

SILAGE DENSITY AND DRY MATTER LOSS OF BAG AND BUNKER SILOS

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ABSTRACT

A silo bag study and research knowledge of bunker silo studies done in Southern Wisconsin is the basis of this paper. The objectives of the silo bag study were to measure densities and losses in bag silos made at three research farms and to determine potential factors affecting both. The primary bagging machines were an 8-ft Ag Bag model G6000, a 9-ft Kelly Ryan model DLX shared by two stations, and a rented 9-ft Ag Bag machine. All loads of forage entering the bags were weighed and sampled. At emptying, all silage removed (both good and spoiled) was weighed and sampled. Across 47 bags, dry matter (DM) density ranged from 10 to 16.9 lb/ft³. At all three farms and across crops, DM density increased linearly with DM concentration except with the Kelly Ryan in corn silage where density was constant. Kernel processing appeared to reduce density in corn silage. The bagging machine, operator, and crop also affected average DM densities. Within bags, density was highly variable. Densities at the top and sides were approximately 40% of densities at the bottom, center of the bag. Losses of DM were measured on 24 bag silos and were highly variable (0 to 40%). However, except for six bags with considerable spoilage loss, total losses averaged 11%. Significant spoilage losses were essentially confined to crops ensiled above 40 % DM. Spoilage was also worse in bags fed out in summer. Gaseous and seepage losses were higher at low DM contents and by feeding out at low rates (8 in/d). While more research is needed to study bagging machines with different systems of filling, the current study suggests that pressed bag silos can do an excellent job of preserving a crop provided: 1) crops are ensiled between 30 and 40 % DM, 2) the bagging machine is set up properly to obtain a smooth bag of high density, 3) feedout rates are a minimum of 8 to 15 in/d, and 4) the farmer routinely monitors for and repairs punctures in the bags. A survey of 168 bunker silos in the Midwest showed an average density of 14.8 lbDM/ft³ for haylage, slightly above recommendations. Bunker density dictates DM loss and silo capacity. Factors influencing density of bunker silos are: packing time, weight of packing tractor, thickness of layers, and number of packing tractors. See website <http://www.uwex.edu/ces/crops/uwforage/storage.htm> to calculate factors needed to reach desired DM density in bunker silos.

KEYWORDS. Silage, bag silo, bunker silo, density, losses, corn, alfalfa

INTRODUCTION

Idaho farmers harvested 4 million tons of alfalfa hay during 2003, the 5th largest state production. Annual survey data is not available showing alfalfa harvested for silage or green chop in Idaho. Wisconsin and New York farmers annually harvest approximately 50% of alfalfa forage as silage. The pressed bag silo is an increasingly popular method of making silage. It is relatively inexpensive.

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Storage size varies with the quantity of forage harvested. For farms that are expanding herd size, silo capacity can be added with little capital cost. Small-diameter bags allow small farms to consider making silage rather than hay. Finally, bag silos make it easy for farmers to inventory and manage silage, e.g., reserving high quality silage for the best animals.

While bag silos have been used for more than 20 years, relatively little research has been published on the performance of these silos. Losses are reputedly low with bag silos. Limited research results generally agree with that reputation. Rony et al. (1984) reported a 9.0% dry matter (DM) loss in a alfalfa:grass silage and 6.1% loss in corn silage. Storage time and feed out rate were not reported. Wallentine (1993) reported a 2.5% loss in corn silage also under unspecified conditions. In contrast, Kennedy (1987) found that losses in two bag silos were double those found in bunker silos.

Densities in bag silos are also difficult to obtain. Esau et al. (1990) indicated that wet densities were on the order of 44 lb/ft³. Assuming 35% DM, that would result in a dry matter density of 15 lb/ft³. Harrison et al. (1998) reported considerably lower DM densities for corn silage in 10-ft diameter bags of only 2.7 to 3.2 lb/ft³. Holmes (1998) calculated DM densities based on filling weight records from several farms and reported a range of 9.1 to 15.7 lb/ft³. Most of the bags were either alfalfa or corn silage, and there were no obvious trends with crop or bag diameter.

Overall, there are limited data on losses from bag silos, and the densities reported are highly variable. This makes difficult an accurate economic assessment of bag silos relative to other types. Information on densities and losses is also important to farmers with bag silos relative to feed inventory and management. The objectives of this study were to measure densities and losses in bag silos and to determine potential factors affecting both.

