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AN UPDATE ON COVERING BUNKER SILOS

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INTRODUCTION

Forage crops are the staple ingredients of dietary rations fed to ruminant animals. They provide the animal with a large source of dietary fiber, critical for normal functioning of the rumen and its associated microenvironment (Driehuis and Oude Elferink, 2000). The preservation of forage crops into a fermented feedstuff known as silage has been an important practice in agriculture, especially in the dairy and beef cattle industries where there has been a documented increase in silage production since the early 1950's (Bolsen and Laytimi, 1987). There are three primary reasons why silage-making is important. First, it allows for the conservation of forage during times of harsh weather conditions like extreme cold, or drought, when forage crops are unable to be cultivated. Secondly, it serves as a means to save surpluses that have been harvested during the growing season, and lastly it allows animal access to forage crops that are difficult to graze (Driehuis and Oude Elferink, 2000).

Silage can be stored in a number of ways, including tower silos, bunker silos, bags and piles. Of these methods, bunker silos have become one of the most attractive methods of preservation because they have high storage capacities, low initial start-up costs, and require relatively little maintenance over time (Berger, 2005; Bolsen et al., 1993). The most common method of covering bunker silos has been polyethylene sheeting, weighted down with tires (Bolton and Holmes, 2004; Berger, 2005). Even though good silage can be made using plastic and tires, there are several disadvantages to this system. First, there is a labor requirement needed to move plastic and tires onto the silo for sealing and in their removal during feedout (Berger, 2005). Disposal of polyethylene sheeting has become an environmental problem because it is non-biodegradable and difficult to recycle (Savoie et al. 2003). Because of the environmental impact of plastic there has been some research into biodegradable, edible sealing strategies that could replace plastic and tires. Apple pulp, candy, chopped straw, molasses, Nutri-shield (Nutri-Shield, Inc., Courtland, KS), peanut butter, sawdust, sod, starch-salt matrices, and wax are a few of the many coatings that have been experimented with in conjunction with bunker silos (Bolton and

Holmes, 2006; Brusewitz et al., 1991; Savoie et al., 2003). In order for an edible covering to be successful, it must be able to minimize surface spoilage as much as polyethylene plastic and tires. No edible covering to date has been able to accomplish this task (Berger and Bolsen, 2006).

Weighing down plastic tarps with tires is common method to secure the plastic and prevent air from penetrating into the silage mass. Full-casing tires are often difficult to move and are able to hold water. Lanyon et al. (2004) noted that a whole tire can weigh as much as 60 pounds; however, with water collection the weight can increase between 40 to 70%. Water collection in tires also serves as a breeding ground for mosquitoes and causes an increased risk of West Nile Virus in many states (Berger and Bolsen 2006; Jones and Heinrichs, 2005). There has been some success with split tires, or tires cut in half, which reduces the weight, the number of tires needed, and limits breeding grounds for mosquitoes (Jones and Heinrichs, 2005).

Because fermentation is an anaerobic process, the most important factor in creating silage is the degree of air exclusion (Bolsen et al., 1993). Once air has infiltrated the silo aerobic microorganisms previously held at bay due to the degree of anaerobiosis, become activated and set off a chain of events that lead to decreases in silage quality and nutritive value (Woolford, 1990). In order for plastic and tires to keep air out of the system, the plastic sheet must be weighted down to avoid movements due to the wind. Also, tires need to be placed so that they are touching over the surface area of the entire silo (Holmes and Muck, 2000). Another important factor of recent interest has been the oxygen permeability of plastics used to cover bunkers and silage piles.

