on wet forage crops in North America has been rather limited because most forages are wilted to 70% moisture or less and are cut at a maturity at which they have adequate WSC to insure a proper fermentation.

Acids that have been used in North America to directly acidify wet forages are acetic, propionic, formic and formic/formaldehyde combinations. The basis for their use is not in reducing pH but in the selective inhibition of certain undesirable microflora. This is evidenced by the fact that acid treated silages often have higher residual WSC and a higher pH than forage that is allowed to undergo a natural fermentation. Typical application rates for the acids range from 0.5-1.0% of fresh forage weight.

Protein preservation can be enhanced by the direct acidification of wet forages. Acidification immediately inactivates plant proteases which would normally degrade proteins into less desirable NPN compounds. Also, products containing propionic acid can extend aerobic stability by inhibition of the growth of molds.

Formic acid and formic/formaldehyde combinations have been used extensively in very wet grass forages in Europe. Formaldehyde is an effective bacteriostat and if applied at high enough levels seems to protect protein from rumen degradation.

Formic acid works best in direct cut situations and is not recommended for crops harvested at 35-65% dry matter. When used on wilted crops, spoilage losses have actually been increased.²⁸ In addition, formic acid treatment may actually decrease aerobic stability due to higher final pH and high residual levels of SC.¹⁷

Other factors that limit the use of acids include high cost per treated ton, difficulty in evenly distributing the acid on the forage, regulatory concerns with formaldehyde treated forage and caustic nature of acids (although this has been reduced somewhat with the more recent marketing of buffered products).

Enzymes

Enzymes that are used in silage additives today are, for the most part, by-products of the growth of *Bacillus subtilis*, *Aspergillus niger* or *Aspergillus oryzae*. These organisms produce various enzymes including cellulase, amylase, glucoamylase and proteases. Other

enzyme preparations that have been used on forages include glucanohydrolase, glucanmaltohydrolase, beta-glucanase and beta-glucosidase.²⁵ All of these enzymes, with the exception of protease, facilitate the degradation of complex carbohydrates into simple sugars for potential use by lactic acid bacteria during the fermentation.

Because purification is costly, many of the enzyme products are currently marketed as non-purified mixtures. This means that any proteases produced during the fermentation of the enzyme producing organisms will be included in the mixture along with the starch degrading enzymes. This can have a negative effect on the quality of the ensiled forage. Over 50% of the protein is degraded in a normal fermentation without the addition of enzymes. One of the goals of a good fermentation is to reduce the amount of protein degraded in the silo. Adding unknown amounts of protease to the silage mass can markedly raise the NPN levels in the ensiled material. This has the potential of causing ration balancing problems with regard to protein quality, especially in situations where the ration consists of high levels of fermented feeds.

Enzymes are primarily added to increase the levels of sugar available for the lactic acid bacteria. This may be of benefit in very wet forages (greater than 70% moisture) with relatively low WSC levels (mature grasses and alfalfa). However, at the maturity and moisture levels which most crops are ensiled in North America, it has been shown that there are adequate levels of WSC available to complete the fermentation without the addition of enzymes.

Enzymes are currently being used by some dairymen to break down fiber components of the forage so that both dry matter intake and fiber utilization will be improved. Some reports have indicated that there is a reduction in ADF and NDF in alfalfa silage treated with an enzyme/bacteria combination product and a resultant increase in dry matter intake. However, animal performance responses have been inconsistent. With combination products containing enzymes and lactic acid bacteria it is unclear which of the components is contributing to the observed forage quality improvements.

Potential problems with the use of enzymes include: no guarantee of activity is required, proper distribution in the silage mass is difficult, potential for excessive effluent in wetter silages due to cellular disruption and potential negative effects on aerobic stability. Reduced aerobic stability can occur if the enzyme causes large increases in sugars which are not used in the fermentation. These extra sugars would then be available as substrate for spoilage organisms when the silage is re-exposed to oxygen.

Non-Protein Nitrogen

Anhydrous ammonia and urea are NPN sources that have been used on low protein forages such as whole

plant corn silage, forage sorghum and mature winter cereals. The primary goal has been to increase the crude protein potential of the ensiled material and to improve aerobic stability by inhibiting the growth of potential spoilage organisms. Application rates vary from 5-10 pounds of anhydrous ammonia to 10-20 of urea per ton of fresh silage.

- Adding anhydrous ammonia to silage quickly raises the pH to near 9.0. This essentially prolongs the fermentation and usually results in lower dry matter recoveries due to the higher requirement for acid to lower the pH to stable levels. This effect is less with urea since only about 30% is hydrolyzed to ammonia and carbon dioxide by enzymes in the forage. The only advantage to this buffering effect is that high pH inactivate proteolytic plant enzymes and may result in as much as a 30% reduction in protein degradation.

Anhydrous ammonia has also been shown to partially degrade fiber in the forage by disrupting hemicellulose bonds. This should increase dry matter intake. These improvements in digestibility and protein preservation have not always shown a positive response in animal performance.¹⁷

The ability of the animal to utilize the additional nitrogen provided by NPN sources is variable and depends on the level of NPN already in the diet, the level of soluble carbohydrates in the ration and the animal's ability to convert NPN to bacterial protein. Generally, young calves and early lactation cows are not good candidates for high levels of NPN. If increased protein potential is the primary goal the use of urea is the most sensible option, even though the cost is somewhat higher than anhydrous ammonia. Urea is safer and easier to handle, has more consistent data showing improvements in animal performance and can be added in the TMR instead of in the silo. This last step may be important to dairymen who do not want to be essentially "locked" into a feeding system by treating an entire silo with an NPN source.