MATERIALS AND METHODS

Three University of Wisconsin Agricultural Research Stations have been making bag silage for several years. At Arlington (Arl) and Prairie du Sac (PDS), bag silage is often made for research studies involving small numbers of cattle. At West Madison (WM), bag silage is made to be re-siled later in small tower silos on the Madison campus. These bag silos are emptied rapidly, typically one-third of a bag in a day, and are resealed between emptying events.

The bagging machine used at Prairie du Sac was an 8-ft Ag Bag model G6000 (AB). The West Madison and Arlington stations shared a 9-ft Kelly Ryan model DLX (KR). This provided us with the opportunity to compare densities from different operators using the same machine. Occasionally, the Arlington station rented a 9-ft Ag Bag machine.

During the 2000 and 2001 harvest seasons, all bag silos made at the three farms were monitored. This consisted largely of alfalfa and corn silages. All loads of forage entering the bags were weighed. While each load was emptied into a bag, a grab sample was taken consisting of a composite of several handfuls. After each load was pressed into the bag, the side of the bag was marked to indicate the distance filled by the load. The distances for each load were measured after the bag was completely filled.

The load samples were analyzed for moisture content by freeze-drying. The remainders of samples were composited by field and date. These composite samples were analyzed for particle-size distribution (ASAE Standards, 2000). At emptying, the weight of all silage removed from a bag was recorded. Any spoiled silage not fed was weighed and specifically identified as such on the emptying log. A grab sample from the face of each silo was taken periodically, one per filling load. Spoiled silage was sampled separately. Samples from emptying were analyzed similarly to the load samples except for particle-size distribution. In addition, the emptying samples were analyzed for pH and fermentation products (Muck and Dickerson, 1998).

Average densities for the bags were calculated based on weight ensiled, overall length, and nominal diameter. Similarly, density variation by load along the bag length was based on individual load weights and the length of bag filled.

Core samples were taken at the face of several bags during emptying to measure density variation across the face. The coring equipment used is described by Muck and Holmes (2000). Up to seven cores were taken per bag, starting at the central vertical axis and sampling either to the right or left side of the axis.

RESULTS AND DISCUSSIONS

Density

Over the two years, 47 bag silos were made at the three farms. All were filled rapidly with no longer than two days from the start of filling until sealing. The DM contents of the hay crop silages were generally drier than recommended (30 to 40% DM), whereas the corn silages were largely within that range. The bags used at the Arlington and West Madison stations were 200 ft long and generally filled to capacity. Most of the bags at Prairie du Sac were 100 ft long and often not completely utilized because the silage was being prepared for specific animal trials.

Average DM densities for individual bag silos in hay crop (all alfalfa except for one of red clover) silages and corn silages are shown in Figs. 1 and 2, respectively. In hay crop silage, DM density increased linearly with DM content. Linear regression of the data across farms resulted in a slope of $.19 \text{ lb/ft}^3\text{-\% DM}$. In corn silage, the effect of DM content on density was not consistent. With the AB machine at PDS in 2000, DM density increased with DM content at $.34 \text{ lb/ft}^3\text{-\% DM}$. The slope for the AB machine at Arl was steeper but used on only three bags with a narrow DM range. In contrast, there was no apparent effect on DM density with DM content with the KR machine used at either Arl or WM.

The effect of DM content on density has been observed in bunker silos. Muck and Holmes (2000) in a survey of bunker silos found that DM density increased with the square root of DM content and varied as a function of other factors. The maximum effect of DM content was approximately $.19 \text{ lb/ft}^3\text{-\% DM}$, assuming a filling rate of 25 t/h, continuous packing with a 20,000 kg tractor, and spreading the crop in 15-cm layers. Higher filling rates or layer thickness and/or small packing tractors reduced the effect of DM content on the resulting density.

Other factors affecting density are also evident in Figs. 1 and 2. How the machines are set up and used can make a difference in density. The same KR machine was used at both Arl and WM. Densities with the KR were generally higher at Arl compared to those at WM. Visually, the bags at WM looked somewhat smoother although the Arl bags had few lumps and bulges. It is not clear if the differences were due to operator set up or the size of the tractor used on the bagging machine. Operator differences were also apparent in the hay crop silages at PDS. After the 2000 season, the PDS crew received advice from the manufacturer about setting up the machine, and higher densities were observed in 2001 (Fig. 1).

It is difficult in this study to determine if there are differences in densities between bagging machines that are not due to operator conditions. The clearest comparisons are from the KR and rented AB machines used by the same farm crew at Arl. These two machines produced very similar densities in hay crop silages (Fig. 1). whereas the corn silage densities were somewhat lower with the AB machine (Fig. 2).

