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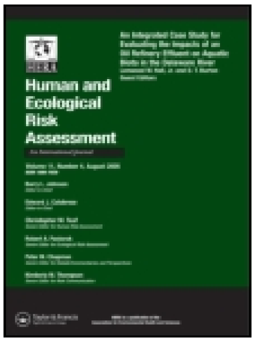

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A Hazard Analysis of Three Silage Storage Methods for Dairy Cattle

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ABSTRACT

Objectives: The study objective was to characterize work methods, hazards and annual hazard exposure hours of three silage storage methods.

Methods: A telephone questionnaire was designed and administered to 24 Wisconsin dairy managers. The exposure durations reported were scaled to a standard-sized dairy herd with equal dry matter tons of silage stored and fed each year.

Results: Managers reported no silo gas hazards with either bunker or bag silos. Compared to tower silos, managers reported reduced fall hazards with bunker silos and no fall hazards with bag silos although both introduced front end loader operation injury hazards. Compared to bunkers, managers who used bag silos reported no exposure to tractor overturns.

Conclusions: Although some hazards are clearly present using any ensling method, dairy farms that adopt silage bag technology can reduce many of the hazards traditionally associated with silage work.

Key Words: agriculture, dairy farming, farmers, injury control, occupational health, safety.

INTRODUCTION

Many beef and dairy operations grow their own forage and ensile large portions of the crop so it can be used later during the winter months (Cromwell *et al.* 1992). The traditional method of ensiling makes use of the familiar tower silo. The work methods associated with traditional tower silo operation have been linked to a

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number of injury risks including falls while climbing, suffocation or asphyxiation from silo gases or silage face collapse, and machinery entanglement during the use or repair of silo loading and unloading equipment (Purschwitz and Skjolaas 1996; Murphy 1992).

In the last 20 years, some Wisconsin dairy farmers have begun to use two different ensiling methods: bunker silos and silage bags. Ensiling in bunkers, and especially bags, compares favorably with tower silos in terms of operating and capital costs and silage quality (Roenfeldt 1998; Josefsson *et al.* 1997; Holmes 1995a,b,c; Rotz 1994; Frank 1991).

We have been unable to locate any studies evaluating or comparing the injury hazard exposures of these three different silage storage methods. Quantifying exposures to traumatic injury hazards involves well-recognized methodological difficulties (Cummings *et al.* 1995; Veazie *et al.* 1994; National Committee for Injury Prevention and Control 1989). In an attempt to quantify and compare exposure to traumatic injury hazards, we interviewed Wisconsin farmers who used these three silage storage methods about associated tasks and hazards and then standardized the reported exposure hours for an example operation with equal silage requirements.

METHODS

Subjects: The location of the study group was Northeastern Wisconsin where dairy operations tended to be larger and more profitable than in the state as a whole (Stephenson and Trechter 1992). We wanted to identify dairy farmers who had experience with one or more types of ensiling and who operated "well run" farms so as the increase the likelihood that the work methods they used were in keeping with generally recognized practices for ensiling. We enlisted a convenience sample of dairy farmers (n = 24) by asking Extension dairy and livestock agents to submit names of operators they felt would be willing to cooperate with the research effort. We requested that the Extension agents refer the names of operators who they knew had experience with one or more of each silage storage method and whom they felt also had well-run, successful operations in general.

Phone Interview Questionnaire And Procedure: We developed a questionnaire intended for telephone data collection based on standardized recommendations (Dillman 1978; 1991). The questionnaire contained items covering operation characteristics, operator demographics, and work activities associated with silage production, loading, feed out and facility maintenance. As part of the interview, operators were asked to estimate the number of hours they spent each season on various tasks. The authors then categorized the types of hazards associated with each set of tasks, which were then used to estimate hazard exposures. The phone interviews were carried out by one of three trained project staff and conducted at times determined to be convenient for the study subjects. The interviews also included some open-ended questions and, in total, required between 20 to 40 minutes to complete. Cooperation by the subject group was very good and no producers refused interviews. For six of the 24 producers (25%), data were collected on-site during a face to face interview using the questionnaire.

