WHAT'S NEW IN SILAGE MANAGEMENT?

B. J. Holmes[1] and K. K. Bolsen[2]
[1]*University of Wisconsin-Madison, Madison, WI 53706, U.S.A. Email: bjholmes@wisc.edu*
[2]*Kansas State University, Manhattan, KS 66506, U.S.A. Email: keithbolsen@hotmail.com*

INTRODUCTION

At the Forage Conservation in the '80s Conference, Zimmer (1980) concluded that the gaps between "proven technology" and "real efficiency" of silage programs on the farm too often were too wide. Almost 30 years later, the silage industry is still faced with the challenges of implementing silage technologies, both old and new. A large segment of this industry is described as the "Silage Triangle". The persons responsible for: 1) the livestock, 2) the forage, and 3) the harvesting process represent the points of the silage triangle. In some beef and dairy operations, one person is responsible for all three points. But in many instances, growing the silage crop and harvesting the crop are done completely on a contract basis, creating situations where a different person is at each point of the triangle. Each person might have different goals and objectives. Where communication between the points of the triangle breakdown, the results can directly affect the efficiency and profitability of each point.

Although a beef or dairy operation's nutritionist, often an outside consultant, is not a direct part of the triangle, he or she has an obvious stake in how well the triangle performs. The nutritionist might be the key person in assuring effective communication between the triangle's three points. The nutritionist's responsibility is generally to the livestock point of the triangle, so among his/her major responsibilities could be: 1) educating the client about proper silage management, and 2) fostering communication. Ideally, the nutritionist might moderate an annual meeting between the cattle manager, the forage grower and the harvesting contractor, making sure all involved are on the "same page" regarding expectations and implementation of the entire silage program. In other cases, a small beef or dairy producer might be on the wrong end of a tight supply/demand situation and lack the economic power to make demands on the forage grower and/or harvesting contractor. Then, the nutritionist must focus on the beef or dairy producer, and make sure things directly under the producer's control are done correctly.

A well-trained and organized silage team is the key to narrowing the gap described by Zimmer by eliminating problems that can occur in almost every silage program (Bolsen and Bolsen, 2006). Several silage management recommendations and decision-making tools available to the silage triangle and silage industry are presented and discussed in this paper.

RENEWED EMPHASIS ON SAFETY

Few farming operations invite as many different opportunities for injury or fatality as a silage program. From harvesting the forage in the field, transporting it to the farm, placing it into storage, and then feeding out the silage, employees are exposed to numerous serious risks (Murphy 1994). Silage-related tragedy knows no age boundary as workers and bystanders of all ages have been injured or killed during silage harvest and feedout (Murphy and Harshman, 2006). Although silage injury statistics are not easily collated, countless stories of PTO and harvesting machine entanglements, highway mishaps between farm equipment and automobiles, entanglement in self-unloading wagons and blowers, and encounters with silo gas exist (Murphy, 1994). Increasingly, stories involve bunker silos and drive-over piles (Murphy and Harshman, 2006; Murphy, 2007; Ag Weekly, 2008; and Bolsen and Bolsen, 2009). Consistently protecting employees, equipment, and property throughout harvesting, filling, and feeding does not occur without thought, preparation, and training. The silage industry has nothing to lose by practicing safety: it has everything to lose by not practicing it (Murphy and Harshman, 2006). Presented here are five major hazards involved with managing silage in bunker silos and drive-over piles, and the primary ways these hazards can be eliminated, reduced, or controlled.

Tractor or truck roll-over

Roll-over protective structures (ROPS) create a zone of protection around the tractor operator. When used with a seat belt, ROPS prevent the operator from being thrown from the protective zone and crushed by the tractor or equipment drawn by the tractor. A straight drop from a concrete retaining wall is a significant risk, so never fill higher than the top of a wall. Sight rails should be installed on above ground walls. Lights should be added to the rail if filling occurs at night. Always form a progressive wedge of forage when filling bunkers or piles. The wedge provides a slope for packing, and a slope shallower than 3 to 1 minimizes the risk of a tractor roll-over. Backing up the slope can prevent roll backs on steep slopes. Use low-clearance, wide front end tractors equipped with well lugged tires to prevent slipping and add weights to the front and back of the tractors to improve stability. If using front-end loaders to move forage into the bunker or pile, do not carry the bucket any higher than necessary to keep the center of gravity low. When two or more pack tractors are used, establish a driving procedure to prevent collisions. Dump trucks can roll over on steep forage slopes, particularly if the forage is not loaded and packed uniformly. Raise the dump body only while the truck is on a firm surface.

Entangled in or run-over by machinery

Keep machine guards and shields in place to protect the operator from an assortment of rotating shaft, chain and v-belt drives, gears and pulleys, and rotating knives on forage harvesters, wagons, and silage feeding equipment. Keep non-workers away from traffic areas, and never allow people on foot (especially children) in or near a bunker or pile during filling or feedout. Adjust rear view mirrors on tractors and trucks and install back-up warning alarms.

Fall from height

It is easy to slip on plastic when covering or uncovering a bunker or pile, especially in wet weather. Standard guardrails should be installed on all above ground level walls. Use caution when removing plastic, tires, or pea gravel bags near the edge of the feedout face, and never stand on top of a silage overhang, as a person's weight can cause it to collapse. Where necessary, use equipment operating from the ground to remove spoiled silage from the surface of bunker silos and drive-over piles.

Crushed by an avalanche/collapsing silage

The authors believe a major factor contributing to injury or fatality from silage avalanche/collapsing silage is over-filled bunker silos and drive-over piles. A dairy nutritionist almost lost his life the day he took silage samples from a bunker silo with a 30-ft high feedout face (Schoonmaker, 2000). "Even though I was standing 20 ft from the feedout face, 12 tonnes of silage collapsed on me. I did not see or hear anything. I had been in silage pits hundreds of times, and you just become kind of complacent because nothing ever happens. It just took that one time". A nutritionist had a near miss (Bolsen and Bolsen, 2009). "I was taking a core sample at one of our large dairy customers and had just moved away from the face when a large section just fell off. This was a very well packed silo and had immaculate face management". Avalanche/collapsing silage does not have to happen. Bunkers and piles should not be filled higher than the unloading equipment can reach safely, and typically, an unloader can reach a height of 3.5 to 4.5 meters. Use proper unloading technique that includes shaving silage down the feedout face and never "dig" the bucket into the bottom of the silage. Undercutting, a situation that is quite common when the unloader bucket cannot reach the top of an over-filled bunker or pile, creates an overhang of silage that can loosen and tumble to the floor. Never allow people to stand near the feedout face, and a rule-of-thumb is never stand closer to the feeding face than three times its height. Fence the perimeter of bunker silos and drive-over piles, and post a sign, "Danger: Do Not Enter. Authorized Personnel Only". When sampling silage, take samples from a front-end loader bucket after it is moved to a safe distance from the feedout face.