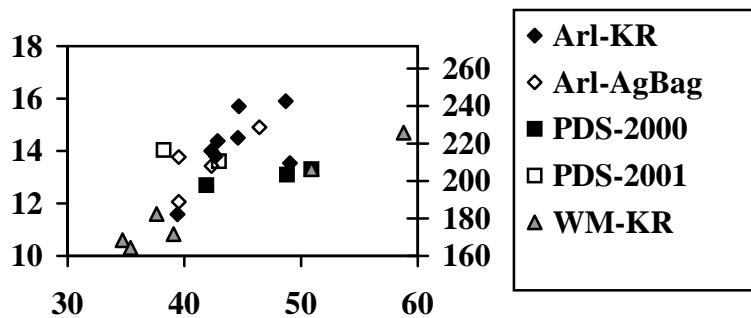


Figure 1. Average dry matter densities (left, lbs./ft³; right, kg/m³) in hay crop silages.

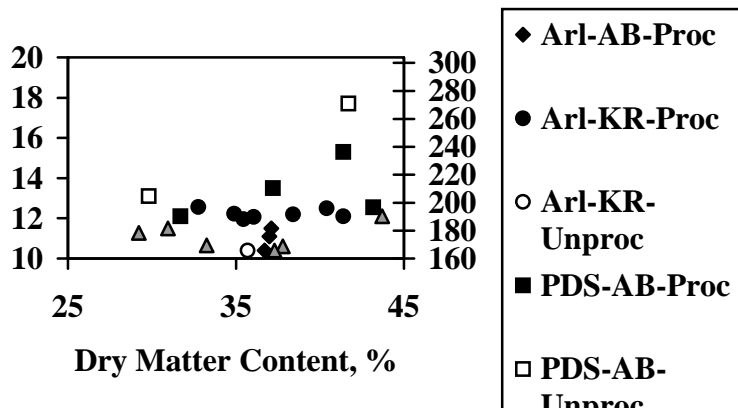


Figure 2. Average dry matter densities (lbs./ft³, left; kg/m³, right) in corn silages. Proc - kernel

Kernel processing in corn silage is a final factor that we observed as having an effect on density. Unprocessed corn silage at PDS was consistently denser than processed (Fig. 2). Four of the six corn silage bags at PDS were produced for a trial comparing processed vs. unprocessed corn silage, one each at early and late maturity. The four bags were filled with corn from the same field, and the two bags of each maturity were filled within a day of each other. Consequently, the difference in density due to processing at PDS was not only consistent but also the result of a planned comparison. In contrast, the one bag of unprocessed corn silage made at Arl had a lower density than those of processed silage made with the same machine.

One potential explanation for differences in density between processed and unprocessed corn silages may be particle size. Based

on bunker silo packing research (e.g., McGechan, 1990; Shinnars et al., 1994), one might expect longer particle size to result in lower density. At PDS, the theoretical length-of-cut on the forage harvester for the processed silage was set at .98 in vs. .75 in for unprocessed. However, the unprocessed corn going into the bags at PDS had an average particle size in both cases that was .06 in longer than the processed corn. At Arl, the average particle size for the unprocessed was within the range for the processed silages. Consequently, the higher densities in the unprocessed corn at PDS was contrary to expectations based on particle size.

The densities obtained in our study were similar to several in the literature. The estimation of 15 lb/ft³ from Esau et al. (1990) was higher than most in our study but within the range of our results. Our results were largely in the middle of the range (9.1 to 15.7 lb/ft³) as reported by Holmes (1998). Only the results (2.7 to 3.2 lb/ft³) of Harrison et al. (1998) were substantially different from ours.

Harrison et al. (1998) compared processed and unprocessed corn silage using an Ag Bag bagger and found no difference in density with long chop length and a trend toward higher density in processed corn silage for medium chop length. These results are the opposite of those found with the AB machine at PDS.

The densities in our study were within the range found for bunker silos. Muck and Holmes (2000) surveyed 168 bunker silos. The range and average for hay crop silages were 6.6 to 27.1 lb DM/ft³ and 14.8 lb DM/ft³, respectively. The range was narrower but the average similar for corn silages (7.8 to 23.6; 14.5 lb DM/ft³). Overall, average densities in the bag silos in this study were approximately 10% lower than average densities in commercial bunker silos in this region.

Typical recommendations for feed-out rates from bunker silos in the northern Midwest are 4 to 6 in/d from the whole face. Based on average densities from our study, minimum feed-out rates of 6 to 8 in/d for bag silos might seem appropriate. However, average densities do not account for variability in density across the face of bag silos and the potential impact on feed-out recommendations.