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Analysis: To standardize the comparisons in a way that accounted for size differences within the study group, data from each operation were scaled to a herd size of 219 cows (*i.e.,* 1382 dry matter metric tons of silage stored and fed per year). For tower silos this meant an estimated four 24.2 m high silos with diameters of 7.9 m. Similarly, 219 cows were estimated to require 8 bunker silos with dimensions 2.4 m high, 12.1 m wide and 30.3 m long or 32 silage bags 2.4 m in diameter and 45.5 m long. Data reported by each manager were adjusted to reflect the equivalent exposure duration for the standardized 219 cow herd.

The study considered only those hazards presented by operation of the silage storage method from the point when chopped forage wagon loads were made available for loading into the storage structure up to the point where ready-to-feed silage had been extracted from the structure and placed into the delivery vehicle (usually a feed cart or a mobile feed mixer). In the case of the tower silos, the conveyors and/or the silo unloader were assumed to put feed directly into the delivery vehicle. In the case of silage in bunkers or bags, the study assumed that silage is retrieved with a front-end or skid-steer loader bucket and then placed into the delivery vehicle. The assessment did not consider hazards associated with forage harvesting, forage transport from the field to the storage site, or hazards associated with the final distribution of feed to the cattle. In some cases, the use of larger capacity machinery may have reduced the time needed to accomplish tasks and thereby shortened periods of exposure to hazards. However, we studied actual farms, including the equipment they had on hand.

Fall hazards were grouped by category with moderate falls defined as less than 4.8 m and major falls considered as those from greater than 4.8 m up to as high as 24.2 m.

RESULTS

Demographics: The 24 operations in the study group had an average herd size of 216 cows (See Table 1), well above Wisconsin's average of 53.7 cows (Wisconsin Agricultural Statistics Service 1996). In addition, the average milk yield in the study group operations was 9529 kg/cow/year, considerably higher than the state average of 6949 kg/cow/year. A number of the farm managers used more than one silage storage technology. For example, of the 18 managers with tower silos, 10 also used silage bags and 6 had both tower and bunker silos. The level of operator education, tenure in dairy farming, and milk production were all comparable across silage storage methods although the operations with bunker silos exhibited larger herd sizes.

Costs: Initial start-up and annual operating costs for each method are shown in Table 2. This information was not derived from the questionnaire data and is included for comparison purposes. The figures were derived from estimates of total labor and equipment costs previously developed and published that were associated with the installation and maintenance of each method (Holmes 1994, 1995a,c). The annual storage cost figures in Table 2 include costs associated with feed spoilage and loss during storage. These costs were estimated at 10% for both bags and towers and 13% for bunkers.

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Table 1. Subject group demographics.

	tower silo n=18	bunker silo n=11	silage bag n=12
more than 15 yrs in dairy farming	16 (83%)	10 (90%)	11 (92%)
high school education or greater	82%	78%	83%
milk cow herd size	163 ± 119	334 ± 303	146 ± 114
milk production (kg/cow/yr)	9,759 ± 1,250	9,373 ± 1,040	9,801 ± 1,460

* note: totals are not the simple sum of columns since dairy farmers may use more than one silage storage method on a single operation.

Tower Silo: On many Wisconsin dairy farms, forage is stored in top-unloading tower silos. Tower silos are vertical, cylinder-shaped concrete stave structures, with a typical diameter of 3.6 to 7.3 m and height of 12.1 to 25.5 m (see Figure 1). Annual injury hazard exposures reported by the 18 managers using tower silos scaled to the standard herd size are shown in Table 2. Loading chopped forage into tower silos with a forage blower powered by a tractor with a power take-off (PTO) drive-line involved 188 hours of exposure to machinery entanglement hazards. Fall hazard exposures were experienced while climbing the tower during preparation for filling (8.4 hr.), and while monitoring the loading process when periodic climbing was required to level the forage and clear the loading pipe (4.2 h). For 1 to 3 weeks after loading, silo gas can be produced as a byproduct of the fermentation process. Silo gas can asphyxiate or suffocate employees who enter the silo or surrounding areas where the heavier than air gas can accumulate. Most managers commence feeding out of a tower silo shortly after they finish filling it but avoid entering the silo during this dangerous initial period. Deriving an annual exposure figure in hours for this risk was difficult so the hazard was classed as "present" for tower silos.

