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Sealing Strategies for Bunker Silos and Drive-over Piles

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Introduction

Bunker silos and drive-over piles are economically attractive for storing both moderate and large amounts of ensiled forage, but by design, they allow large percentages of the ensiled material to be exposed to the environment. In addition to the weather influences, silage in bunkers and piles is affected by other interacting factors involving crop DM content, exposed surface area during filling, permeability of the silo walls, length of storage, and rate of silage removal during feedout (McDonald et al., 1991). These factors produce a wide range of silage DM and nutrient losses on dairy farms.

In a 1,000-ton capacity bunker silo, (approximately 40 ft width × 12 ft depth × 100 ft length), depending on silage DM density, 15 to 25 percent of the initial tons of forage is within the top 3 feet. When no seal is applied or when the seal is inadequate, air and water enter the silage mass and affect the preservation efficiency during the storage phase and the quality of silage during the feedout phase (Bolsen, 1995).

Although weighted polyethylene sheeting has been the most common method used to protect silage near the surface (Oelberg et al., 1983), the protection provided is highly variable and often changes during storage (Savoie, 1988). In a survey, Ruppel (1993) rated the opinion of farm managers for the importance of six specific bunker silo management practices (chopping, additives, filling, packing, sealing, and feedout) in determining the quality of hay crop silage. All managers rated sealing as the first or second most important practice. The farm managers who rated sealing the most important practice also placed, on average, twice the number of tires per square ft of plastic sheet compared to other farm managers.

However, ‘plastic and tires’ have numerous disadvantages. First, several people are required to apply the plastic and tires, and additional labor is needed to remove them at feedout. Second, proper disposal of the plastic is a real concern in many states. Third, full-casing tires make an excellent breeding area for mosquitoes and increase the risk of West Niles virus, which is becoming a major issue in some states (Lanyon et al., 2004). And fourth, cattle, deer, dogs, raccoons, rats, and other vermin can tear the plastic, which allows air and water to penetrate the silage mass and create localized surface spoilage.

Because of these challenges, there are beef and dairy producers who decide not to seal their bunker silos and drive-over piles. Many producers are quick to point out that putting tires on a plastic sheet is not an activity that is enjoyed by most farm employees. And there are producers, nutritionists, and silage custom operators who just do not realize or appreciate the enormous benefits from properly sealing bunkers and piles.

There have been very few published research studies that evaluated alternatives to ‘plastic and tires’, such as improved sealing materials or edible covers for bunkers and piles. Bolton and Holmes (2004) summarized data with alternative covers, which included lime, soil, a roof, candy, molasses and molasses-based products (Liqui-Seal), Nutri-Shield, sod, sawdust, chopped straw, and composted manure solids. Data from Nieto-Ordaz et al. (1984) (as derived by Holmes, 1996) with corn silage in 8.5 ft deep bunker silos showed a 27% total DM loss for a sod cover (from sown wheat) compared to a 10% total DM loss for a plastic cover. Savoie et al. (2003) used apple pulp and peanut butter as covers for grass silage in laboratory silos and found that neither material offered adequate protection against the infiltration of air. The bottom line is that none of the alternative sealing materials evaluated have been as effective as ‘plastic and tires’ in controlling surface spoilage.

This paper summarizes research that documents DM and nutrient losses when bunker silos and drive-over piles are not sealed and how feeding surface-spoiled silage affects DM intake and nutrient digestibilities. Recent developments in edible bunker covers and oxygen barrier film are presented. The paper concludes with a spreadsheet to calculate the profitability of sealing bunkers and piles and practical steps that dairy producers can implement to minimize surface spoilage.

Field Surveys to Estimate Losses from Surface-spoiled Silage

From 1990 to 1993, the top 3 ft of silage from 127 bunker silos and piles in Kansas was sampled at three locations across the width of the silos. Sampling depths were: 0 to 18 inches from the surface (depth 1) and 18 to 36 inches (depth 2). Reference samples were taken at least 5 ft from the top at the feedout surface (depth 3 or ‘face’). All sealed silos

Table 1. Effects of crop and sealing treatment on ash contents and estimated additional spoilage losses of OM at the top two depths in bunker silos and piles in 1990 and 1991.

	Depth 1[2]		Depth 2[2]		Depth 1		Depth 2	
Crop and treatment[1]	1990	1991	1990	1991	1990	1991	1990	1991
	% ash				estimated OM loss[3]			
All crops (30, 30)[4]	13.6	15.5	8.1	8.7	39	51	6	13
Corn (14, 11)	11.8	12.3	7.0	7.1	38	49	7	17
Sorghum (13, 19)	13.6	17.4	8.9	9.6	38	52	3	12
Treatment								
unsealed (25, 22)	14.1	17.3	8.1	8.8	43	61	6	17
sealed (5, 8)	10.2	10.7	8.3	8.4	27	24	2	4
Corn								
unsealed (12, 8)	12.0	13.8	6.8	7.3	49	60	9	19
sealed (2, 3)	11.2	8.3	8.2	6.8	31	22	1	5
Sorghum								
unsealed (10, 4)	14.5	19.2	9.0	9.7	42	61	3	16
sealed (3, 5)	9.5	12.2	8.4	9.4	23	26	2	4

[1] Number of silos per crop or treatment in parentheses for 1990 and 1991, respectively.