Seven core samples were taken to estimate within-bag density variation on five bags during emptying according to the pattern in Fig. 3. Densities at the seven locations are listed in Table 1. Generally the highest densities were at locations B and C and the lowest densities at location A and F. On average A and F were approximately at 40% of the density at location C; however, this may be an

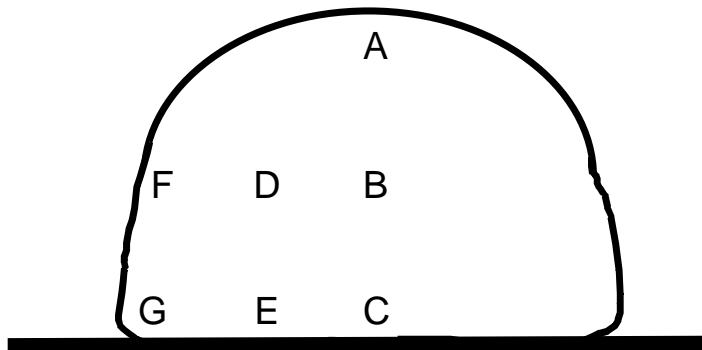


Figure 3. Location of core samples taken at the face of bag silos during emptying. Locations A, C, E, F and G were 6 in from the plastic wall. Locations A, B and C were along the vertical axis. Locations B, D, and E were at midpoints between other cores.

underestimate of actual density at A and F because sampling with the 2-in dia. corer was difficult in low density situations. Even so, the density of approximately the outer 12 in was of substantially lower density than the center and lower portions of the face. Occasionally, such as at location D in the first silo from PDS, areas that were expected to have a high density had low densities. Such random pockets of low density may explain pockets of mold in the middle of the face that our farm crews have seen in a few bags in the past. Overall, the low densities around the outer portion of the bag and the occasional low density pockets elsewhere suggest

that higher feed-out rates than indicated by average bag densities may be needed to minimize feed-out losses.

Table 1. Dry matter densities (lb/ft³) at various locations across the face of five bag silos.

Bag Information	Location as per Fig. 3						
	A	B	C	D	E	F	G
PDS-Hay-AB	3	18	12	2	13	7	8
PDS-Hay-AB	8	11	17	12	12	8	10
Arl-Hay-KR	3	17	20	16	15	9	13
Arl-Corn-KR	5	9	11	11	12	4	11
WM-Corn-KR	72	15	14	9	9	4	10
Average	5.2	13.9	14.8	10.2	12.1	6.4	10.3
Relative, %	37	94	100	71	83	42	72

Finally in relation to density, our study observed three relatively similar bagging machines (machines with a backstop, cables that run outside the bag between the backstop and bagger, density affected by cable tension, and the setting of the tractor brakes). Other models and makes differ in how the crop enters the bag, is pressed in, and how density is adjusted. These issues would be expected to influence average bag densities, as well as density variation across the face. Certainly more research is needed to compare the performance of these different bagging machines.

Losses

Losses from all the 2000 bag silos (24 bags) have been calculated. The range and average DM losses for these bags are shown in Table 2. Losses are divided into two categories: spoilage losses and invisible plus uncollected losses. Spoilage represents the silage removed from the bag but not fed. The invisible plus uncollected loss is a measure of difference between the amount ensiled and the total amount (good and bad) removed from the bag so it is the sum of gaseous loss, seepage and silage left on the ground during filling and emptying. Seepage losses occurred in only two bags. They were the two wettest (30 and 32% DM) corn silage bags from PDS that had 10.1% and 11.5% invisible plus uncollected losses, respectively.

Table 2. Losses from 24 bag silos made in 2000.

Type	Range	Average	Average without worst six
Invisible plus uncollected	-0.3 to 22.8	9.5	8.7
Spoilage	0.0 to 25.4	6.9	2.7
Total	-0.3 to 39.9	16.4	11.4

The ranges of losses were considerable, both in spoilage and other losses. However, the bags could be largely divided into two groups: six with substantial spoilage and the rest with modest or no spoilage losses. Of the worst six (25 to 40% total losses), one had bird damage, and the plastic burst on another early in fermentation. Both situations were repaired, but the incidents apparently had an effect on spoilage. Four of the six were fed out during the summer. Five of the six were ensiled at above 40% DM. Feed-out rates for five of the six were greater than 22 in/d so that low feed-out rates were not likely to have been an issue. Consequently, the high losses were generally associated with either plastic damage or feeding out drier silages under warm conditions.