When required for feeding (usually twice a day), the ensiled forage was unloaded by the silo unloader machinery suspended on top of the silage mass. The unloader was powered by an electric motor and featured a rotating auger arm and a blower. The unloader augered silage to the center of the silo, blew it to the perimeter and out through one of the 0.6 × 0.6 m doors that ran vertically down one side of the silo. The silage then fell down to ground level through an external chute. The mechanical unloader was remotely controlled and operated from below. Once or twice a week, as silage was unloaded from the silo, the operator needed to climb a ladder on the side of the tower silo inside the unloading chute to open a lower silo door and close the one above, incurring an estimated 7.2 hours annually of fall hazard exposure. Periodically, the operator also needed to climb the silo to main-

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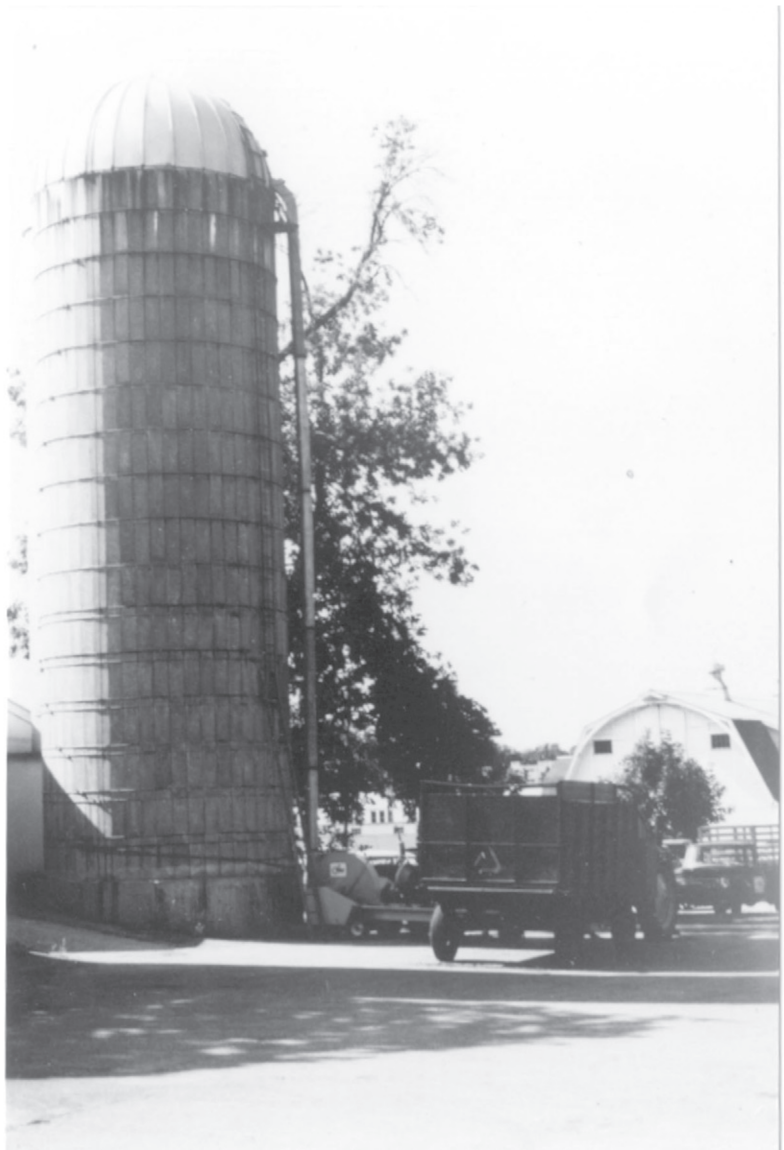

Figure 1. Tower silo: typically 16-30 feet wide and 60 to 120 feet high.