[2] Depth 1 = 0 - 18 in. and depth 2 = 18 - 36 in. from the surface on the day of sampling.

[3] Expressed as a percentage unit increase in spoilage loss of OM.

[4] Includes data from three unsealed silos of alfalfa, wheat, and oat silages in 1990.

Table 2. Effects of crop and sealing treatment on ash contents and estimated additional spoilage losses of OM at the top two depths in bunker silos and piles in 1992 and 1993.

	Depth 1[2]		Depth 2[2]		Depth 1		Depth 2	
Crop and treatment[1]	1992	1993	1992	1993	1992	1993	1992	1993
	% ash				estimated OM loss[3]			
All crops (46, 21)[4]	13.6	16.6	8.1	10.1	38	41	11	10
Corn (25, 13)	14.4	17.7	7.9	9.7	40	46	11	11
Sorghum (19, 8)	12.1	14.9	8.0	10.8	33	32	9	9
Treatment								
unsealed (37, 20)	16.9	17.0	7.7	10.1	41	43	12	10
sealed (9, 1)	11.0	11.0	7.6	8.9	23	7	9	3
Corn								
unsealed (21, 13)	17.7	17.9	8.3	9.7	44	46	12	11
sealed (4, 0)	15.2	—	6.5	—	17	—	6	—
Sorghum								
unsealed (14, 7)	12.5	15.5	7.8	11.1	36	36	18	10
sealed (5, 1)	11.1	11.0	8.5	8.9	27	7	12	3

[1] Number of silos per crop or treatment in parentheses for 1992 and 1993, respectively.

[2] Depth 1 = 0 - 18 in. and depth 2 = 18 - 36 in. from the surface on the day of sampling.

[3] Expressed as a percentage unit increase in spoilage loss of OM.

[4] Includes data from two unsealed silos of soybean silage in 1992.

were covered with a single sheet of black or white on black, 4 to 6 mil polyethylene, which was held in place with discarded tires, sidewall disks, or soil. More details about the procedures in these studies are reported by Dickerson et al. (1992a), Bolsen et al. (1993), and Holthaus et al. (1995a).

Additional OM losses (losses in addition to the losses in well-preserved silage) at depths 1 and 2 were estimated by comparing the ash content in these samples to the ash content in the reference samples. The relationship between ash content in a silage sample and estimated additional spoilage loss of OM (in excess of that lost in the presumably well-preserved face sample) was described by Dickerson et al. (1992a) and Bolsen (1997).

The effects of crop and sealing treatment on ash contents and estimated additional spoilage losses of OM at the top two depths in bunker silos and piles are shown in Tables 1 and 2. In the top 18 inches, additional OM losses ranged from 7 to 61%, and losses were higher in bunkers and piles that were not sealed. Applying a seal reduced OM losses in the top 18 inches by a range of 16 to 37 percentage units. Sealing also reduced additional spoilage losses in the second 18 inches by 3 to 13 percentage units. Silage near the exposed surface of the unsealed silos had pH values ranging from 4.75 to 8.55 (data not shown), which were typical of severely deteriorated silage. Several of the silages in sealed bunkers and piles had OM losses and pH values in the top 18 inches that were higher than expected, suggesting that sealing techniques were not effective or the polyethylene sheets were damaged during the first several months post-filling.

Research to Document Losses from Surface-spoiled Silage

Sealed vs. unsealed bunker silos. Presented here is an abbreviated summary of data from Holthaus et al. (1995b). Whole-plant corn (2/3 milk line maturity and 34.2% DM) was chopped and packed into four, 13.5 ft wide x 16 ft long x 4 ft deep, bunker silos (Trial 1). During filling, nylon net bags, each containing 4.5 lbs of fresh, chopped forage, were placed at average depths of 10, 20, and 30 inches from the surface of the original ensiled mass (three bags per depth per silo). The forage was packed with single-tired tractors to equal densities of about 14 lbs of DM per cubic foot.

Treatments were: 1) unsealed; 2) sealed; 3) unsealed, with a roof; and 4) sealed, with a roof. Silos were sealed with a single sheet of 4 mil polyethylene weighted with full-casing, discarded car tires for treatments 2 and 4. A galvanized, tin roof was used for treatments 3 and 4. Bunkers were emptied at 180 days post-filling. The nylon net bags were recovered, and the silage was weighed; mixed; sampled; and analyzed for DM, ash, pH, and fermentation end products. Ruminal DM disappearance was determined for the silages from the nylon net bags recovered from the bunker silos.

Whole-plant, Northrup King 300, forage sorghum (late-dough maturity and 37.1% DM) was chopped and packed into four bunker silos to equal densities of about 11 lbs of DM per cubic foot. Treatments and procedures were the same as in Trial 1.