Of the 18 other bags, seven had no spoilage. Another seven had less than 4% spoilage, representing bags with spoilage largely at the ends. The remaining four had spoilage losses between 6.6 and 10.6%.

Figures 4 and 5 show spoilage losses plotted against DM content and mid-point emptying date. All of the cases with spoilage losses above 5%, except for two, occurred in bags ensiled above 40% DM. Expressed another way, substantial spoilage losses (>5%) occurred in only 20% of the bags made below 40% DM, whereas substantial spoilage losses were observed in 57% of the bags above 40% DM. Most of the cases with >5% spoilage losses were fed out at least partially under warm conditions (Fig. 5).

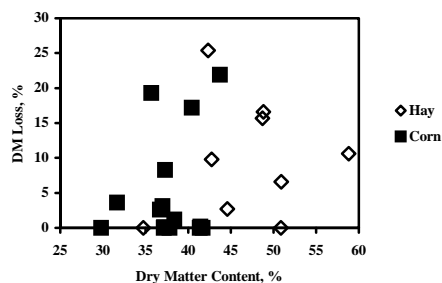


Figure 4. Spoilage losses in the 2000 bags as correlated with dry matter content.

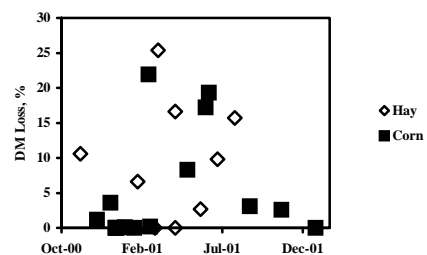


Figure 5. Spoilage losses in 2000 bags as correlated with the mid-point emptying date.

The corn silage with the highest spoilage loss was fed out during winter, but that was the bag that was bird-damaged. Interestingly, all of the last five corn silage bags that were emptied came from Arl. While one of the high spoilage loss bags in mid-summer was the bag that burst, the other four bags show a distinct reduction in the amount of spoilage, as each succeeding bag was opened in progressively cooler weather. This suggests that in bags where plastic integrity is maintained, most spoilage is probably occurring only during feed-out and is highly influenced by ambient temperatures during feed-out.

Spoilage losses did not appear to be influenced by the base on which the bags were set. Two bags were laid on compacted fill, seven bags on soil, 15 bags on asphalt, and one bag half on soil and half on asphalt. The six bags with major spoilage losses were on compacted fill (1), soil (1), asphalt (3), and soil/asphalt (1). The burst bag was on the soil/asphalt, and the base was unlikely to have been a factor in that case. Thus, no trends were evident.

Gaseous and seepage losses would be expected to increase with wetter crops, slower feed-out rates, warmer temperatures, higher porosity, and longer storage times. The invisible plus uncollected losses did tend to decrease the drier the crop at ensiling (Fig. 6). Seepage was observed only in the two wettest corn silages. Notice with the exception of the burst bag (23% DM loss), the invisible plus uncollected losses for the bags with high spoilage losses were not substantially different than those for the other bags.

Higher feed-out rates did not appear to reduce invisible plus uncollected losses (Fig. 7). However, greater variability occurred among bags at low feed-out rates. Also, several of the corn silages fed out at less than 10 in/d did experience heating problems, even though fed out principally in cool weather.

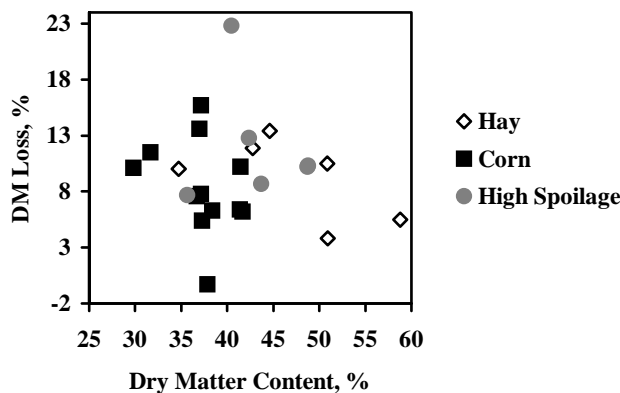


Figure 6. Invisible plus uncollected losses in 2000 bags as correlated with dry matter content.