AEROBIC INSTABILITY OF SILAGE

The most important factor in making good silage is preventing air infiltration into the silo. Once air has entered the system aerobic microorganisms that were previously kept at bay, due to the anaerobic conditions, become activated and begin the spoilage process. This is a major problem for silage producers because nothing can be done to stop aerobic deterioration once it has begun (Woolford, 1990). Aerobic spoilage results in large losses of nutrients, primarily residual sugars, which mineralize to water and carbon dioxide (Honig and Woolford, 1980; Woolford, 1990). There is also an accompanying generation of large amounts of heat, along with increases in ammonia and pH. The increase in pH can be attributed to the degradation of VFA's, like lactate and acetate, produced during ensiling (Honig and Woolford, 1980; Lowes et al., 2000).

The principle initiators of aerobic spoilage are considered to be lactate-assimilating yeasts of the species *Candida*, *Endomycopsis*, *Hansenula*, and *Pichia* (Lowes et al, 2000; Woolford, 1990). Populations of yeasts are capable of log-phase growth in a relatively short period of time. Woolford (1990) noted that yeast populations of only 10^2 cfu/g DM can increase to 10^{12} cfu/g DM in 3 days. Silages with more then 10^5 cfu of yeasts/g DM are especially prone to deterioration; however, smaller populations have also been known to cause rapid spoilage (Honig and Woolford, 1980; Woolford, 1990).

Bacteria and moulds also play important roles in aerobic spoilage; however, they are primarily restricted to the later stages of deterioration. During the first few days of ensiling, after respiration of the plant material is complete, lactic acid bacteria cause a rapid decline in pH to around 4.0. Enterobacteria are normally decreased by this reduction in pH; however, with introduction of air to the silo, and subsequent rise in pH, numbers can grow as high as 10^8 cfu/g fresh matter. Studies have shown that *E. coli* 0157 is able to survive for at least 3 weeks at a pH of 4.0 to 4.6 in grass and whole-plant corn silages (Driehuis and Oude Elferink, 2000).

Other bacteria with proteolytic properties have been identified in aerobically spoiled silage. *Bacillus* species *cereus*, *firmus*, *lentus*, and *sphaericus* were all isolated from grass and maize silage upon exposure to air (Honig and Woolford, 1980). Another spore-forming genus commonly found in aerobically spoiled silage is *Clostridium*. The most common species are *C. tyrobutyricum*, *C. butyricum*, *C.sporogenes*, and *C. bifermentans*. Clostridial species are able to break down protein and amino acids. For example, *C. tyrobutyricum* can degrade lactate to butyric acid, hydrogen, and carbon dioxide. Silage that has undergone clostridial fermentation is characterized by a high pH, allowing for additional growth of aerobic microorganisms (Driehuis and Oude Elferink, 2000).

Moulds commonly target areas of the silo where there is poor sealing. They are also usually segregated to the uppermost layers of the silo. Seeing a dense layer of mould is characteristic of long-term aerobic spoilage. Genera of moulds including *Absidia*, *Arthrinium*, *Aspergillus*, *Bysoclamys*, *Fusarium*, *Geotrichum*, *Monascus*, *Mucor*, *Paecilomyces*, *Scopulariopsis*, and *Trichoderma* have been found in aerobically spoiled silage (Crashaw and Woolford, 1979; Driehuis and Oude Elferink, 2000).

IMPACT OF FEEDING SPOILED SILAGE

A variety of microorganisms found in aerobically spoilage silage can be considered dangerous to human and animal health. Enterobacteria make nitrous oxide (N_2O) that can be reduced to a variety of gaseous nitrogen oxides. Nitrogen oxides are sometimes visible during silage fermentation as yellow-brown gases escaping the silo surface. These gases are dangerous due to their ability to damage lung tissue and cause respiratory distress. In humans this is commonly known as silo-filler's disease. The symptoms commonly mimic the early stages of pneumonia. Enterobacteria also form biogenic amines and ammonia. It has been seen that large amounts of these compounds affect silage palatability, decreasing overall intake in cattle (Driehuis and Oude Elferink, 2000).