Results for the unsealed and sealed treatments in Trials 1 and 2 are presented in Table 3. Corn and sorghum silages in the sealed bunker silos were well-preserved and had lower DM losses and higher in situ DM digestibilities at all three depths than the silages in the unsealed silos. Silages in the unsealed bunkers had dramatically lower DM content at the all three depths than silages in the sealed silos. Corn and sorghum silages in unsealed bunkers were extensively deteriorated at the 10-inch depth, partially deteriorated at the 20-inch depth, and only silages at the 30-inch depth were of acceptable visual quality. Silages at the 10-inch depth in the unsealed silos had very low *in-situ* DM digestibilities, high pH values, and high concentrations of ash and fiber (data not shown), which indicated that much of the digestible OM had been lost through aerobic spoilage.

Sealed vs. unsealed bunker silos: with and without a roof. The effects of placing a roof over the unsealed silos on preservation efficiency and silage quality were presented in detail by Holthaus et al. (1995b) and Bolsen (1997). In general, water from rain and snow percolated through the unsealed, no roof silages, and silage at all three depths was much wetter than the pre-ensiled forages. In contrast, silages at the 10- and 20-inch depths in the unsealed, roofed silos were much drier than the pre-ensiled forages, because considerable dehydration/evaporation took place in the absence of an oxygen barrier. The DM and OM losses at the 10- and 20-inch depths indicated that unsealed, roof silages were better preserved than their unsealed, no roof counterparts. However, visual appraisal suggested that only the corn and sorghum silages at the 30-inch depth were ‘feedable’ in the unsealed, roofed bunker silos.

The authors stated that their primary reason for putting a roof over the unsealed bunkers was to simulate an arid environment, in which the silage surface would not be exposed to rainfall. The results clearly indicated that bunkers and drive-over piles in both temperate and arid climates should be sealed to prevent excessive surface spoilage. There are dairy producers in North America who store silage in sealed bunker silos under a roof (Waybright, 1997). A roof has several advantages: 1) it protects the feedout face from rainfall, which reduces daily variation in DM content of the silage being fed; 2) it prevents the accumulation of snow on the sealed surface, which makes it easier to remove ‘plastic and tires’; and 3) it allows a water soluble material to be used to seal the surface of the bunker.

Sealed immediately vs. delay-sealed bunker silos. Holthaus et al. (1993) ensiled field-wilted alfalfa (52% DM) in pilot-scale, drum silos; and DM losses were measured at three depths within the top 3 ft of original forage. Treatments presented here were: 1) unsealed, 2) sealed immediately after filling, and 3) sealed 7 days post-filling. Silos for treatments 2 and 3 were sealed with a single sheet of 4 mil polyethylene, which was secured to the top of the drums with adhesive tape. Three silos per treatment were opened at 90 and 180 days post-filling. Results are presented in Table 4. The silages in the immediate and delay-sealed silos had similar DM contents, DM losses, and fermentation profiles at the 12 to 24-inch and 24 to 36-inch depths from the original surface at 90 and 180 days post-filling. However, at both opening times, delay-sealed silos had higher DM losses at the 0 to 12-inch depth (14.7% at 90 days and 15.7% at 180 days) compared to DM losses in silos sealed immediately after filling (8.0% at 90 days and 6.8% at 180 days). The unsealed silo had a 62.2% DM loss at the 0 to 12-inch depth at 90 days post-filling and a 64.5% DM loss at 180 days.

Table 3. Effects of sealing treatment and depth from the original surface on the DM content, DM loss, pH, and in-situ DM digestibility (DMD) of the corn and sorghum silages from the bunker silos in Trials 1 and 2.

		Corn silage (Trial 1)				Sorghum silage (Trial 2)			
Sealing treatment	Depth inches	DM %	DM loss[1]	pH	In-situ DMD, %	DM %	DM loss[1]	pH	In-situ DMD, %
Unseal	10	15.6	75.1	7.11	37.1^{b,y}	14.0	47.7	6.68	35.8^{b,y}
	20	23.2	25.0	3.94	63.1^{b,x}	24.1	25.0	5.08	57.7^{b,x}
	30	24.4	23.3	3.90	65.7^{b,x}	25.6	8.5	4.94	55.1^{b,x}
Sealed	10	32.4	10.0	3.92	71.4^{a}	34.2	3.6	4.57	57.8^{a,y}
	20	33.6	7.6	3.81	71.2^{a}	37.6	3.2	4.49	60.8^{a,x}
	30	32.8	6.4	3.83	71.9^{a}	36.5	3.4	4.38	61.0^{a,x}

[1] DM loss is reported as a % of the original crop DM ensiled.

[a,b] Means within a depth across treatment with different superscripts differ ($P < 0.05$).

[x,y] Means within treatment across depth with different superscripts differ ($P < 0.05$).

Table 4. Effects of sealing treatment, depth from the original surface, time of sealing, and time post-filling on the DM content, DM loss, and pH of alfalfa silage stored in pilot-scale silos.