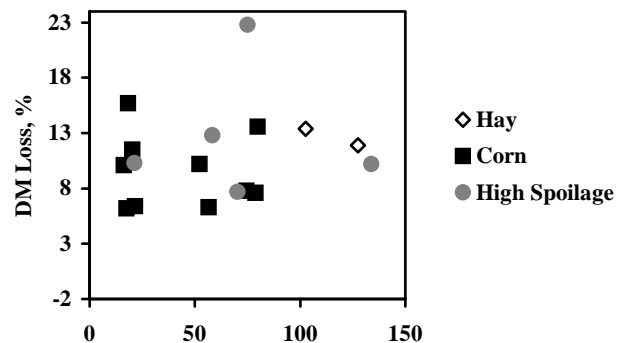


Figure 7. Invisible plus uncollected losses in 2000 bags as correlated with feed out rate.

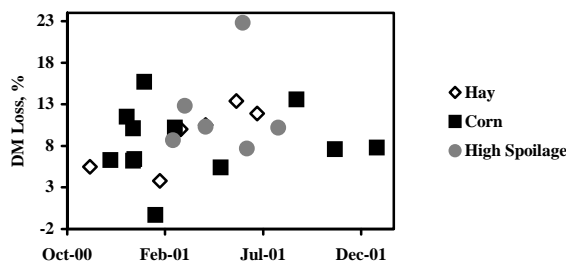


Figure 8. Invisible plus uncollected losses in 2000 bags as correlated with the mid-point emptying date.

Invisible plus uncollected losses as related to the mid-point emptying date are shown in Fig. 8. There appeared to be an upward trend in the hay crop silage with increasing time and/or outside temperature. However there was no discernable trend in corn silage even though the last two bags were more than one-year-old when emptying was completed. No trends in invisible plus uncollected losses relative to density or porosity were observed (data not shown).

A more complete correlation of these factors with dry matter losses will be performed when losses from all 47 bags have been analyzed. Additional cases will hopefully strengthen some of the trends seen and more solidly implicate the factors correlated with losses in other silo types as found by other researchers (Pitt and Muck, 1993; Buckmaster et al., 1989).

The total losses for many of our bag silos were similar to those reported elsewhere. Rony et al. (1984) reported losses of 9.0% and 6.4% for an alfalfa/grass and corn silage bag, respectively. Wallentine (1993) observed a 2.5% loss in corn silage. We observed bags with losses in this range, but we also had bags with substantially greater losses. In some cases, damage to plastic was a cause of high losses, but clearly feeding out drier (>40% DM) silages under warm ambient conditions can result in high spoilage losses. Consequently, when silage crops are ensiled in bags silos at drier than recommended levels, these bags should be fed out under cool temperatures to minimize losses.

Bunker Silo Filling

The recommended filling procedure for bunker silos begins by filling the back end of the storage by pushing forage up a sloped filling face in a progressive wedge technique. With this preferred method of filling, the forage is added in thin (<6-inch) layers to this filling face until the storage is full. The progressive wedge method allows a plastic cover to be applied to the top surface soon after that area is full.

Packing Density

Attaining a high density in a silo is important for two primary reasons. Firstly and most importantly, density and DM content determine the porosity of the silage. Porosity, in turn, sets the rate at which air moves into the silo and subsequently the amount of spoilage which occurs during storage and feed-out. Ruppel (1992) measured dry matter loss for alfalfa silage and developed an equation to relate the loss to density. Table 3 summarizes those results. Secondly, the higher the density, the greater the capacity of the silo. Thus, higher densities generally reduce the annual cost of storage per ton of crop by both increasing the amount of crop entering the silo and reducing losses during storage. The factors affecting density in bunker silos are not well understood. General recommendations have been to spread the crop in 6-inch layers and pack continuously with heavy, single-wheeled tractors. In a survey of alfalfa silage in 25 bunker silos, Ruppel et al. (1995) found tractor weight and packing time (min/T AF or min/ft²) were the most important factors affecting density. However, both factors only explained a small fraction of the variation observed, and layer thickness was not measured.

Table 3. Dry matter loss as influenced by silage density (Ruppel, 1992)

Density (lbs DM/ft ³)	Dry Matter Loss, 180 days (%)
10	20.2
14	16.8
15	15.9
16	15.1
18	13.4
22	10.0

The objectives in a study conducted by Holmes and Muck (1999c) were to measure density in a wider range of bunker silos and to correlate those densities with filling practices. The range of densities and DM contents are shown in Table 4. Ranges of DM densities were similar for both hay crop and corn silages. Densities on the low end suggested little packing, whereas the highest densities were in the range observed in tower silos. Average DM densities were slightly higher than a recommended minimum density of 14 lbs DM/ft³. Forage becomes denser in response to the weight of forage piled

above it. Densities were positively correlated with the height of silage above the core. To put densities on a common basis, all densities were adjusted to the median depth below the surface (7.1 ft) using Equation 15 of Pitt (1983) and assuming a compressibility of 2.2×10^{-9} /psi. Adjusted DM density was positively correlated with average packing tractor weight, packing time, and DM content and inversely correlated with the initial depth of the crop layer when spread in the silo.