Complacency

Think safety first! Even the best employee can become frustrated with malfunctioning equipment and poor weather conditions and take a hazardous shortcut, or misjudge a situation and take a risky action (Murphy, 1994). Here is one example cited in Bolsen and Bolsen (2009). "The accident happened on June 14, 1974 while making silage at Kansas State University's Research Farm. The blower pipe plugged for about the eighth time that afternoon, and I started to dig the forage out from the throat of the blower. The PTO shaft made one more revolution. Zap! The blower blade cut off the ends off three fingers on my right hand".

INCREASING HARVEST RATE: IMPACT ON FILLING AND PACKING

For many years, silage making specialists have recommended filling the storage unit as quickly as possible to avoid the effects of precipitation, over-drying of wilted forage, extended periods of crop respiration, and exposure to aerobic decomposition during the filling process. Forage harvesting equipment has been increasing in capacity to meet this need. Self-propelled forage harvester, estimated capacity as a function of machine power, is shown in Figure 1.

Power requirements of 1.97 and 2.47 kW-hr/t were used to develop the upper and lower bounds for the harvest rate (Shinners, 2009). The power values used in developing the graph were obtained from web sites for the four major manufacturers of self-propelled forage harvesters (April, 2009). The harvest rates are the maximum expected under ideal conditions. Factors that would reduce actual capacity are: 1) forage available is limiting due to not bringing enough windrows together to satisfy the throughput capacity of the harvester, 2) transport vehicles limiting by vehicle exchange or not enough vehicles available to present to the harvester, 3) field capacity constrained by small fields, reduced speed due to obstructions or ground surface conditions, and 4) service and maintenance. Even with these possible limitations to achieving full capacity, one can assume forage could be arriving at the storage unit at 75% of these values under certain harvest conditions.

As new harvesters with these high harvest rates are introduced, the harvest/storage team often is not prepared to deliver and pack the forage in the storage unit. Frequently, filling and packing machines for the bunker silos or drive-over piles are insufficient in numbers and weight to get the forage packed to the desired density. Using the spreadsheet of Holmes and Muck (2007b), with the assumptions of 4.3 m sidewall, 5.5 m peak height, 35% dry matter (DM) forage, 0.15 m packing layer thickness, and a harvest rate of 54.4 t As Fed (AF)/hr; a 14.5 t tractor is needed to push and pack the forage to achieve about a 705 kg AF/m^3 density with a porosity of 0.40. The values in Table 1 were developed using the range of harvest rates reduced to 75% of the upper bound of Figure 1 and the above spreadsheet trying to achieve a similar 705 kg AF/m^3 density and a porosity of 0.40. The values in Table 1 suggest current high capacity harvesting can be accommodated when enough tractors of sufficient weight are employed to pack the bunker silo. The bunker must also be of sufficient width to accommodate the numbers of tractors operating safely or more than one bunker must be filled simultaneously to allow the tractors to operate.

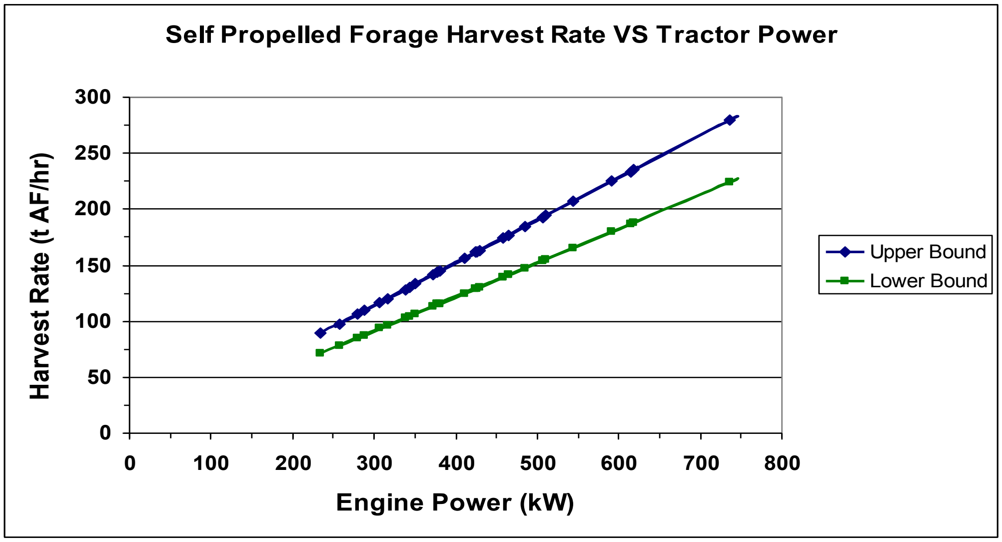

Figure 1. Maximum estimated harvest rate for self propelled forage harvesters based on engine power **(AF = As Fed)**

Table 1. Number of packing tractors required in a bunker silo at different harvest capacities

Harvest capacity (t AF/hr)	Number of tractors	Tractor weight (t/tractor)
89	1	19
193	2	19
225	3/2	17/21
279	3	19

NEW EMPHASIS ON POROSITY

Previously, recommendations for packing in bunker silos and drive-over piles by Holmes and Muck (Holmes, 2006a) have been based on DM density. However, DM density does not account for porosity. Porosity is a measure of the voids between the solid particles of a material. Pore space can be filled with fluids, including gas and/or water in silage. The “air filled” porosity allows gases to move within the material. For gases to move throughout the material, the pores must be continuous. Closed pores do not contribute to gas flow. Figure 2 shows porosity as calculated using the equations of Richard et al (2004). From Figure 2, porosity is most influenced by bulk density (fresh weight density) over the range of DM contents recommended (0.30 to 0.40) for ensiling in bunkers, piles, and bags. Bulk density in silage is affected by the same packing practices as DM density: tractor weight, packing time and spreading layer thickness as well as depth of silage; however, the same packing practices result in a lower bulk density as DM content increases. This trend is the opposite of what occurs with DM density. As forage becomes drier, the porosity increases for the same DM density. Higher porosity allows for increased oxygen infiltration rate with consequent increased DM loss due to aerobic deterioration.