Animal health problems associated with moulds are not uncommon, due to their ability to produce mycotoxins. The degree of seriousness often varies depending on the type and amount of mycotoxin present at feeding. Ailments can range from minor digestive upsets, and infertility to serious kidney and liver damage (Driehuis and Elferink, 2000). Moulds of the genus *Paecilomyces* produce patulin, a mycotoxin that has been linked to hemorrhagic disorders in cattle. Another serious disorder in cattle, mycotic abortion, has been linked to consumption of the mould *Aspergillus fumigatus* (Crashaw and Woolford, 1979). Berger (2005) noted that the economic cost of feeding mycotoxin contaminated silage to the Vermont dairy industry usually falls between 4.5 and 9 million dollars a year.

The effect of feeding spoiled silage has been looked at in relatively few studies. Hoffman and Ocker (1997) saw a decrease in milk yield in 18 mid-lactation Holstein cows, when aerobically spoiled high-moisture corn was incorporated into the total mixed ration. It was observed that the forage mat in the rumen had been also been compromised as a result of feeding the spoiled HMC. The mat was either partially or completely destroyed. No effect was seen with dry matter intake. Whitlock et al. (2000) however, did see an effect with dry matter intake. In this study twelve ruminally canulated steers were fed diets with varying degrees of surface-spoiled whole-plant corn silage (0, 25, 50 and 75%). Dry matter intake went down as the level of surface-spoiled corn silage increased from 0 to 75% (7.95, 7.35, 6.95, and 6.66 kg/day). Substantial decreases in digestibility were also seen as the percentage increased from 0% to 75%, in % DM (74.4, 68.9, 67.2, 66.0), % organic matter (75.6, 70.6, 69.0 67.8), % crude protein (74.6, 70.5, 68.0, 62.8), % NDF (63.0, 56.0, 52.5, 52.3), and % ADF (56.1, 46.2, 41.3, 40.5) (Whilock et al. 2000).

COVERING BUNKER SILOS

It has long been known in the agricultural community that the practice of sealing horizontal silos with a covering improves silage quality. A covering of plastic and tires is often sufficient enough to create a boundary between the anaerobic environment of the silo and the aerobic conditions of the atmosphere surrounding it. When no covering is used the spoiled portion that forms on the uppermost layer effectively acts as the seal for the healthy layers beneath it. As much as a .3 m of spoilage can be seen on the top uncovered horizontal silos. This material has little to no nutritional value to the animal; therefore farmers will often discard it as compost. This material is not only a loss of nutrients; it is a considerable economic loss to the farmer (Pritchard and Conrad, 1974). Researchers at Kansas State University (Manhattan, KS) estimated that between 5 and 10 million dollars are lost annually to farmers who leave their silos uncovered in western Kansas (Berger et al., 2005). The value of spoiled silage was estimated to be four times the cost of buying plastic and tires, in addition to paying for labor to install and remove them both (Berger et al. 2005; Savoie et al. 2003).

There have been few studies that have compared the effect of sealing versus not sealing horizontal silos. One experiment conducted at Kansas State University looked at the effect of sealing whole-plant corn silage in unsealed and sealed bunker silos, with and without a roof. Sealed treatments were covered with 0.4 mm polyethylene plastic are tires. It was observed that water entered the silos that had no roof (Berger and Bolsen, 2006). Water entry into the silo can be a considerable loss of nutrients because of seepage out of the silo, in addition to supplying an oxygen source to aerobic microorganisms (Holmes and Muck, 2000). In this experiment samples were taken at three depths (0-0.3 m, 0.3-0.6 m, and 0.6-0.9 m). Unsealed treatments had considerable decreases in %DM in all three layers (top layer: 15.6%, middle layer: 23.2%, bottom layer: 24.4%) compared with the sealed treatments, which remained relatively constant (32.4%, 33.6%, 32.8%). The pH values were also very different when looking at the uppermost layer between sealed and unsealed silos. For unsealed treatments the pH of the upper layer was 7.11, whereas sealed treatments had a pH of 3.92 (Berger and Bolsen, 2006).