		90 days post-filling				180 days post-filling			
Sealing treatment	Depth inches	DM %	DM loss[1]	Lactic acid[2]	pH	DM %	DM loss[1]	Lactic acid[2]	pH
Unseal	0-12	27.1	62.2	none	7.71	24.3	64.5	none	8.28
	12-24	22.7	33.2	0.96	5.28	21.3	40.3	none	5.94
	24-36	23.5	22.1	1.14	5.10	18.1	44.1	0.38	5.21
Sealed	0-12	49.1	8.0	1.64	5.08	46.8	6.8	1.70	5.00
	12-24	52.1	6.4	1.75	5.18	52.1	5.9	1.73	5.07
	24-36	50.2	5.5	1.79	5.10	50.2	6.8	1.83	5.06
Delay-sealed	0-12	49.1	14.7	1.25	5.33	52.8	15.7	1.26	5.36
	12-24	51.4	7.8	1.35	5.16	54.2	7.6	1.36	5.13
	24-36	49.9	5.3	1.60	5.06	51.9	7.4	1.53	5.10

[1] DM loss is reported as a % of the original alfalfa DM ensiled.

[2] Lactic acid is reported as a % of the silage DM.

Dickerson et al. (1992b) ensiled whole-plant corn and forage sorghum using similar treatments and experimental procedures as Holthaus et al. (1993). At both opening times, delay-sealed silos had about 10 percentage higher DM losses at the original 0 to 12-inch depth (average of 23.0% for corn and 20.6% for sorghum) compared to DM losses in silos sealed immediately after filling (average of 12.1% for corn and 10.4% for sorghum). Unsealed silos for both crops had about a 54% DM loss at the 0 to 12-inch depth at 90 days post-filling and a 64% DM loss at 180 days.

In a typical 1,000-ton capacity bunker silo, these data indicate that a 7-day delay in applying an effective seal would result in the loss of approximately 6 to 10 tons of silage compared to sealing immediately after filling is completed.

Research at the University of Illinois to Develop an Edible Cover for Bunker and Drive-over Pile Silos

Criteria for a replacement of 'plastic and tires'. The following criteria were used in developing an alternative cover: 1) provide effective protection from air and water for several months, 2) be edible, 3) provide essential nutrients, 4) be palatable, 5) be easy to apply, and 6) be cost effective. For an alternative cover to be successful it must be equal or superior to 'plastic and tires' in its ability to protect the silage and minimize surface spoilage. The cover should be edible or significant cost would be incurred in the removal and disposal of an inedible cover. If the cover provides essential nutrients then a portion of the cost is offset by its nutritional value. However, the edible cover must retain its nutritional value and not develop anti-nutritional properties while protecting the silage. The cover must be palatable so DM intake of the ration is not impaired. Ease of application is critical to the acceptance by the producer and his or her employees. Finally, the total benefits of the edible cover must be greater than the cost.

Initial research with an edible bunker cover. The objective was to determine whether a starch-salt matrix could serve as an edible cover that would simultaneously reduce surface spoilage and serve as a nutrient source. Whole-plant corn (40% DM) was chopped and packed into six, side-by-side mini-bunkers, 6 ft wide x 12 ft long x 6 ft deep. Equal amounts (3,455 lbs of DM) of chopped material were weighed into each bunker, leveled, and packed with a small tractor. The three treatments were: uncovered, covered with 6-mil plastic and tires, and covered with the starch-salt matrix. The starch-salt matrix was mixed in a motar mixer with boiling water added to gelatinzed the starch. The matrix was applied by hand to achieve a 0.5- to 0.75-inch thick layer using a cement trowel. After the matrix cured for 3 days, paraffin wax was melted and a thin layer applied with a paint roller. After 92 days of storage, visibly spoiled silage and well-preserved silage was separated by hand prior to feeding. A 1 ft x 5 ft wooden frame was used to measure the spoilage under a fixed area. The measurements were made at three locations on each silo. Surface spoilage under the frame averaged 31.5, 36.0, and 2.6 lbs of DM ($P < 0.05$) for the uncovered, plastic and tires, and starch-salt, respectively. Forty-eight Angus heifers were allotted by weight to 12 pens. Two pens of heifers were randomly assigned to each mini-bunker. Silage DM fed was 1549, 1951, and 2684 lbs ($P < 0.05$) for the uncovered, plastic and tires, and starch-salt, respectively. The DM recoveries were relatively low because of the small size of the bunkers, which had a large surface area to volume ratio. In addition, the forage at harvest was drier than optimum for bunker silos. Animal days per bunker were 140, 152, and 212 ($P < 0.05$) for the uncovered, plastic and tires, and starch-salt, respectively. During the feeding period the starch-salt matrix was removed from the silage prior to feeding. For the last 6 days, heifers fed the starch-salt matrix silage were fed the covering material at the rate of 2.0 lbs (as-fed) per day. The heifers consumed approximately 91% of the covering material offered.

The ash content of the pre-ensiled forage and spoilage from uncovered, plastic and tires, and starch-salt matrix bunkers averaged 5.8, 11.4, 8.7, and 18.3% ($P < 0.05$), respectively. These data suggest that a portion of the salt diffused into the silage immediately under the covering material. Cai et al. (1997) showed that some strains of lactic acid bacteria are salt tolerant. A combination of the air-tight covering and preservative effects of the salt helped to minimize surface spoilage. Also, the salt contained in the silage did not inhibit intake when it was mixed with the well-preserved silage below it.

These initial results showed promise, but there were several significant huddles to overcome. First, this starch-salt product required boiling water to gelatinize the starch, a costly and awkward procedure on a large scale. Second, wheat flour was used as the starch but a cheaper and more easily obtained source of starch was needed. Finally, a more practical means of application was needed.