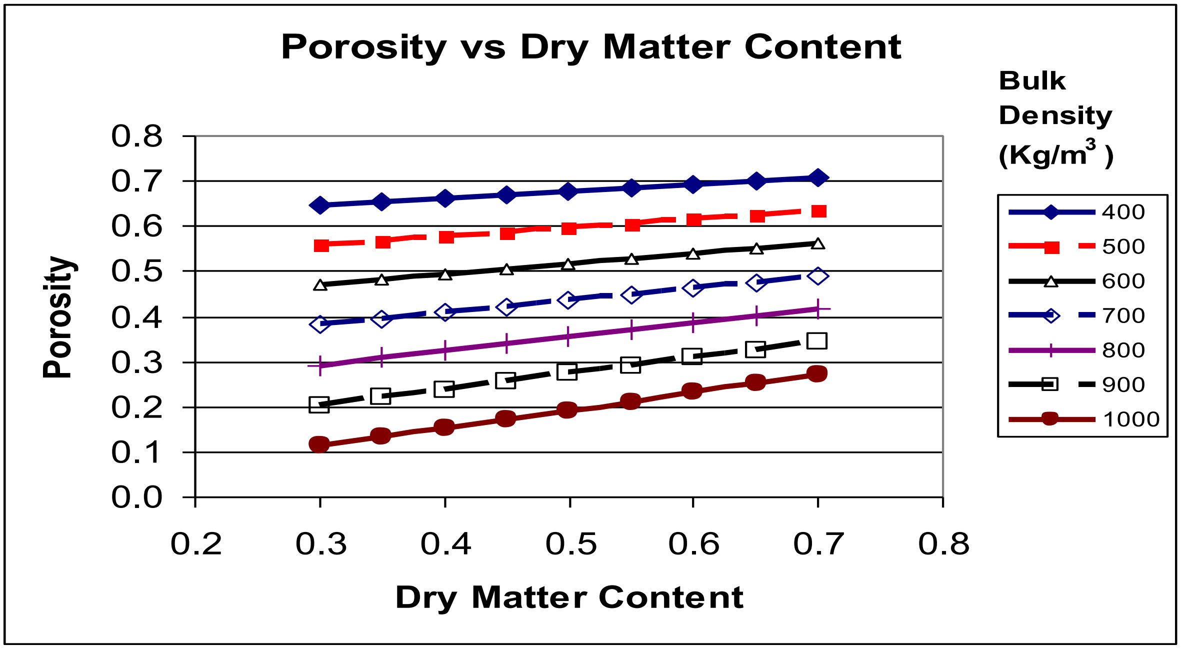

Figure 2. Graph of porosity (decimal) vs. DM content (decimal) for various bulk densities

Thus, Holmes and Muck (2007a) recommended a minimum bulk density of 705 kg AF/m^3 and a maximum porosity of 0.40 as a goal when packing forage in bunker silos and drive-over piles. To reach these goals, forage DM at harvest needs to be in the recommended range of 30 to 40 % and packing effort needs to be adequate. If forage DM exceeds 40%, packing effort needs to be much higher to produce high bulk density and to keep porosity at or below the 0.40 target. In the field, the authors have observed an increase in factors leading to lower bulk density and higher porosity. These factors include the increased harvest rates without increased packing effort mentioned above as well as a trend for field-wilted forages to be harvested drier. Arguments for drier forage at harvest include a desire to avoid a clostridia fermentation, and a desire to increase the DM content of the total mixed ration when other feed ingredients are high in moisture. When field mowing and raking rates exceed harvest rate, drying occurs too fast (drying gets ahead of harvest rate). Whatever the reasons for ensiling forage too dry, the nutrient losses will increase but the recognition of those losses will not occur until sample analyses document the reduced feed quality. Some feed companies and nutritionists are using infrared photography to show the differences in the temperature of silage on the feedout face in bunker silos and drive-over piles. The temperature differences show up as different colors on the infrared photo image. This might be a good troubleshooting tool for producers who experience excessive DM loss or aerobically unstable silage. The multi-colored images might help identify silage management practices that need to be changed/improved.

TECHNOLOGIES FOR PACKING BUNKER SILOS AND DRIVE-OVER PILES

The conventional pushing and packing tractor used in the USA is an agricultural tractor with four wheel drive or front wheel assist and weighted with one or more of: steel wheel weights, front end weights, three-point hitch weight, or liquid in tires weight. Fully weighted tractors are usually in the range of 18 to 23 tonnes. Tractors often use dual wheel arrangements with well lugged tires for good traction. Pushing tractors use tall and wide blades (i.e., bulldozer blades). Some producers have experimented with alternative packing vehicles. Industrial wheel loaders are heavier than agricultural tractors on an equivalent power basis (Figure 3). They are often used for silage feedout from bunker silos and drive-over piles. This makes them prime candidates for alternative packing vehicles. The tires on industrial loaders are not as well lugged

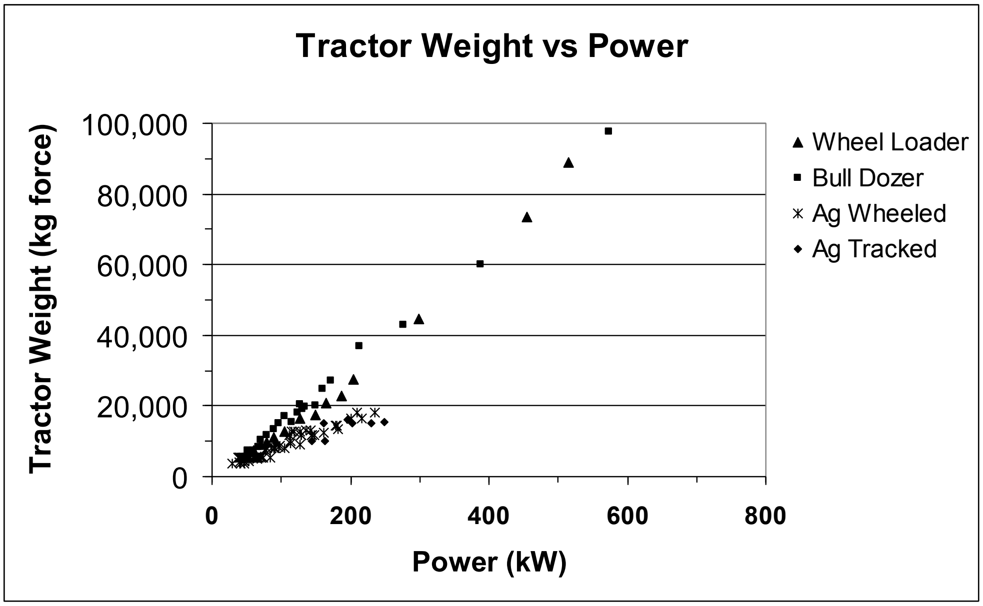

Figure 3. Tractor weight vs power capacity for agricultural wheeled, agricultural tracked, commercial wheel loader, and tracked commercial tractors Caterpillar (1994)

as farm tractors, which allow them to slide more easily on sloped forage surfaces. This makes the operators very uncomfortable about their safety while packing. Tracked industrial bulldozers have been tried by some producers. The naturally heavy weight and some vibration can contribute to good packing. There have been few studies on the effect of bulldozers on silage density. One study by Zhao and Jofriet (1991) reported a density of 874 kg fresh wt/m^3 for 71% moisture whole-plant corn and 822 kg fresh wt/m^3 for 66% moisture whole-plant corn packed with a 21-t bulldozer. Tracked vehicles are likely more stable on wet sloped surfaces than wheel loaders. Some producers have used loaded dump trucks and concrete mixing trucks as packing vehicles. These vehicles might be loaded up to 36 t Gross Vehicle Weight (GVW) on many state highways but on farms they can be loaded up to 45 t GVW with sand, gravel, stone, or concrete. With these kinds of loads, forage could be packed to very high densities. Some concerns about these vehicles are: 1) the failure of bunker silo sidewalls due to loads imposed, 2) the likelihood of roll over due to a high center of gravity, and 3) lack of traction on a sloped forage surface.