Dickerson et al. (1992a) looked at the effect of sealed versus unsealed silos in corn and sorghum silages sampled across western Kansas in 1991 and 1992. Sampling technique was limited to two layers of silage (0-45.72 cm and 45.72-91.44 cm). The unsealed silos of both silages had higher levels of % ash, % OM, % DM, and pH in both layers, compared to the layers of sealed silos. The top layers of sealed and unsealed silos had higher values for each of the above characteristics, compared to the layer beneath. A similar experiment was conducted by Dickerson et al. (1992b) using corn and sorghum packed into 55-gallon drums. Each drum was lined with polyethylene, and sealed with four different treatments. Treatment 1 involved leaving the drums unsealed, while treatment 2 involved sealing with .4 mm polyethylene sheeting. The other two treatments studied the effects of a commercial mold inhibitor and delayed sealing, which will not be discussed here. The top 0.91 m was sampled over a 180-day period. The most significant losses were seen in the top 0-0.3 m of unsealed silos, where DM and OM continued to increase as time advanced (Dickerson et al., 1992b).

Effect of Plastic Thickness and Color on Aerobic Spoilage of Bunker Silos

Plastics that are thicker are more resistant to physical damage from the weather and animals. They also act as a better barrier to oxygen infiltration into the silo (Holmes and Muck, 2000). Forristal el al. (1999) looked at the effect of thickness and color of plastic when wrapped around grass bales (1.2 m × 1.2 m). Bales were wrapped in 2, 4, or 6 layers of plastic, of 5 different colors (black, clear, green, light green, and white). There was no effect observed with color; however there was an effect with the number of layers used to wrap bales. Bales with 2 layers of plastic had 21.5 (% area) of visible mould growth, while more layers of plastic yielded significantly less growth. Four layers of plastic had 1.7%, and 6 layers had 0.6% (Forristal et al., 1999).

Snell et al. (2002 and 2003) also looked at the effect of color and thickness on silage preservation in two studies. In 2002, researchers looked at five different types of plastic, each with varying thicknesses and colors (90 µm white, 150 µm transparent, 150 µm white, 150 µm black, and 200 µm white). Thirty mini-silos (0.3 m^3) were filled with whole-plant corn silage and covered with one of the five film types. Only three of the film types were tested for oxygen permeation (90 µm white: 459 $cm^3 (m^2d)^{-1}$, 150 µm white: 248 $cm^3 (m^2d)^{-1}$, 200 µm white: 188 $cm^3 (m^2d)^{-1}$). Four silos of each treatment were placed in open air, and two were kept inside and subjected to artificial solar radiation in the form of mercury vapor and metal halide lamps. The study completed in 2003 was very similar to the one completed in 2002. The same containers, number of replications, number of plastics, and environments were used. Instead of corn, grass silage was used, and there were slight variations in the color and thickness of plastics. The plastics used were 90 µm white, 125 µm green, 150 µm black, and 200 µm green, and 200 µm white. There were no significant differences observed in any of the chemical characteristics between types of plastic in either study. Temperatures directly underneath plastic surfaces were significant between types; however, researchers concluded that increases were too little to cause a change in the silage microenvironment. Researchers concluded that optimal silage fermentation is not dependent on thickness or color of plastic but these results were based on using experimental mini silos.

Oxygen Barrier Plastics

Polyethylene sheeting used to cover bunker silos is not completely impervious to air and thus a completely enclosed anaerobic system can never be achieved. Holmes and Muck (2000) noted that thicker plastics of at least 6 mm should be more resistant to oxygen; however there has been very little research on plastics of varying thickness to prove that point. Creating thicker plastics will not serve to decrease the total amount of plastic used in agriculture. Ideally a plastic would be able to minimize waste, as well as reduce the infiltration of oxygen into the silo. Recently a plastic has been manufactured by Industria Plastica, (Mongralese, Italy) trade-named Silostop, which attempts to address both of these issues. This triple co-extruded film (TCF) is composed of two layers of polyethylene, and a middle layer of polyamide, totaling 0.45 µm in thickness. This film is also an oxygen barrier film, which could lead to decreases in surface spoilage on top of bunker silos (Wilkinson and Rimini, 2002).