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Table 2. Costs and hazard exposure durations for three silage storage methods on a standard farm*.

	tower silo n=18	bunker silo n=11	silage bag n=12
labor and equipment costs ($ 000)[a]			
initial capital investment	202.3	135.6	54.4
total annual storage cost	53.7	53.0	43.6
annual labor requirements (hrs/yr)[b]	649	1188	864
hazard exposures (hrs/yr)[b]			
major falls	77	0	0
moderate falls	0	81	0
machinery entanglement	209	30	126
tractor overturn	0	349	0
front end loader injury	0	728	728
silo gas	present	none	none
silage face collape	none	present	none

*note: for example farm with 219 cows; 1,382dry matter metric tons of silage stored and fed each year; equal to 4 tower silos @ 7.9 m diameter by 24.4 m high, or 8 bunker silos @ 12.1 m wide x2.4 m high by100'long, or 32 bags @2.4 m diameter by45.5 m long.

[a] based on field data and model in Holmes (1995a).
[b] based on telephone interview data.

tain and adjust the unloader, which involved both fall (57 h) and machinery entanglement (20.8 h) hazard exposures.

Bunker Silo: Bunker silos are less widely used than tower silos in Wisconsin (Roenfeldt 1998). Bunkers are large, concrete, open-top boxes on or below ground level that typically feature a floor and walls on two or three sides. Each bunker compartment or bay is usually 6.1 to 12.1 m wide and may be 18.2 to 30 m long (see Figure 2). To fill a bunker silo, wagon loads of chopped forage were mechanically unloaded onto the concrete pad and distributed with a tractor with a front blade (or front-end loader), forming a pile inside the bunker. This procedure involved 30.1

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Table 3. Tasks, exposure types, and durations for three silage storage methods (in person hours/year*).

tower silo:	task duration	major falls	moderate falls	machinery entanglement
filling				
1. prepare silo for filling	8.4	8.4		
2. operate forage blower	188.0			188.0
3. monitor/manage filling	4.2	4.2		
unloading				
4. prepare silo for unloading	7.2	7.2		2.2
5. monitoring and maintenance	27.9	27.9		7.0
6. non-routine work at unloading level	29.1	29.1		11.6
7. operate loader and conveyors	384.0			
total	648.8	76.8	00.0	208.8
bunker silo:				
filling				
1. unload forage wagon	30.1			30.1
2. operate packing tractor	349.4			
3. apply plastic & tires	59.6		59.6	
unloading				
4. remove tires and roll back plastic	18.6		18.6	
5. remove spoilt silage	2.5		2.5	
6. operate unloader	728.0			
total	1188.0	00.0	80.7	30.1
silo bagging:				
filling				
1. unload forage wagon/run bagging machine	126.0			126.0
2. seal bag after filling	8.5			
unloading				
3. open bag to start unloading	1.6			
4. operate unloader	728.0			
total	864.1	00.0	00.0	126.0

* note: for example farm with 219 cows; 1,382dry matter metric tons of silage stored and fed each year; equal to 4 tower silos @ 7.9 m diameter by 24.4 m high, or 8 bunker silos @ 12.1 m wide x2.4 m high by100'long, or 32 bags @2.4 m diameter by45.5 m long.

hr. of machinery entanglement hazard from the forage wagon's power take-off unloader. The forage was then compacted by driving a heavy tractor back and forth repeatedly on top of the pile, which presented tractor overturn risks (349 h). Forage was stored up to or above the height of the sidewalls (2.4 to 4.8 m high). After packing, the employee worked at a 2.4 to 4.8 m elevation to cover the open bunker top with plastic sheeting and placed used truck or automobile tires on the sheeting to hold it in place. Spreading the plastic and placing tires was accompanied by a risk of moderate falls (59.6 h). To unload and use silage, employees needed to periodically climb onto the top of the bunker, remove some of the tires, and pull back the protective plastic covering to expose the silage face. This procedure was associated with moderate fall hazard exposures (18.6 h). Occasionally, spoiled feed at the top

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of the silage face needed to be removed while standing atop the bunker (2.5 h moderate fall exposure). A front-end loader or similar device then scraped off and removed bucket-loads of silage out of the vertical removal face and transferred it to the feed mixer or feed area, which involved 728 h of front end loader injury exposure. During unloading, the bunker silage face may collapse, burying the operator and presenting an entrapment and suffocation risk. Deriving an annual exposure figure in hours for this risk was difficult so the hazard was classed as “present” for bunker silos.