Towed packing devices and conventional earth packing machines, including sheep's foot and vibrating smooth rollers, have been used by some producers in an effort to increase silage density. Spanjer (2009) offers a three-point hitch mounted wheeled roller (Spanjer Impact Silage Packer). The authors are not aware of research on the effect of these machines and devices on the density of various ensiled forages compared to convention packing vehicles. The distributed loading of the roller machines might limit their effect at depth, and thus the final silage density. Towed equipment might limit ability to pack moving forward and backward. Because the Spanjer machine is attached by three-point hitch, it can be operated moving in both directions.

NEW TECHNOLOGIES FOR SEALING BUNKER SILOS AND DRIVE-OVER PILES

From 2004 to 2008 an average of 97.36 million tonnes of whole-plant corn was harvested annually for silage in the USA (United States Department of Agriculture, 2008), and about 82 to 84% of this silage was made in bunker silos and drive-over piles. Bunkers and drive-over piles allow a large percentage of the ensiled material to be exposed to the environment. Although polyethylene sheeting, which is typically weighted with discarded car or truck tires or tire sidewalls, has been the common method used to protect silage near the surface, the protection provided is highly variable and often changes during storage (Bolsen et al., 1993). Many livestock producers are quick to point out that putting tires on plastic is not an activity enjoyed by most farm employees (Ruppel, 1993).

At the XII International Silage Conference, Dagano (1999) introduced an oxygen barrier film (OB film) (http://www.silostop.com) as an alternative to standard black or white on black polyethylene to seal bunker silos. The OB film, which is 45µm in thickness, has dramatically improved the preservation efficiency and nutritional quality of silage within 0.5 to 1.0 m of the surface in bunker silos and drive-over piles.

Wilkinson and Rimini (2002) ensiled ryegrass in steel drum, pilot silos and compared three sealing treatments: 1) a single sheet of 125 µm thick black polyethylene (standard plastic); 2) double sheets of standard plastic; and 3) a single sheet of OB film. At 175 days post-filling, 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 plastic-sealed silos.

Bolsen and Bolsen (2006) compared the OB film, 45 microns in thickness, to standard plastic, 125 micron in thickness, in two field trials conducted with large bunker silos on commercial beef cattle feedlots in the High Plains of the USA. The first trial was with whole-plant corn; the second trial was with high moisture (HM) ground shelled corn. In Trial 1, the OB film and standard plastic were applied to side-by-side, 12.2 m wide x 18.3 m long areas of the bunker surface; in Trial 2, OB film and standard plastic were applied to side-by-side, 39.6 m wide x 18.3 m 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 covered the film below the tires or sidewalls. At about 240 days post-filling, there was virtually no visible discoloration or surface spoilage under the OB film, however there was visible mold and aerobic spoilage under the standard plastic, especially in the top 30 cm of corn silage. The corn silage and HM ground shelled corn in the top 0 to 45 cm under the OB film had better fermentation profiles and lower estimated additional spoilage losses compared to the corn silage and HM ground shelled corn under the standard plastic. Kuber et al. (2008) and Bolsen et al. (2009) compared OB film to standard plastic in three field trials conducted with large drive-over piles of whole-plant corn silage on commercial dairies in California. Representative samples were taken of the pre-ensiled forage. Single sheets of OB film and standard plastic were applied side-by-side on 30 m wide x 12 m long areas of the side and top surfaces of the piles. The two sheets were weighted with discarded car tire sidewalls. A sheet of standard plastic covered the OB film below the tire sidewalls. At about 250 days post-filling, the sealing materials were removed and samples taken at 0 to 15, 15 to 30, and 30 to 45 cm from the surface at four locations across both the side and top of the piles. Results of the trials are shown in Table 2.

Table 2. Effect of standard (Std) plastic and OB film on fermentation, nutritional quality, and estimated loss of corn silage OM at 0 to 45 cm from the surface (Kuber et al., 2008; Bolsen et al., 2009)

	Trial 1		Trial 2		Trial 3	
Item	Std	OB film	Std	OB film	Std	OB film
DM, %	29.7	31.2	25.2	31.5	22.2	25.5
pH	4.46	3.80	4.97	3.84	5.44	3.80
Est. OM loss, %[1,2]	40.1	31.8	37.8	24.2	41.1	19.0
NDF, % of DM	51.3	48.1	55.8	46.1	61.4	51.7
Starch, % of DM	22.4	25.1	15.3	25.1	11.6	17.5
Lactic acid, % of DM	2.10	3.42	1.32	3.87	1.1	4.7
Acetic acid, % of DM	3.27	5.16	2.15	2.64	2.4	3.5
Ash, % of DM	5.27	4.52	5.77	4.57	8.1	5.6

[1]Estimated OM loss, calculated from ash content using the equations by Bolsen et al. (1993).
[2]Ash content of the pre-ensiled forage was 3.1% in Trial 1, 3.5% in Trial 2, and 4.6% in Trial 3.

There was very little visible discoloration or spoilage under the OB film-sealed area of the piles, however there was visible mold and extensive aerobic spoilage under the standard plastic-sealed area of the piles, particularly between 0 cm and 30 cm from the surface. When averaged across sampling depth, silage on both the side and top of the piles under OB film had better fermentation profiles, higher nutritional quality, and lower ash concentrations than silage under standard plastic. Note the estimated mean loss of OM between 0 and 45 cm was consistently lower with the OB film than the standard plastic in all three trials. The OB film was more effective than standard plastic in preventing the entry of oxygen into the silage during the storage and feedout phases. This effect was observed on both the top (higher DM density) and side (lower DM density) of the piles.

McDonell et al. (2007) reported significantly higher nutritional quality for corn silage within 0 to 0.45 m of the surface in a bunker silo sealed with OB film compared to a bunker sealed with standard plastic. Results from Borreani et al. (2007) showed an improved fermentation quality and lower DM losses for corn silage within 0 to 0.4 m of the surface in bunker silos sealed with OB film compared to standard plastic. The OB film used by Borreani was white-on-black, 125 µm thick, and ultraviolet light-stabilized.