There has been some work with decreased oxygen permeable plastics in Europe. Borreani and Tabacco (2005) looked at the effects of an oxygen barrier (OB) film compared to polyethylene. Both plastics were 0.25 µm in thickness. Italian ryegrass bales were wrapped in 6 layers of either OB film, or polyethylene. After 4 months of ensiling OB wrapped bales had 3.14 log cfu/g yeasts, 1.06 log cfu/g moulds and 1.52 log cfu/g clostridia. The polyethylene wrapped bales had increased counts for all three organisms, being 4.26, 2.72, and 3.12 1.06 log cfu/g respectively. Silage wrapped in OB film also had decreased ammonia (77 g/kg total N) compared to the polyethylene (113 g/kg).

Degano (1999) looked at the effect of TCF (45 µm) versus polyethylene sheeting (200 µm) in two bunker silos filled with whole-plant corn silage. The polyethylene covered silage was observed to have a higher pH (3.97), and ammonia concentration (6.12% total N) compared to the TCF, which had a pH of 3.78 and an ammonia concentration of 5.33%. TCF covered silage had a higher concentration of lactic acid (3.67% DM) compared to polyethylene (3.18%). Wilkinson and Rimini (2002) also looked at the effect of TCF on ensiled feeds. In this study ryegrass was treated with an additive containing ammonium tetraformate (2.0L/tonne fresh weight) and ensiled in mini-silos (55 cm x 46 cm). Silos were covered with either a single, or double layer of 125 µm polyethylene, or a single layer of TCF. After a 175 day storage period, the single layer polyethylene covered silos had 14.4% DM loss and 15.3 cm of top surface mould growth. A second layer of polyethylene improved DM loss (12.5%) and mould growth (9.30 cm). A single layer of TCF was able to decrease DM loss even further to 7.4%, and completely prevent visible mould growth.

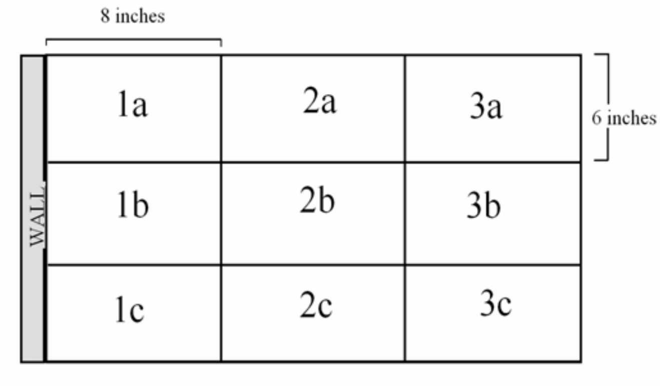
In a recent experiment (McDonell and Kung, 2006, unpublished data, University of Delaware) we filled three identical bunker silos (43 m × 7 m) with approximately 600 tons of whole-plant corn silage (Dekalb 62-63rr, Monsanto, St. Louis, MO; Golden Harvest L9h93bt and H9461, Golden Harvest Seeds, Inc., Waterloo, NE) on August 25 through September 3, 2006. Corn was harvested at about 30% DM using a New Holland FP240 pull-behind chopper (New Holland, Pa). Roller clearance on the processor was set at about 1.35 mm. Silos were packed using a Ford 8160 tractor weighing 14 tons, and a Ford 8770 tractor weighing 8 tons. Two treatments systems were compared. The first system was composed of extruded film (TCF, composed of two layers of polyethylene, and a middle layer of polyamide, totaling only 0.45 µm in thickness) placed along the length of the sidewall before filling, with approximately 0.91 m of excess draped over the wall. After filling the excess film was pulled over the wall, and another sheet of TCF was placed on top, extending 3.69 m width-wise. A protective tarpaulin was then placed on top of the TCF. The TCF was weighted down with gravel bags where TCF met the concrete wall, and down the middle of the silo, at the point where treatments met, and also every 3.66 to 4.57 m perpendicular to the silo wall. The second treatment involved using a traditional 6 mm black/white polyethylene (BWP, Up North Plastics Bunker Covers, Cottage Grove, MN). The BWP was also 3.69 m wide, which allowed for 0.30 m of overlap between treatments. No sidewall plastic was used with the BWP treatment. The BWP was weighted down with sidewall tires in a normal fashion. (See Figure 1)