Table 4. Summary of core samples collected from 168 bunker silos (Holmes and Muck , 1999c)

Characteristic	Haycrop Silage (87 silos)			Corn Silage (81 silos)		
	Average	Range	SD*	Average	Range	SD*
Dry Matter (%)	42	24-67	9.50	34	25-46	4.80
Wet Density (lbs/ft ³)	37	13-61	10.90	43	23-60	8.30
Dry Density (lbs/ft ³)	14.8	6.6-27.1	3.80	14.5	7.8-23.6	2.90
Avg. Particle Size (in)	0.46	0.27-1.23	0.15	0.43	0.28-0.68	0.08

*SD = STANDARD DEVIATION.

Use of rear duals or all duals on packing tractors had little effect on density. Other factors such as tire pressure, crop, and average particle size were not significantly correlated with density. Thus, the low r^2 of the regression of dry matter density vs. the 5-parameter packing factor probably reflects variability in accurately estimating parameters such as initial depth of the crop and packing time per ton rather than missing factors important to determining density. Holmes and Muck (1999d) developed a spreadsheet to simplify the process of solving those equations. The spreadsheet can be downloaded from the Team Forage web site with URL:

<http://www.uwex.edu/ces/crops/uwforage/storage.htm>.

One practical issue raised in the study was packing time relative to crop delivery rate to the silo. Packing time per ton was highest (1 to 4 min/T AF) under low delivery rates (<30 T AF/hr) and generally declined with increasing delivery rate. Packing times were consistently less than 1 min/T AF at delivery rates above 60 T AF/hr in the survey. These results suggest that farmers using contractors to harvest their silage crops probably will need to pay particular attention to spreading the crop in a thin layer and would benefit from using several packing tractors simultaneously.

Rapid forage harvest and delivery to storage requires a corresponding rapid rate of storage filling. A producer selecting a self-propelled forage harvester may see a doubling of forage delivery rate (Table 5) compared to a large pull-behind harvester, provided transportation is also increased. This requires larger and perhaps more push-up/packing tractors at the bunker silo.

Table 5. Forage harvester average capacity (Shinners, 2001)

Forage Harvester Type	Capacity (T AF/hr)	
	Hay	Corn
Pull, 250 HP	60	110
Self-propelled, 450 HP	100	180

The desire to improve feed quality drives the need to have rapid harvest and silo filling. As herd size increases, the quantity of forage harvested also increases. However, the window of harvest opportunity remains the same. Any bottlenecks in the harvest/delivery system cause cost increases due to equipment downtime and/or forage quality losses. Some custom operators offer a complete service of harvesting through silo filling. With an adequate complement of equipment and labor force, bottlenecks found on many farms can be eliminated, and rapid harvest/delivery can be accomplished. This service requires a higher out-of-pocket cost to the producer, but will be covered by the preservation of feed quality.

The spreadsheet of Holmes and Muck (1999d) was used to estimate density for a hypothetical case where a producer increased harvest rate from 50 T AF/hr to 100 T AF/hr. The storage averaged 9 ft tall, the forage dry matter was 35%, forage layer thickness was 6 inches, and one tractor (30,000 lbs) was being used to distribute/pack the forage. The results are summarized in Table 6.

The packing tractor should be as heavy as possible to achieve high forage density. Tractor weight can be augmented by adding weight to the tractor within the limits set by the manufacturer. Weight can be increased by adding iron wheel weights, adding liquid to tires, or adding front end and 3-point hitch weight. As the harvest rate increases, the need for more than one pushing/packing tractor increases. One 40,000-lb tractor will handle a harvest rate of about 90 T AF/hr while two or more 33,000-lb tractors may be needed between harvest rates of 90 to 120 T AF/hr. Dual wheels all around will improve traction and tractor maneuverability on a slippery surface. Tractor rollover protection (ROPS), the use of a seat belt, and selecting an experienced operator helps to improve safety in an inherently unsafe process. A shuttle shift transmission is very convenient for the operator making frequent changes of direction while packing.