Berger and Bolsen (2006) presented the following eight management practices that are necessary to minimize or eliminate surface-spoiled silage in bunker silos and drive-over piles: 1) Achieve a minimum packing density of 195 to 225 kg DM/m^3 in the top 1 m of silage. 2) Shape all surfaces so water drains off the bunker or pile, and the back, front, and side slopes should not exceed a slope of 3 to 1. 3) Seal the forage surface immediately after filling is finished. 4) Two sheets of plastic or a sheet of OB film and a sheet of plastic or tarpaulin are preferred to a single sheet of plastic. 5) Overlap the sheets that cover the forage surface by a minimum of 1.5 to 2 meters. 6) Arrange plastic sheets so runoff water does not come into contact with silage, and sheets should reach 1.5 to 2 m off the forage surface around the perimeter of a drive-over pile. 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. Sandbags, filled with pea gravel, are an effective way to anchor the overlapping sheets, and sandbags provide a heavy, uniform weight at the interface of the sheets and bunker silo wall. 8) Prevent damage to the sheet or film during the storage period and patch holes with sealing tape as they occur.

Table 3. Economics of sealing corn silage and alfalfa haylage in bunker silos with standard (Std) plastic and OB film[1]

Variables (Numbers in bold are user inputs)	Bunker 1 corn Std plastic	Bunker 2 corn OB film	Bunker 3 alfalfa Std plastic	Bunker 4 alfalfa OB film
Silage value, $/tonne	**44.00**	**44.00**	**66.00**	**66.00**
Silage density in top 0.9 m, kg/m^3	**624**	**624**	**576**	**576**
Silage density below top 0.9 m, kg/m^3	**768**	**768**	**672**	**672**
Silo depth, m	**3.66**	**3.66**	**3.66**	**3.66**
Silo width, m	**12.2**	**12.2**	**12.2**	**12.2**
Silo length, m	**45.7**	**45.7**	**45.7**	**45.7**
Silage lost in the original top 0.9 m:				
unsealed, % of the crop ensiled[1]	**50**	**50**	**50**	**50**
sealed, % of the crop ensiled[1]	**20**	**10**	**20**	**10**
Cost of covering sheet, ¢/m^2	**50.0**	**140.0**	**50.0**	**140.0**
Silage in the original top 0.9 m, tonnes	313	313	289	289
Value of silage in original top 0.9 m, $	13,778	13,778	19,076	19,076
Value of silage below original top 0.9 m, $	52,000	52,000	68,250	68,250
Value of silage lost if unsealed, $	6,889	6,889	9,538	9,538
Value of silage lost if sealed, $	2,755	1,378	3,815	1,908
Sealing cost, $	937	1,387	937	1,387
Net value of silage saved by sealing, $	3,196	4,124	4,786	6,243

[1]Values are from the data by Bolsen et al. (1993) and Berger and Bolsen (2006).

Economics of sealing corn silage and alfalfa haylage in bunker silos

An Excel spreadsheet to predict the economics of sealing ensiled forage or HM grain in bunker silos and drive-over piles was developed from research conducted at Kansas State University from 1989 to 1995 and from the original equations published by Huck et al. (1997). Example results from the Excel spreadsheet are presented in Table 3. In a 12.2 m wide x 45.7 m long bunker silo of corn silage**,** which has an average depth of 3.66 m, OB film would save an extra $928 of corn silage in the original top 0.9 m compared to standard plastic. In a similar size bunker silo of alfalfa haylage, OB film would save about $1,457 of haylage in the original top 0.9 m compared to standard plastic. The economics of properly sealing bunkers and piles with standard plastic or OB film makes it clear that producers should pay close attention to the details of this "troublesome" task.

Economic impact of surface-spoiled corn silage

Aerobic spoilage occurs to some degree in virtually all sealed bunkers and piles, but discarding surface-spoiled silage is not always a common practice on the farm (Berger and Bolsen, 2006). Whitlock et al. (2000) determined the effect of surface-spoiled corn silage on the nutritive value of a silage-based ration. The original top 0.9 m of corn silage in a bunker silo was not sealed for 90 days, and the surface-spoilage was fed to steers fitted with ruminal cannulas. The addition of surface-spoiled silage had large negative associative effects on DM intake and organic matter and neutral detergent fiber digestibilities. The first increment of "slimy" spoilage (5.4% of the ration on a DM basis) had the greatest negative impact. Rumen evacuation revealed spoiled silage severely damaged the integrity of the forage mat. The results clearly showed surface spoilage reduced the nutritive value of corn silage-based rations more than expected. Bolsen et al (2009) reported the predicted combined effects of silage management and feeding practices associated with surface-spoiled corn silage in a growing cattle operation based on the data of Whitlock et al. (2000). The rations in the example contained 0 to 5.4% "slimy", surface-spoiled silage on a DM basis, and the estimated NEg of the rations ranged from 0.9 to 1.0 Mcal/kg (DM basis). The DM intake ranged from 7.26 to 7.70 kg per day, and silage DM recovery ranged from 77.5 to 87.5% of the crop ensiled. When only DM intake was affected by feeding "slime", the predicted live weight gain per tonne of crop ensiled was decreased by 1.4 kg, and the value of the lost gain was $3.64. In a worst case scenario, which assumed DM intake, NEg, and DM recovery were all negatively affected by creating and feeding slime, the predicted live weight gain per tonne of crop ensiled decreased by11.9 kg and the value of the lost gain was $30.94.

Silage feedout techniques for bunker silos and drive-over piles

Feeders should maintain a smooth and tight silage feedout face. A smooth face minimizes the surface area of forage particles exposed to oxygen. Reduced oxygen exposure limits aerobic deterioration of the silage between feedout events. Front-end loaders are the predominant equipment for removing silage from bunkers, piles and bags. Operators who scrape down the feedout face or shear off the face with the side of the bucket while driving parallel to the face, can leave a smooth and undisturbed face. Those who jab the bucket into the silage and lift, leave a rough and very disturbed face. Rotating face cutters mounted on arms of a power unit have been gaining use and leave a very smooth and undisturbed face. These face cutters have also been mounted to continuously deliver silage to a feed wagon (largely European machines). Arm extensions or telescoping arms allow facers to operate on taller feedout faces. Where the silage removal equipment can not reach the top of the feedout face, undermining during feedout causes silage overhangs. With sufficient undermining, overhangs eventually collapse as an avalanche, which endangers the operator and anyone working under or on top of the overhang, and leaves a rough disturbed face. Thus bunker silos and drive-over piles should be sized to be no higher than the feedout equipment can reach. Block cutters, developed in Europe, have been introduced to the USA market but have not found applications. The advantage of a block cutter is maintenance of a smooth tight feedout face and the loading of the silage into a transportable form in a one step process. A producer-developed silage face rake has recently been introduced in the USA. This machine leaves a rougher feedout face than a face cutter but it could have a faster removal rate.