Several of these issues were addressed in the laboratory, which involved testing approximately 40 different formulations of the starch-salt matrix. All of the modifications still allowed the original criteria to be met, and results showed that finely ground wheat could replace the flour. By adding additional feed-grade ingredients, the boiling water could be eliminated and still achieve a starch-salt matrix that was adhesive and flexible. However, to have a product that could be sprayed on and not crack after it dried required additional testing of the formulations.

Research with alternative application methods for the edible bunker cover. The goal was to develop a commercially feasible method to apply the edible cover to bunker silos and drive-over piles. The previous formulation had a bread-dough consistency, and it had to be modified before it could be sprayed. After evaluating several pieces of equipment, a commercial CEJCO concrete pump, model CSS 2489 with a vertical shaft mixer and screw pump, was used. A 50 ft long x 3-inch diameter hose was used to apply the product. A spray nozzle was connected on the end of the hose to a 110 CFM Ingersoll-Rand industrial air compressor for atomizing the product as it was applied. Approximately 700 lbs of dry ingredients were added to the mixing chamber, and water was added to bring the final product to approximately 30% moisture. This unit was chosen because it could be powered by the hydraulic system of a farm tractor. This approach was used to cover mini-bunker silos and small drive-over piles. The wax was applied as described above. When the silos were opened, surface spoilage was similar to what had been observed in the initial research presented above.

Research with protective coatings for the edible bunker cover. The objective was to develop a protective cover for the edible starch-salt matrix that was easier to apply than the paraffin wax. The control treatment, 6-mil black plastic weighted with 2 to 3 inches of soil, was compared to the starch-salt matrix coated with either a sprayable wax emulsion, molten paraffin applied with a paint roller, or wax paper. The wax paper was made by Georgia-Pacific Paper Company (Clatskanine, OR) and was food grade, which can be fed to animals. The sprayable wax emulsion has the advantage of eliminating the need for equipment and fuel to melt the paraffin wax. The wax paper could be applied directly behind the spraying apparatus for the edible cover, and it was bound to the starch-salt matrix by running small press wheels on top the paper. The wax paper has the potential advantage of holding the starch-salt matrix in place on steep slopes of bunker silos and drive-over piles.

On September 11, 2003 eight, 7 ft wide x 24 ft long x 4 ft deep mini-bunker silos were each filled with 21,330 lbs of chopped whole-plant corn (39.1% DM). The forage was packed with a tricycle IH farm tractor, and the silos were opened at 117 days post-filling. Less weight on the rear wheels of the tractor resulted in a low silage DM density near the walls and, as a result, more spoiled silage along the walls. Visibly spoiled silage and well-preserved silage was separated by hand prior to feeding. The amount of DM fed for the plastic (control), sprayable wax, paraffin wax, and wax paper treatments were: 4759, 4378, 5861, and 5493 lbs, respectively. Less DM was fed from the sprayable wax bunkers than the control bunkers ($P < 0.05$). The DM fed from the paraffin and wax paper treatment bunkers was 23 and 15% greater than the DM fed from the control silos.

Recent Developments in Improved Oxygen Barrier Film.

At the XII International Silage Conference, Dagano (1999) introduced an improved oxygen barrier film (OB film) as an alternative to standard black polyethylene to seal bunker silos. The OB film, which is used in the packaging of food and in the horticulture industry for the sterilization of soil, is 45µm in thickness and is manufactured by Industria Plastica, Monregalese, Italy.

Wilkinson and Rimini (2002) ensiled mature ryegrass in steel drum, pilot silos and compared three sealing treatments: 1) a single sheet of black polyethylene, of 125 µm thickness (standard film); 2) double sheets of standard film; and 3) a single sheet of OB film. The packing density was 36.6 lbs per cubic ft, and there were three silos per treatment. At 175 days post-filling, the silage in each silo was judged visually to be either ‘inedible’, by virtue of being moldy and/or foul-smelling, or ‘edible’. Results in Table 5 show total DM loss was numerically lower in the silos sealed with the single OB film compared to silos sealed with single and double standard film. There was virtually no visible surface mold and a markedly lower percentage of inedible silage for the OB film-sealed silos compared to the single and double standard film-sealed silos.

Bolsen (2004) compared the OB film to 6-mil black plastic in two field trials conducted from September, 2003 to May, 2004. The first trial was with whole-plant corn at a commercial feedyard near Dimmit, TX; the second trial, with high moisture (HM) corn at a feedyard near Garden City, KS. In Trial 1 the OB film and black plastic were applied to side-by-side, 40 ft wide x 60 ft long areas of the bunker surface; in Trial 2, the OB film and black plastic were applied to side-by-side, 130 ft wide x 60 ft long areas. The covers were weighted with either full-casing, discarded car tires (Trial 1) or truck sidewall disks (Trial 2). Because the OB film did not have protection from ultraviolet light, a thin tarpaulin was put over the film ahead of the tires or sidewalls. At about 240 day post-filling, the sealing materials were removed and samples taken at 0 to 6, 6 to 12, and 12 to 18 inches from the surface at four locations across the width of each test area.