Figure 1. Picture of a bunker silo with two covering treatments. Left: Plastic on the side wall, low oxygen barrier plastic on silo, reusable protective tarp and gravel bags. Right: Normal 6 mil plastic with tires. (McDonell and Kung, 2006).

Corn silage was sampled after 5 months of ensiling. Blocks of silage were taken at three heights extending in 15.24 cm increments downward, and three sampling widths extending in 20.32 cm increments outward from the wall (Figure 2). This sampling scheme yielded 9 “blocks” in total that were 20.32 cm × 20.32 cm × 15.24 cm, and was replicated twice, per time-point, per treatment.

Figure 2. Sampling scheme used in study by McDonell and Kung, 2006.

Width 1 Width 2 Width 3



Preliminary data from this study is shown in Table 1. Lower DM for silage closest to the wall (19.77% for Width 1 and 23.52% for Width 2 compared to a DM of 27.80% for Width 3) is most likely an indication of infiltration of water along the sidewall. The DM content of silage was fairly consistent among the three widths (29.01 to 30.33%) for the TCF covering system suggesting that the plastic on the sidewall protected this material from water. Contamination with water in the Control silos was probably responsible for the marked differences in pH and fermentation end products when compared to TCF silages. The differences were most evident at Width 1 and decreased progressing further away from the wall to Width 3. Although NH3-N concentrations were not affected by Width or treatment, the NDF and ash contents of silages were substantially greater for Control than for TCF silages. These differences were most striking when comparing treatments in Width 1.

Table 1. The effect of a conventional covering system (Control[1]) versus an oxygen barrier system (TCF[2]) on the chemical composition of corn silage stored for 5 months in three bunker silos.[3]

	Width 1		Width 2		Width 3		
Item	Control	TCF	Control	TCF	Control	TCF	P value
DM, %	19.77	29.01	23.52	29.13	27.80	30.33	0.0001
pH	5.19	3.96	4.26	3.76	4.04	3.74	0.0002
Lactic acid, %	0.39	1.67	1.09	2.21	2.44	2.76	0.2974
Acetic acid, %	0.94	3.65	2.81	4.42	4.60	4.71	0.0013
Butyric acid, %	0.22	0.07	0.39	0.02	0.21	0.08	0.0042
NDF, %	62.20	46.01	54.86	46.44	47.87	43.00	0.0001
NH3-N, %	0.09	0.09	0.11	0.11	0.13	0.12	0.6239
Ash, %	3.08	2.68	3.04	2.82	3.29	2.85	0.7702

[1]Normal plastic and sidewall tires.
[2]Low-oxygen permeable plastic on the side wall and on the silo, a protective reusable tarp and gravel filled bags used as weights.
[3]Preliminary data only, subject to change. McDonell and Kung, 2006. University of Delaware.

Edible Coverings for Bunker Silos

Non-biodegradable plastics currently make up as much as 30% of municipal solid waste across the country (Denoncourt et al., 2004b). Plastics used for covering bunker silos, and piles fall into this category. Because of this problem, along with cost of labor and risk of WNV associated with the plastic and tires method, researchers have looked at ways to develop edible coverings (Berger et al., 2005). Berger and Bolsen (2006) noted that in order for the plastic and tires method to be replaced by an edible covering there are several criteria should be met. The covering should be easy to apply, cheap, and serve as an effective barrier against air and water. In addition, the material should be edible, nutritious and palatable to animals consuming ensiled materials.