SOFTWARE FOR BUNKER SILOS, DRIVE-OVER PILES AND BAG SILOS

Bunker silo, drive-over pile, and bag silo sizing and management can benefit from many mathematical calculations to consider some of the "What if?" scenarios. Numerous spreadsheets are available for download from the Harvest and Storage page of the University of Wisconsin-Extension Team Forage web site: http://www.uwex.edu/ces/crops/uwforage/storage.htm

Bunker silo sizing calculator

This spreadsheet (Holmes, 1998) is designed with three major areas. The first allows the operator to list the number of animals in various groups within the herd and the amount of DM consumed each day for each animal in three hay-crop silage categories and one corn silage category. The section calculates the total quantity of each of the four silages required to feed the herd each day. These values are then entered by the user one at a time into the second (Input) section of the spreadsheet. The user also enters values for storage loss, feeding loss, bulk density, moisture content, removal rate, storage period and maximum bunker silo length. Finally, the results are tabulated in section three (Results) as a listing of bunker silo average dimensions that satisfy the design criteria. A similar spreadsheet (Barnett and Holmes, 2009) uses operator information to determine dimensions of a drive-over pile.

Bunker silo volume and weight calculator

Often the question arises about the quantity of silage in an existing bunker silo. This is usually needed as part of a feed inventory process. In this spreadsheet (Holmes, 2008a), the operator is asked to enter bunker silo dimensions, silage moisture content and DM density. The spreadsheet output includes the DM and as-fed weight and the volume of silage in the bunker silo.

Silage pile capacity and cost calculator

Often the question arises about the quantity of silage in an existing drive-over pile. This is usually needed as part of a feed inventory process. In the spreadsheet (Holmes, 2007a), the user is asked to enter pile dimensions, silage moisture content and DM density. The spreadsheet output includes the silage DM and as-fed quantity in each pile and total quantity of silage.

Average density of silage in storage

This spreadsheet (Holmes, 2005) determines average bulk density and DM density in bunker, pile, bag and tower silos. It uses the principle of weight of silage removed divided by the volume removed to calculate the density. The weight is the sum of weights placed in the feed mixer wagon during feeding. The volume is calculated after the user enters the dimensions of feed removed from the storage. Accuracy is influenced by precision with which weight is recorded and how much feed volume is removed during the test period. Measurement accuracy increases if the test period is greater than 1 week. This method has the possibility of giving more accurate values than the face probing method used by many researchers and nutritionists because the point density can vary quite a bit over the feedout face of a storage unit and the probing method can have inaccurate results if a bore hole is made into a non-representative site on the feedout face. The procedure is also much safer.

Silo bag sizing calculator

This spreadsheet (Holmes, 2007b) determines the number of silo bags and the pad size needed to store them for three hay-crop silage qualities, corn silage, and high moisture ground shelled corn. The user enters the following data: quantity of DM fed to the herd each day for each feed ingredient, DM density, bag diameter, bag length, storage period, distance between bags, pad buffer length on the ends of each bag and the DM loss. Output of the spreadsheet includes:

number of bags for each forage/feed type, quantity of feed DM placed into storage and that removed, and storage pad dimensions.

Bunker silo density calculator

Packing bunker silos to achieve high bulk density is important to limit the silage porosity and subsequently the penetration of oxygen into the silage (Holmes and Muck, 2007a). Also, the higher the density, the greater is the storage capacity of the silo. Thus, higher densities generally reduce the annual cost of storage per tonne of crop by both increasing the amount of crop entering the silo and reducing the loss of nutrients during storage and feedout. Holmes (2006a) summarizes some of the research and field trials related to density achieved in bunker silos and drive-over piles. Some of the field trial findings are: 1) DM density is greater near the bottom of the silage than toward the top. 2) DM density is lower next to the wall than in the center of the bunker or pile. 3) Average DM density is higher for hay-crop silage than for corn silage. 4) Increasing packing tractor weight, number of packing tractors and reducing layer thickness result in increased DM density.

One practical issue is packing time relative to crop delivery rate. Assuming one packs continuously with one tractor throughout filling, packing time per tonne (1 to 4 min/t fresh basis) is high under low delivery rates (<30 t fresh/h) and declines with increasing delivery rate. This result suggests producers using high capacity forage harvesters need to pay particular attention to their packing practices. If a satisfactory density is not being achieved, a silage team can select one or more of the following options to increase bulk density: a) Reduce delivery rate of forage to the bunker or pile; b) Increase depth of forage in the bunker or pile; c) Decrease DM content by allowing a shorter crop field-wilting time; d) Increase average tractor weight by adding more weight to each tractor or replace existing tractors with heavier tractors; e) Add more packing tractors or use heavier rather than lighter tractors so the average weight is not reduced when adding a tractor; f) Reduce packing layer thickness; g) Pack for additional time. Items a. and b. are difficult to accomplish if the harvest and storage are currently being pushed to the limit and the storage is already sized. Items c. to g. are more often within the control of the producer and silage team. When the delivery rate to the bunker or pile is quite high, additional packing tractors will be needed. In a well-packed bunker or pile, all tractor tires pass over the entire packing layer surface at least once. Because density near the wall is frequently lower than toward the interior, pack tractor operators should make additional passes near the walls.

A spreadsheet (Holmes and Muck, 2007a**)** was developed to guide silage teams as they consider how to increase bulk density in bunker silos. User provided inputs include: bunker wall height and peak height, harvest rate, forage DM content, tractor weight, packing layer thickness and percent of filling time each of up to four tractors spend packing. Outputs of the spreadsheet include: an estimate of bulk and DM density following the filling and fermentation phases, maximum achievable bulk and DM density and porosity. Silage teams can use this spreadsheet to try some "what if" scenarios by changing the input variables over which they have control to attempt to reach a desired density and porosity. A similar spreadsheet (Holmes and Muck, 2008**)** can guide silage teams as they consider how to increase bulk density in drive-over piles. Figure 4 was developed using a modified version of the spreadsheet for calculating average density in a bunker silo by Holmes and Muck (2007a). From Figure 4, it is apparent porosity increases with harvest rate and increasing forage DM content. To keep porosity below 0.4, multiple heavy tractors and lower forage DM content are needed when harvest rate is high.