Results from the field trials are shown in Table 6. There was virtually no visible discoloration or surface spoilage in the OB film-sealed bunkers, however there was visible mold and aerobic spoilage in the black plastic-sealed bunkers, particularly in the top 12 inches of corn silage. The corn silage and HM corn in the top 0 to 18 inches under the OB film had better fermentation profiles and lower estimated additional spoilage losses of OM compared to the corn silage and HM corn under the black plastic. Further information about the improved oxygen barrier film is located at www.silostop.com.

Table 5. Effects of standard film and oxygen barrier film (OB film) on DM loss, visible surface mold, and inedible silage.

Item	Single standard film	Double standard film	Single OB film
DM loss, % of the DM ensiled	14.4	12.5	7.4
Depth of visible surface mold, inches	6.0^{a}	3.7^{a}	$<0.1^{b}$
Inedible silage, % of the silage DM	20.1^{a}	14.0^{a}	3.5^{b}

[a,b]Means with different superscripts are differ (P<0.05)

Table 6. Effects of 6-mil black plastic and oxygen barrier (OB) film on pH, fermentation profile, estimated additional spoilage loss of OM, and ash content in corn silage and HM corn at 0 to 18 inches from the surface at 240 days post-filling.

	---------- Corn silage ---------		------------ HM corn -----------	
Item	Black plastic	OB film	Black plastic	OB film
DM content, %	29.2	31.6	72.3	73.2
pH	4.28	3.78	4.70	4.09
Estimated OM loss[1,2]	27.3	8.4	12.6	7.2
	----------------------- % of the silage DM ----------------------			
Lactic acid	2.7	6.8	0.86	1.08
Acetic acid	2.6	2.2	0.25	0.31
Ash	11.2	9.1	2.10	1.98

[1] Values are estimated additional spoilage loss of OM, which were calculated from ash content using the equations described by Dickerson et al. (1992a).

[2] Ash content of the face samples was 8.4% for the corn silage and 1.85% for HM corn.

Nutritional Value and Economic Impact of Surface-spoiled Corn Silage

Nutritional value of surface-spoiled corn silage. A single source of irrigated corn was harvested at 80% milk line and chopped to 3/8-inch theoretical length of cut (Whitlock et al., 2000). Three pilot-scale bunker silos, which were 3 ft deep, and a 30-ft section of a 9-ft diameter AgBag® (normal silage) were filled with alternating loads of chopped forage. The bunkers were left unsealed for 90 days post-filling and then sealed with a single sheet of polyethylene (surface-spoiled silage). Four rations, which contained 90% silage and 10% supplement on a DM basis, were fed to 12 steers fitted with ruminal cannulas. The proportions of silage in the rations were: A) 100% normal, B) 75% normal: 25% spoiled; C) 50% normal: 50% spoiled, and D) 25% normal: 75% spoiled.

The amount of the original top 18-inch and bottom 18-inch layers in the composite surface-spoiled silage was 24 and 76%, respectively. The original top 18-inch layer was 7 inches thick and visually typical of an unsealed surface where the silage had undergone several months of exposure to air and rainfall. It had a foul odor, was black in color, and had a 'slimy', mud-like texture. Its extensive deterioration was reflected in very high pH (8.22) and high ash and fiber values. The original bottom 18-inch layer was 15 inches thick and had an aroma and appearance associated with very wet, high-acid corn silage, i.e., a bright yellow color, a low pH (3.67), and a very strong vinegar smell.

The addition of surface-spoiled silage had large negative associative effects on DM intake and OM, NDF, and ADF digestibilities (Table 7). The first 25% increment of spoilage had the greatest negative impact. When the rumen contents were evacuated, the spoiled silage had also partially or completely destroyed the integrity of the forage mat. The results clearly showed that surface-spoiled silage reduced the nutritive value of corn silage-based rations more than was expected.

Table 7. Effect of the level of surface-spoiled corn silage in a growing ration on DM intake and nutrient digestibilities.

	Ration			
Item	A (0) [1]	B (5.4%)[1]	C (10.7%)[1]	D (16.0%)[1]
DM intake, lbs per day	17.5^{a}	16.2^{b}	$15.3^{b,c}$	14.7^{c}
	------------------------- Digestibility, % -------------------------			
OM	75.6^{a}	70.6^{b}	69.0^{b}	67.8^{b}
CP	74.6^{a}	70.5^{b}	68.0^{b}	62.8^{c}
NDF	63.2^{a}	56.0^{b}	52.5^{b}	52.3^{b}
ADF	56.1^{a}	46.2^{b}	41.3^{b}	40.5^{b}

[1] Amount of the original top 18-inch layer of silage in the ration (DM basis).

^{a,b,c}Means within a row with different superscript differ ($P<.05$).