NPN sources should not be added to forages over 70% moisture or to those with high buffering capacity (alfalfa). In these cases the WSC may be depleted before the pH is low enough to insure a stable silage. This could lead to poor aerobic stability and in the case of higher moisture material may lead to a clostridial fermentation.

Nutrients

In some situations, dry or wet molasses is added to wet forage with the purpose of improving the fermentation. The concept is to provide a source of sugar for the lactic acid bacteria in situations where they may be limiting. As was stated before, in most harvest conditions encountered in North America sugar levels are not limiting and the addition of additional sources of sugar will not improve the fermentation. The extra sugar may,

in fact, contribute to poor aerobic stability by providing a nutrient source for spoilage organisms.

The only conditions where additional sugar from molasses may be of benefit are when crops that are high in buffering capacity are ensiled at moisture levels above 70%. The typical application rate for dry molasses is approximately 2% of the wet forage weight or 40 pounds per ton.

Bacterial Inoculants

Of the silage additives that are being used by dairymen today, nearly 75% are bacterial inoculants.⁸ In addition many of the enzyme based products also contain lactic acid bacteria (LAB) in significant numbers. The reason for the preponderance of products utilizing LAB is that researchers have shown that the primary limiting factor to an efficient fermentation are the numbers and type of LAB present on the forage at time of ensiling.

Most of the bacterial inoculants on the market consist of live cultures of homofermentative (non-gas producing) LAB of the genres *Lactobacillus*, *Streptococcus* and *Pediococcus*. These organisms ferment five and six carbon sugars entirely to lactic acid. Production of lactic acid is the most efficient fermentation pathway, resulting in the least amount of dry matter loss (Table 5).

Table 5. Simplified Silage Fermentation Pathways.

Homofermentative:				
1 Glucose				2 Lactic acid
Sum:				Recovery (%)
Dry matter (g)	1000	1000		100
Energy (kcal/mole)	673	652		97
Heterofermentative:				
1 Glucose				1 Lactic acid + 1 Ethanol + 1 CO ₂
Sum:				Recovery (%)
Dry matter (g)	1000	500	256	76
Energy (kcal/mole)	673	326	327	97
3 Fructose				1 Lactic acid + 2 Mannitol + 1 Acetic acid + CO ₂
Sum:				Recovery (%)
Dry matter (g)	3000	500	2022	333
Energy (kcal/mole)	2025	326	1456	209

The effectiveness of silage inoculants depends on several important factors. The existing background microbial population (epiphytes) can have an effect. The epiphytic LAB populations can range from non-detectable to several million colony forming units (CFU) per gram of fresh forage. This variation is due to several factors. For example, corn usually has much higher counts than legumes. Solar radiation has a negative effect on bacterial growth as evidenced by the fact that counts increase faster on the crop on cloudy days. Low

environmental temperatures (<60 degrees F.) also tend to limit microbial growth.

Research has shown that inoculant organisms should be added in levels that are at least ten times the epiphytic counts to be economically effective.¹⁷ Other research with alfalfa silage has shown even when control silages had high epiphytic counts (over one million per gram), inoculated silages fermented much more quickly and efficiently.³ This is observed because selected strains of LAB rapidly dominate and drive the fermentation to the desired endpoint.

Other factors that affect the inoculant's effectiveness include the WSC of the crop to be ensiled, the buffering capacity of the crop and the quantity / quality of LAB inoculant organisms added to the forage.

When selecting a bacterial inoculant the quality of the organisms in the product is critical. All bacterial inoculants are not the same, even if the ingredient list shows two products containing the same genus and species of organisms. It has been shown through strain selection research that as many as 5000 strains can be found within one genus and specie of LAB. Furthermore, this research has shown that these strains differ in the type of crop they prefer, their ability to ferment various substrates, their growth potential at various temperatures and moisture levels and in their ability to enhance fiber digestibility.⁴

It is important that the strains of LAB selected for a commercial product are matched to maximize their combined effect on the silage quality. It has been shown that eliminating one strain or changing the numbers of a strain within a product can dramatically alter the outcome of the fermentation.

It has been shown that selected strains of LAB will rapidly dominate the fermentation in well managed silages. They will lower pH rapidly and efficiently utilize the WSC in the crop. This will result in improved dry matter recoveries in most cases. Dry matter recovery alone will more than cover the cost of the inoculant with most crops in most types of storage structures. The return on investment for dry matter recovery alone will range from break-even for whole plant corn silage in tower structures to over 3:1 for alfalfa silage stored in bunker or trench silos.

When selecting an inoculant the dairyman should look for a product that goes beyond controlling only the front end of fermentation. If the correct strains of LAB are used there are many more improvements that can be made in the forage quality in addition to increased dry matter recovery. Certain inoculants have been shown to improve protein quality by reducing ammonia nitrogen in the silage by 20-25%, acid detergent fiber digestibility has been improved by 10-17% and aerobic stability has been dramatically increased.¹¹

Most important, if a bacterial inoculant is used that has demonstrated all the benefits mentioned, feeding and lactation studies have shown dramatic improvements in animal performance. The animal performance trials have shown that dairymen can expect up to a 7:1 return on investment with inoculated whole plant corn silage diets and up to a 10:1 return with inoculated alfalfa haylage based diets.¹¹

Conclusion

Silage comprises a major portion of the TMR in most of today's progressive dairies. Any TMR is only as strong as it's weakest link which means that the quality of the forage is critical to maximizing performance in the cow. As nutritionists we can formulate any ration we want on the computer, but what we actually feed and what the cow actually eats are what counts. Managing forages for quality becomes critical when dry matter intake counts. 80% of putting up quality forage is the management practices that are followed. Silage inoculants are a management tool that will provide added value to quality silage. They should be considered an integral part of every quality forage management program.

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