Calculator to determine length of a bunker silo or drive-over pile floor to achieve a given forage layer thickness

Recommendations for many years have included distributing forage in thin layers before packing. Preliminary research by Muck and Holmes (2007) has not confirmed the value of thin layers when packing time per tonne is kept constant. However, when a given weight of forage is distributed in thin layers, each pass of the packing tractor results in more packing time per tonne when the layer is thin than when the layer is thicker. A spreadsheet is available to calculate the

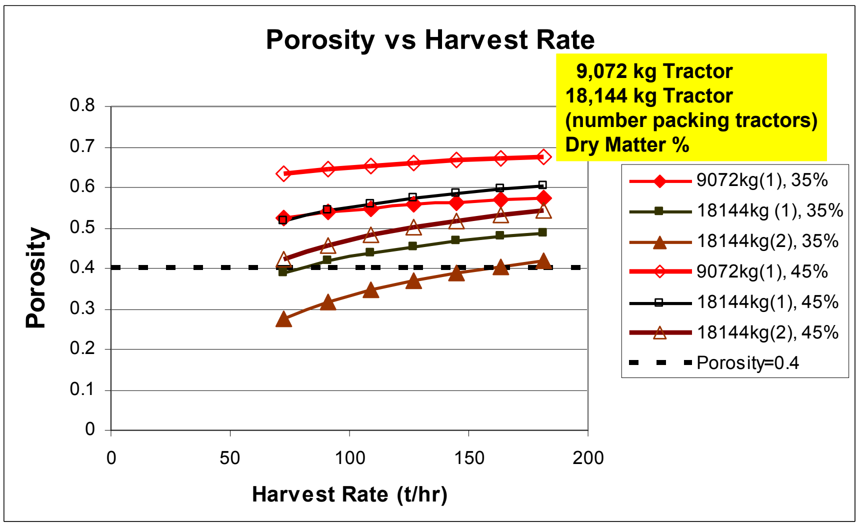

Figure 4. The relationship between porosity, harvest rate, and forage DM content

length of floor needed to achieve a given layer thickness when filling bunker silos and drive-over piles (Holmes 2006b). The user enters: average bunker or pile fill height and width, desired unpacked forage layer thickness, unpacked forage DM density, and transport truck or wagon dimensions. Consider this example for determining the length of the filling slope when one load is pushed onto the filling slope at a layer thickness of 0.15 m:

Example 1.

Assume:

Weight per load = 6804 kg DM/ load = 6.8 tonne/load
Forage density on filling slope = 80.1 kg DM/m^3
Forage DM = 32 %
Packing layer thickness = 0.15 m   Tractor width = 3 m
Bunker height = 3.7 m   Bunker width = 12.1 m
Packing speed = 4.8 km/hr   Tire width per trip = 0.5 m/trip

Packing area = (6804 kg DM/80.1 kg DM/m^3) / (0.15 m) = 566 m^2
Length of packing surface = 566 m^2/12.1 m = 46.8 m (Figure 5)
Packing Trips = (12.1 m -3 m)/0.5 m/trip = 18 trips per pass across the packing surface
Total packing length = 46.8 m/trip x 18 trips = 842 m
Time/pass = 842 m/4800 m/hr = 0.18 hr = 10.5 min = 10.5 min/load

Packing time per tonne = 10.5 min/load/6.8 t DM/load = 1.55 min/t DM= 0.5 min/t AF

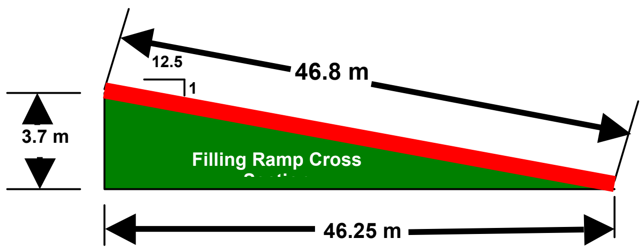

Figure 5. Cross section of progressive filling wedge for Example 1

The more conventional recommendation is to use a 3:1 progressive wedge filling slope. In Example 2, a filling slope ratio of 3:1 is used and the remaining assumptions of Example 1 are used. The resulting layer thickness and the time spent packing that layer for one packing pass is developed in Example 2.

Example 2

Assume: Length of packing surface = 11.6 m
Layer thickness = (6804 kg DM/80.1 kg DM/m^3)/(12.1 m x 11.6 m) = 0.61 m
Total packing length = 11.6 m/trip x 18 trips = 208.8 m
Time/pass = 208.8 m/4800 m/hr = 0.044 hr = 2.6 min = 2.6 min/load
Packing time per tonne = 2.6 min/load/6.8 t DM/load = 0.38min/t DM= 0.12 min/t AF

By selecting the longer filling slope of Example 1, the layer thickness becomes about one fourth that of Example 2, and the packing time per tonne becomes four times larger.

How much value can be saved by implementing good silage management practices?
The answer to this question depends on current practices. If a producer and silage team can be viewed as doing a moderate job of silage management, some savings can be obtained. If on the other hand, large improvements in silage management are needed, much greater savings are possible. To help address this issue, a spreadsheet is available (Holmes, 2008b).

CONCLUSIONS

This paper introduced the concept of the “silage triangle” and the importance of effective communication among the members of the silage “team”. Several silage management recommendations and decision-making tools available to the silage industry were presented, including: safety; harvest rate; packing and sealing technologies for bunker silos and drive-over piles; silage feedout techniques, and software for sizing and managing bunkers, piles, and bags. Regarding safety, it is best to take steps to eliminate or control hazards in advance than to rely upon yourself or others to make the correct decision or execute the perfect response when a hazard is encountered. Only experienced people should be permitted to operate equipment associated with harvesting, filling, packing, sealing, and feeding in a silage program. The ability to harvest forage quickly has put pressure on the filling process and made it more difficult to achieve high density silage. Producers should be prepared to increase tractor weight, add more tractors, and increase the packing time per tonne. The availability of oxygen barrier film and improved sealing techniques has made it possible for a silage team to virtually eliminate visible surface spoilage in bunkers and piles. Correct sizing of bunkers, piles and bags for increased feedout rates, achieving high bulk density, and using proper face management techniques can significantly reduce DM and nutrient losses during feedout. Spreadsheet software is available to assist producers and silage teams to better design and manage bunker silos and drive-over piles.

REFERENCES

Ag Weekly. 2008. S. Idaho dairy slapped with OHSA fine. Web site accessed 5-06-09. http://www.agweekly.com/articles/2008/06/23/commodities/dairy/dairy49.txt

Barnett, K., and B. J. Holmes. 2009. Silage Pile Dimension Calculator. University of Wisconsin-Extension Team Forage, Harvest and Storage web site[1].

Berger, L. L., and K. K. Bolsen. 2006. Sealing strategies for bunker silos and drive-over piles. Pg. 266-283. *In*: Proc. Silage for Dairy Farms: Growing, Harvesting, Storing, and Feeding. NRAES Publ.181. Ithaca. NY.