Silage Bagging: Silage bags are the newest silage storage method on Wisconsin dairy farms and are believed to be less common than bunkers, although substantial numbers of farmers have begun to ensile with bags in the last 5 to 10 years. Chopped forage was loaded from forage wagons into a machine (bagger), which compacted the forage, by “stuffing” the material into a wide tube of industrial strength plastic. The bagger was powered by a tractor with a power-take-off driveline and this work involved 126 hours of exposure to machinery entanglement hazards. One end of the plastic tubing was tied off before the loading started. The tubing gradually unfolded on the ground like a sausage as more forage was compacted by the machine and pressed into the tube. Silage bags usually measured 2.4 to 3 m in diameter and 30.3 to 75.8 m long (Figure 3). To unload silage bags, the plastic was cut away from one end to expose the silage face. A skid steer loader then extracted bucket-loads of silage and moved them to the feed area or to a feed mixer. This unloading entailed 728 hours of front end loader hazard exposure.

Figure 2. Bunker silo: typically constructed with side walls 8 to 16 feet high. Figure shows a step in the bunker filling process as chopped forage was being spread and compacted, layer by layer, using a tractor.

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Figure 3. **Bag silo: typically 8 to 12 feet wide and 100 to 250 feet long. Figure shows unloading a bag with a skid-steer loader.**

DISCUSSION

Two limitations of this study were our nonrandom selection of interview subjects and our reliance on farmer self-reports to estimate hours spent on various ensiling tasks each year. Our results may underestimate hazard exposures during ensiling because we limited our interviews to dairy farmers with well run, successful operations. Our reliance on self-report to determine the amount of time spent on various tasks was less exact than having an independent observer collect the data during controlled field studies. However, we did not have the resources required to conduct detailed field observations continuously over the course of an entire season on dozens of operations. There may also be other hazards beyond those we focused on in this paper (*e.g.,* injuries to helpers or bystanders, ergonomic risks, hazards associated with or exacerbated by extreme weather). Furthermore, there may be engineering approaches that are capable of mitigating hazards but we do not present that information in this paper. Additional research on ensiling hazards to remedy these limitations is warranted.

In our assessment, we determined that silage bag technology did not involve any elevated work or fall hazards. The fall hazard exposures associated with bunkers (63 h per yr.), although greater in terms of total time than tower silos (31 h per yr.), were considered moderate falls since they were from a considerably lower elevation (up to 2.4 to 4.8 m) compared with the tower silo fall hazard exposures (as high as 24.2 to 27.3 m).

Tower silos were the only method involving dangerous exposures to silo gas and they are, by definition, a confined space. Although silo gas is not entirely eliminated

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with either bag or bunker silos, hazardous exposures are far less likely because of ambient ventilation. You could conceivably create a silo gas hazard but a sequence of clear management failures would be required. Bunkers were the only method involving exposures to tractor overturn hazards (during the 349 h per yr. needed to pack silage down). Bags and bunkers both required exposures to front end loader injury hazards (728 h per yr.), which tower silos did not.

A change from conventional tower silos to bunker silos would be expected to practically eliminate one hazard (silo gas). It could also reduce two hazards (machinery entanglement and falls from elevation). On the other hand, bunker technology would introduce two additional hazards (tractor overturns and front end loader injuries).

Similarly, a change from tower silos to silage bags could be expected to practically eliminate two hazards (silo gas and falls from elevation). In addition, the change could reduce one other hazard (machinery entanglement) due to the absence of silo unloader machinery. The change in technology would also introduce one additional hazard (front end loader injuries).

In cost comparisons, silage bags had the lowest initial capital investment and the lowest annual cost. However, estimated labor requirements were lowest for tower silos. The annual cost comparison data included labor hours, so bag silos have the overall economic advantage. The conjunction of safety and profit advantages for silage bagging makes it an excellent candidate innovation for public health intervention efforts to reduce agricultural injuries (Josefsson 1997a,b).