Economic impact of feeding surface-spoiled corn silage to growing cattle. The predicted combined effects of silage management and feeding practices associated with producing and feeding surface-spoiled corn silage in beef cattle backgrounding or dairy heifer growing operations are presented in Table 8. The cattle in this example had an average weight of 650 lbs, the ration contained 87.5% corn silage (DM basis), and the live weight price of the cattle was $1.10 per pound. Rations B, C, and D contained 2.7% ‘slime’, surface-spoiled silage, which was 50% of the lowest level fed in the study above (Table 7). Ration E contained 5.4% slime. The estimated NEg values used for the five corn silages ranged from 0.45 to 040 Mcal per lb (DM basis); silage DM recoveries, from 87.5 to 77.5% of the crop ensiled; and DM intakes, from 17.0 to 16.0 lbs per day.

Table 8. Economic impact of creating and feeding surface-spoiled corn silage to growing cattle[1, 2]

Item	Ration and silage management combinations				
	A	B	C	D	E
Amount of ‘slime’, surface-spoilage in the ration, % on a DM basis	0	2.7	2.7	2.7	5.4
Corn silage NEg , Mcal per lb of DM	0.45	0.45	0.425	0.425	0.40
DM recovery, % of the crop ensiled	87.5	87.5	82.5	77.5	77.5
Dry matter intake, lbs per day	17.0	16.5	16.5	16.5	16.0
Avg daily gain, lbs	2.25	2.12	2.00	2.00	1.75
DM per lb of gain, lbs	7.55	7.80	8.25	8.25	9.15
Silage per lb of gain, lbs as-fed[3]	19.85	20.5	21.65	21.65	24.05
Gain per ton of crop ensiled, lbs	88.2	85.4	76.2	71.6	64.4
Lost gain per ton of crop ensiled, lbs	---	2.8	12.0	16.6	23.8
Value of lost gain per ton of crop ensiled, $	---	3.08	13.20	18.26	26.18

[1] Adapted from Whitlock et al. (2000).

[2] Assumes an average cattle weight of 650 lbs and a live weight price of $1.10 per pound.

[3] Assumes silage is 87.5% of the ration on a DM basis, and the silage is 33.3% DM.

Combination B assumed that only DM intake was affected by feeding the slime and this produced 2.8 lbs less live weight gain per ton of crop ensiled, and the value of this lost gain was $3.08. Combination C, which assumed that NEg and DM recovery were also negatively affected by the slime, resulted in 12.0 lbs less live weight gain per ton of crop ensiled, which had a value of $13.20. Combinations D and E, which assumed further decreases in either NEg, DM recovery, or DM intake compared to combinations B and C, produced dramatically lower live weight gains per ton of crop ensiled (16.6 and 23.8 lbs, respectively), and much higher values of lost gain per ton of crop ensiled ($18.26 and $26.18, respectively).

Spreadsheet to Calculate the Profitability of Sealing Bunker Silos

Huck et al. (1997) published equations, which could be hand-calculated or incorporated into a computer spreadsheet, to allow producers to estimate the value of silage saved by applying an effective seal on bunker silos and drive-over piles. The authors noted that about 75 percent of the total tons of corn and sorghum silage made in Kansas from 1994 to 1996 were not sealed, and the value of silage lost to surface spoilage was estimated at 6 to 10 million dollars annually.

Presented in Table 9 are examples from a spreadsheet, which was adapted from Huck et al. (1997) by Bolsen et al. (2005), to calculate the profitability of sealing bunker silos and drive-over piles. Data presented in Tables 1 to 4 in this paper can be used as guidelines to estimate the DM losses in the original top 3 feet for sealed and unsealed bunker silos. The return on investment from effective sealing makes it very clear that dairy producers should pay close attention to the details of this ‘troublesome’ practice.

Table 9. Profitability of sealing corn and alfalfa silages in bunker silos.

	Example and silage		
Inputs and calculations	1. corn	2. alfalfa	3. corn
Silage value, $ per ton	30	55	30
Silage density, lbs per cubic ft	45	40	45
Silo width, ft	40	40	85
Silo length, ft	100	100	225
<u>Silage lost in the original top 3 feet:</u>			
unsealed, % of the crop ensiled	50	50	50
sealed, % of the crop ensiled	15	15	15
Labor cost, $ per hr	20	20	20
Cost of the covering sheet, ¢ per square ft	4.0	4.0	4.0
(Allows for a 20 % overlap of the sheets)			
Silage in the original top 3 ft, tons	270	240	1,291
Value of silage lost if unsealed, $ per silo	4,050	6,600	19,364
Value of silage lost if sealed, $ per silo	1,215	1,980	5,809
Sealing cost, $ per silo	560	560	2,678
Value of silage saved by sealing, $ per silo	2,275	4,060	10,877

Note: Numbers in the highlighted squares are producer inputs and user changeable.

Important Steps to Minimize Surface-spoiled Silage in Sealed Bunkers and Piles

Problems can occur in even the best silage program. But regardless of the size of a dairy operation, there are several management practices that are in the producer's control. The practice that is, perhaps, the most poorly implemented is effective sealing of bunker silos and drive-over piles. Here are eight steps that producers and their employees should consider to minimize surface-spoiled silage (Jones et al., 2004 and Bolsen et al., 2005):

1. Achieve a high packing density (minimum of 15 lbs of DM per cubic ft) in the forage within the top 3 feet of the silage surface.

2. Shape all surfaces so water drains off the bunker or pile, and the back, front, and side slopes should not exceed 30 to 35 degrees.