To date there have been numerous edible alternatives proposed using a wide array of materials (Table 2). Each one of these studies has made progress toward an edible cover development; however, none have been 100% successful due to a host of problems. Brusewitz et al. (1991) experienced cracking in the cover, allowing for air and water infiltration into the silos. Denoncourt et al. (2004b) offered some possible reasons for the failure of this commercial covering. The viscosity of the solution prevented it from staying completely on the surface of the silage. The solution that was left following seepage into deeper layers was not thick enough to form a stable barrier against air and the environment. Also, the solution contained hydrophilic polymers that could have increased the % DM by binding water.

In Denoncourt et al. (2004a, and 2004b), Minson and Lancaster (1965), Nieto-Ordaz et al. (1984), and Savoie et al. (2003) the materials used were also unsuccessful in keeping air out of their respective systems. Many of the studies had increased DM loss with edible coverings when compared to conventional plastic sealing systems. Denoncourt et al. (2004a) had a DM content of 387 ± 1.8 g/kg with a plastic seal (88 µm thickness) compared to the edible cover (531.4 ± 1 4.4 g/kg). Nieto-Ordaz (1984) experienced a DM loss of 10% with plastic, while the edible covering was much higher, being 27%. Minson and Lancaster (1965) had a slightly higher loss of 11% with plastic. There was a broad range of variation between the edible coverings of this study. Limestone preformed the best, with 23.6% DM loss, compared to soil (25.1%) and sawdust (30.0%). Pritchard and Conrad (1974) had relative success with molasses as a covering for piles. The %DM and average daily consumption were better for the molasses-treated silage (26.3%, 56 lbs.) compared to the silage covered with plastic (25.0%, 54 lbs.). Even though the molasses-covering did fair better than plastic in the final outcome, researchers did encounter some problems during application and storage. During the first application rain diluted the molasses, causing it to run off the pile. Also, during storage the molasses-treated surface was ridden with flies and maggots. The top 4 to 5 inches had to be discarded, but all of the silage underneath was fed to dairy cows with little refusal.

Recently, Berger et al (2005) attempted to use a starch-salt matrix to cover whole-plant corn silage in bunker silos (3.66 m x 1.83 m x 1.83 m). The starch had to be mixed with boiling water prior to application for gelatinization to be achieved. Two silos each were used between three treatments: uncovered, covered with 6 mm plastic, or covered with 1.27-1.90cm of starch-salt matrix and a think layer of paraffin wax. The salt-starch matrix/wax was fed to heifers at a rate of 2.0 lbs/day, with refusal averaging 9% of the total covering offered. Ash content was significantly higher for the starch-salt matrix treatment (18.3%) compared to the uncovered (11.3%) and 6 mm covered (8.7%) treatments. Because of the cost necessary to apply the salt-starch matrix/wax treatment researchers sought an alternative application method in another trial. Instead of using a mortar mixer and cement trowel to apply the matrix, the consistency was altered so that it could be sprayed on. A commercial application was not available at the time of preparing this review.

CONCLUSIONS

Infiltration of air and water into the silage mass during storage results in decreased forage quality. Besides a loss in total DM and nutrients, feeding spoiled silage has adverse effects on rumen function and animal performance. Research continues on practical methods to exclude oxygen from the stored silage mass in bunker silos. Successful practices will be user friendly and economical. There have been too few studies investigating edible materials over multiple trials to conclude that edible coverings are better than plastic. Several studies are currently underway investigating the efficacy of low oxygen permeable plastic (McDonell and Kung, University of Delaware and Muck et al., USDFRC, Madison, WI).

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