While preparing this report, we examined 12 years (1987 to 1998) of previously published data from Wisconsin's registry of fatal occupational injuries associated with production agriculture in an attempt to learn more about typical silage storage fatalities (Purschwitz and Skjolaas 1996). This injury surveillance data must be interpreted cautiously since tower silo technology has been and continues to be the overwhelmingly predominant silage storage method in Wisconsin. On 1988 producer surveys, 7% of dairy farmers reported using silo bags alone or in combination with tower silos and 15% reported using bunker silos. On the 1998 survey, 20% reported using silo bags and 18% reported using bunker silos on their operations (Hoard's Dairyman 1999). For the period examined (1987 to 1998), 28 (5.7%) of 488 farm work related fatalities were attributable to tower silo work, including asphyxiation or suffocations (13), falls (10), and machinery entanglements (5). After accounting for changes in the size of the workforce, the tower silo fatalities amounted to an average annual rate of 2.2 per 100,000. For bunker silos there were five fatalities and most were associated with the collapse of silo walls (n = 2) or a cave in (n = 1) during bunker construction. One death was attributed to being pinned by a silage face collapse and one death was due to asphyxiation after a silage face collapsed and buried an individual. No fatalities were associated with silo bags. Injuries during use of front end or skid steer loaders can include fatalities when operators are crushed between the bucket and frame (Moore and Pratt 1996; CDC 1996). However, we failed to identify any front end loader fatalities clearly associated with silage storage or feeding out in our examination of 1987 to 1998 Wisconsin data.

Recently, we learned of two fatalities associated with silo bags that occurred after our 1987 to 1998 review was completed. In 1999, a Wisconsin farmer was killed while

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unloading a silo bag with a front end loader when he was attempting to disentangle some bag plastic from a wheel and inadvertently activated the control, which dropped the bucket on him. We also learned of a 1999 death of a New Hampshire farmer who was using a fence post to force wet silage into the bagging machine when he became entangled in the machinery.

Conducting and interpreting injury hazard assessments that compare different work methods entail a number of well-recognized difficulties (Cummings *et al.* 1995; Veazie *et al.* 1994; National Committee for Injury Prevention and Control 1989). First, different hazard types are not likely to be interchangeable in either the type or degree of injury they can produce. For example, the average severity of injury produced by a machinery entanglement can differ from the average injury severity associated with a major fall. Similarly, a limb amputation attributable to an entanglement injury is hard to equate with the serious head trauma often suffered after a major fall.

Second, in seeking to reduce hazards and thus overall risk, sometimes offsetting effects are encountered (Kniesner 1997). These are essentially injuries, which occur as a result of efforts made to decrease risk. These can be a risk-risk tradeoff, where a person changes their behavior and causes an injury in a different manner in their lives, such as the increased risk of front end loader injury we found using alternative methods of silage storage. While not all inclusive, we have attempted to identify these offsetting effects where appropriate.

Finally, comparing the number of hours of exposure to different hazard types or to the same hazard type with different work methods can be problematic when there is no good information about the likelihood of injury or death associated with each type of exposure. For example, is 100 hours of tower silo machinery entanglement exposure more or less dangerous than 100 hours of bagging machinery entanglement exposure? There are very few data available on rates of injury per hour of exposure to any agricultural hazard (Doss and Pfister 1974). We could find no information on injury rates with exposure hour denominators specific to any of the silage storage methods we investigated.

The hazard assessment reported in this paper does provide one important data element; the amount of time individuals spent exposed to particular types of hazards associated with three different silage storage methods. We attempted to reduce the difficulties inherent to injury hazard assessment by establishing specific hazard categories and constraining our comparisons between the different storage methods to those that could be made within each specific hazard category. However, our findings must be interpreted cautiously since our categories may not be strictly comparable. As noted above, there may be real differences in injury severity and frequency for 100 hours of machinery entanglement hazard exposure for a tower silo versus a bunker or a silo bag.

In summary, this hazard assessment determined that a change to either bunkers or silage bags has potential to eliminate or substantially reduce several hazards associated with conventional storage in tower silos, while introducing some additional hazards. However, compared with bunkers, silage bag technology goes somewhat further in hazard reduction; falls from elevation and tractor overturns are eliminated. A change to silage bag technology on dairy farms has potential to reduce or eliminate most of the hazards associated with silage work, while introducing only one additional hazard, front-end loader injuries.

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