3. Seal the forage surface immediately after filling is finished.

4. Two sheets of plastic or a single sheet of improved oxygen barrier film are preferred to a single sheet of plastic.

5. Overlap the sheets that cover the forage surface by a minimum of 4 to 6 feet.

6. The sheets should reach at least 4 to 6 feet off the forage surface around the entire perimeter of drive-over piles.

7. Put uniform weight on the sheets over the entire surface of a bunker or pile, and double the weight placed on the overlapping sheets. For many years, full-casing discarded tires were the norm for anchoring bunker silo covers. These waste tires are cumbersome to handle, messy, and standing water in full-casing tires can help spread the West Nile virus, which is another reason to avoid using full-casing tires on dairy farms.

- Bias-ply truck sidewall disks, with or without a lacework of holes, are the most common alternative to full-casing tires.
- Sandbags filled with pea gravel are another effective means of anchoring the overlapping sheets, and sandbags provide a heavy, uniform weight at the interface of the sheets and bunker walls.
- Sidewall disks and sandbags can be stacked, and if placed on pallets, they can be moved easily and lifted to the top of a bunker wall when the silo is being sealed and lifted to the top of the feedout face when the covering materials are removed.
- A 6- to 12-inch layer of sand or soil or sandbags are an effective way of anchoring sheets around the perimeter of drive-over piles.

8. Prevent damage to the sheets during the entire storage period.

- Mow the area surrounding a bunker or pile and put up temporary fencing.
- Regular inspection and repair is recommended but extensive spoilage can develop quickly when air and water penetrate the silage mass.

Summary

One hundred and twenty seven bunkers and piles were sampled at three locations across their width and depth, and loss of OM from surface-spoiled silage was estimated by using ash content as an internal marker. Silos sealed with a single sheet of plastic had lower spoilage losses in the top 3 feet than unsealed silos, and sealing reduced OM loss in the 0 to 18-inch depth by an average of 28 percentage units, and in the 18 to 36-inch depth by 7 percentage units.

Whole-plant corn and forage sorghum silages were stored in small, 4-ft deep bunker silos for 180 days, and DM loss and *in-situ* DM digestibility measured at three depths from the original silage surface. Unsealed silages in the top 0 to 20 inches had extensive deterioration and applying a single sheet of polyethylene weighted with tires decreased DM losses dramatically. Placing a roof over the unsealed bunkers silos increased the DM content of the silages, especially in the top 20 inches, but it did not consistently affect the storage efficiency or silage quality compared to unsealed, no roof bunkers.

Research showed that a 7-day delay in applying an effective seal to bunkers and drive-over piles would produce about a 10 percentage unit higher DM loss in the top 0 to 12 inches compared to sealing immediately. In a typical 1,000-ton capacity bunker silo, delayed sealing would result in the loss of 6 to 10 tons of silage compared to sealing immediately after filling is finished.

There are several reasons why the starch-salt matrix sealed with wax would be superior to plastic in reducing surface spoilage. The matrix forms an air-tight seal, and it does not just lay on the surface of the forage similar to plastic. It bonds to the forage particles without creating an air-layer interface. In addition, the salt diffuses into the top 10 to 15 inches of silage and acts as a preservative to prevent the growth of yeast and mold. These qualities allow the starch-salt matrix to meet the first criteria of an alternative cover, which is to provide effective protection from air and water.

All the ingredients in the formulation are GRAS and feed grade, making it totally safe to feed to livestock. The ingredients in the matrix also provide essential nutrients that would be added to the ration, and the cover will blend with the other ingredients in a normal feed mixer. When the edible cover was fed at 2.5% of the ration (DM basis), there was no reduction in DM intake. Seldom would the cover be a higher proportion of the ration because the desired application thickness is 0.5 to 0.75 inches. If the silage in a bunker silo was more than 3 feet deep, the edible cover would be less than 2.5% of the silage and edible cover mixture.

Ease of application is the focus of much of the current research at the University of Illinois. Application would be done on a custom operation basis, or where the equipment was rented from a local feed supplier. The dry ingredients would be delivered in bulk and loaded into a feed mixing truck. Water would be added to achieve the desired consistency and then the edible cover material unloaded into a spreader, which would be mounted on a tractor or low profile vehicle.

Most of the cost of the original ingredients would be recovered when they are fed, so application is the main cost that must be recovered through reduced surface spoilage. Although there are significant issues that must be solved, progress has been made in developing an edible bunker cover that would help dairy producers manage bunker silos and drive-over piles more efficiently.

The discarding of surface-spoiled silage from bunker silos and drive-over piles is not always a common practice on dairy farms. However, research reported in this paper clearly showed that surface spoilage reduces the nutritive value of corn silage-based rations far more than would be expected. The economic impact of creating and feeding surface-spoiled corn silage to growing cattle could cost the producer as much as 15 to 25 dollars per ton of crop ensiled.

An Excel spreadsheet was introduced, which incorporates research data and individual farm inputs, to estimate the profitability of sealing bunker silos and drive-over piles. The return on investment from effective sealing makes it obvious that dairy producers should pay close attention to the details of this practice. Finally, eight important steps, which can help minimize surface-spoiled silage, are discussed.

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