Bolsen, K. K., and R. E. Bolsen. 2006. Common silage pitfalls. Penn State Dairy Nutr. Workshop. http://www.das.psu.edu/dairynutrition/education/workshop2006/

Bolsen, R. E., and K. K. Bolsen. 2009. Bunker silo and drive-over piles safety reminders. KSU Silage Team web site, http://www.oznet.ksu.edu/pr_silage

Bolsen, K.K., J.T. Dickerson, B.E. Brent, R.N. Sonon, Jr., B.S. Dalke, C.J. Lin, and J.E. Boyer, Jr. 1993. Rate and extent of top spoilage in horizontal silos. J. Dairy Sci. 76:2940-2962.

Bolsen, K. K., R. Kuber, S. Wigley, and R. E. Bolsen. 2009. Unpublished data. Kansas State University, Manhattan, KS.

Borreani, G., E. Tabacco, and L. Cavallarin. 2007. A new oxygen barrier film reduces aerobic deterioration in farm-scale corn silage. J. Dairy Sci. 90: 4701-4706.

Caterpillar Inc. 1994. Caterpillar performance handbook – 25th Edition. Peoria, IL.

Dagano, L. 1999. Improvement in silage quality by innovative system. In: Proc. 12th International Silage Conf. Uppsala, Sweden (Ed. T. Pauly). Pg. 296-297.

Holmes, B. J. 1998. Bunker Silo Sizing. University of Wisconsin-Extension Team Forage, Harvest and Storage web site[1].

Holmes, B. J. 2005. Average Density of Silage in Storage. University of Wisconsin-Extension Team Forage, Harvest and Storage web site[1].

Holmes, B. J. 2006a. Density in Silage Storage. Silage for Dairy Farms: Growing, Harvesting, Storing, and Feeding (NRAES-181). Ithaca, NY: Natural Resource, Agriculture and Engineering Service.

Holmes, B. J. 2006b. Calculator to Determine Length on Bunker/Pile Silo Floor to Achieve a Given Forage Layer Thickness. University of Wisconsin-Extension Team Forage, Harvest and Storage web site[1].

Holmes, B. J. 2007a. Silage Pile Capacity and Cost Calculator. University of Wisconsin-Extension Team Forage, Harvest and Storage web site[1].

Holmes, B. J. 2007b. Silo Bag Sizing Calculator. University of Wisconsin-Extension Team Forage, Harvest and Storage web site[1].

Holmes, B. J. 2008a. Calculate the Volume and Weight in a Bunker silo. University of Wisconsin-Extension Team Forage, Harvest and Storage web site[1].

Holmes, B. J. 2008b. Determine the Value of Good Silage Management. University of Wisconsin-Extension Team Forage, Harvest and Storage web site[1].

Holmes, B. J., and R. E. Muck. 2007a. Packing bunkers and piles to maximize forage preservation. Sixth International Dairy Housing Conference. ASABE. St. Joseph, MI.

Holmes, B. J., and R. Muck. 2007b. Spreadsheet to Calculate the Average Silage Density in a Bunker Silo. University of Wisconsin-Ext. Team Forage, Harvest and Storage web site[1].

Holmes, B. J., and R. Muck. 2008. Spreadsheet to Calculate the Average Silage Density in a Silage Pile. University of Wisconsin-Extension Team Forage, Harvest and Storage web site[1].

Huck, G. L., J. Turner, M. K. Siefers, M. A. Young, R. V. Pope, B. E. Brent, and K. K. Bolsen. 1997. Economics of sealing horizontal silos. KS Agric. Exp. Sta. Rpt. of Prog. 783:84.

Kuber, R., K. K. Bolsen, S. Wigley, M. Wilkinson, and R. E. Bolsen. 2008. Preservation efficiency and nutritional quality of maize sealed in large pile silos with an oxygen barrier film or std. polyethylene. In: Proc. 13th Int. Conf. on Forage Cons. Nitra, Slovakia. Pg. 87-88.

McDonell, E. E., C. M. Klingerman, R. J. Schmidt, W. Hu, and L. Kung, Jr. 2007. An evaluation of two methods to cover bunker silos to maintain the nutritive value of silage. J. Dairy Sci. 90 (suppl.): 975.

Muck, R. E., and B. J. Holmes. 2007. Bunker Silo Management: Spreading Layer Thickness and Plastic Film Effects. Power Point Presentation. ASABE Annual Meeting. Unpublished ASABE Paper 071025.

Murphy, D. J. 1994. Silo filling safety. Fact sheet E-22. Agric. and Biol. Engineering Dept., The Pennsylvania State University, University Park, PA.

Murphy, D. J. 2007. It's dangerous in those bunkers. Agriculture Safety and Health News. Agric. And Biol. Engineering Dept., Volume 18, Number 2. March/April (D. Murphy Editor). The Pennsylvania State University, University Park, PA.

Murphy, D. J., and W. C. Harshman. 2006. Harvest and storage safety. Pg. 171-187. In: Proc. of Silage for Dairy Farms: Growing, Harvesting, Storing, and Feeding. NRAES Publ. 181. Ithaca, NY.

Richard, T. L., A.H.M. Veeken, V. de Wilde, and H.V.M. Hamelers. 2004. Air-filled porosity and permeability relationships during solid-state fermentation. Biotechnology Progress. 20: 1372.

Ruppel, K. A. 1993. Management of bunker silos: opinions and reality. In: Proceedings of Silage Production: From Seed to Animal. Pg. 266-273. NRAES Publ. 67. Ithaca, NY.

Savoie, P. 1988. Optimization of plastic covers for stack silos. J. Agric. Eng. Res. 41:65-73.

Schoonmaker, K. 2000. Four ways to be safe around silage. Dairy Herd Mngt. October 2000.

Shinners, K. 2009. Personal communication. Biological Systems Engineering Dept., Univ. of Wisconsin-Madison.

Spanjer (2009). Spanjer web site accessed 4-19-09. http://www.spanjermachines.com/

Whitlock, L. A., T. Wistuba, M. K. Siefers, R. Pope, B. E. Brent, and K. K. Bolsen. 2000. Effect of level of surface-spoiled silage on the nutritive value of corn silage-based rations KS Agric.Exp. Sta. Rpt. of Prog. 850:22.

Wilkinson, J. M., and R. Rimini, 2002. Effect of triple co-extruded film on losses during the ensilage of ryegrass. In: Proc. 13th International Silage Conf., Auchincruive, Scotland (Ed. L Gechie and C. Thomas). Pg. 168-169.

Zhao, Q., and J. C. Jofriet . 1991. Structural loads on bunker silo walls: Experimental study. J. Agric. Eng. Res. 50:273-290.

Zimmer, E. 1980. Efficient silage systems. Occasional Symposium of British Grassland Society - Forage Conservation in the '80s Conference, No. 11: 176-194.

[1]http://www.uwex.edu/ces/crops/uwforage/storage.htm