Table 6. Scenarios for trying to improve silage density when forage delivery rate is increased from 50 T AF to 100 T AF/hr

Variables Changed from the Base Case	Est. Dry Matter Density (lbs DM/ft ³)
No change in packing procedure	12.3
Add 20,000-lb tractor for 50% time	12.7
Add 20,000-lb tractor for 100% time	13.1
Add 5,000 lbs weight to 30,000-lb tractor and do not use 20,000-lb tractor	13.0
Add 5,000 lbs weight to both tractors and use both tractors 100% of time	14.1
Reduce layer thickness from 6 inches to 4 inches	14.5
Use both tractors 100% of time and reduce layer thickness to 4 inches.	15.6
Add 5,000 lbs to 30,000-lb tractor and reduce layer thickness to 4 inches	15.5
Add 5,000 lbs to both tractors, use each 100% of time, and reduce layer thickness to 4 inches	17.1

In narrow bunker silos, the most logical packing direction is from back-to-front. In wider bunkers, consider packing in both directions to achieve a more uniform packing of the forage. In either case, the packing pattern should allow the wheel patterns in the forage to overlap about half a tire to improve uniformity of packing. When dual wheels are used, try to have a wheel pack the forage left unpacked between the wheels of the previous pass. If packing in both directions between bunker silo walls, remove the drawbar to avoid damage to the bunker walls and/or to the tractor.

CONCLUSIONS

Dry matter densities across 47 bag silos ranged from 10 to 17 lb/ft³. Dry matter density increased with DM content in hay crop silages on average .19 lb/ft³-% DM. The effects of DM content on density in corn silage varied by bagging machine. Density increased with DM content with the Ag Bag G6000, whereas density was unaffected by density with a Kelly-Ryan DLX.

Relative to crop differences, DM densities in corn silage were generally lower than those in hay crop silages with the Kelly-Ryan. Densities with the Ag Bag were generally higher in corn silage, particularly corn silage without kernel processing.

Operators affected density. The Kelly-Ryan was used at two farms, and one farm consistently averaged higher densities than the other. Densities in hay crop silage with the Ag Bag machine improved the second year after the crew received advice from the manufacturer.

Core samples taken at the face of bags during emptying found considerable variation in density. The outer 12 in on the top and upper sides had densities on average 40% of those in the center and lower portions, suggesting the need for higher feed out rates than might be anticipated for similar average densities in bunker silos.

Dry matter losses were measured on the first year's bags. Average DM losses were 9.5% invisible plus uncollected losses and 6.9% spoilage losses for a total of 16.4% loss. Of the 24 bags, six had severe total losses of more than 25%. The high losses were attributed to either issues of plastic integrity or overly dry silage (>40% DM) being fed out under warm weather. Removing those six bags from the average determination reduced spoilage and total losses to 2.7% and 11.4%, respectively. These are losses similar to those in tower silos.

Invisible plus uncollected losses were higher in low DM silages. Spoilage losses in bags without plastic integrity issues were primarily associated with drier, porous silages and with emptying silos under warm weather. Overall, the variation in losses appears to confirm that deviations from good management (harvesting between 30 and 40% DM, operating the bagger to get a smooth bag of high density, monitoring routinely for and patching holes, and feeding out at a minimum of 30 cm/d) result in greater losses.

Finally, more research is needed on other makes/models of silo baggers because of the diversity of mechanisms used for making bag silage and their potential effect on density and losses.

REFERENCES

1. ASAE Standards, 47th Ed. 2000. ANSI/ASAE S424.1. Method of Determining and Expressing Particle Size of Chopped Forage Materials by Screening. St. Joseph, Mich.: ASAE.
2. Buckmaster, D.R., C.A. Rotz, and R.E. Muck. 1989. A comprehensive model of forage changes in the silo. *Trans. ASAE* 32(4): 1143-1152.
3. Esau, C.A., A.M. St. Laurent, and G.C. Misner. 1990. Clean-out device for silage compactor. *Appl. Engr. Agric.* 6(1): 29-31.
4. Goering, H.K. and P.J. Van Soest. 1970. Forage and fiber analyses (apparatus, reagents, procedures and some applications). Agric. Handbook No. 379. Washington, D.C.: USDA-ARS.
5. Harrison, J.H., L. Johnson, D. Davidson, D. Huot, M. Horn, L. Morgan, K. Shinnars, D. Linder, C. Rotz, and R. Muck. 1998. Effect of maturity, chop length, mechanical processing, and silo type on packed density of corn silage. *J. Anim. Sci.* 76(Suppl. 1): 773.

6. Holmes, B.J. 1998. Choosing forage storage facilities. In *Dairy Feeding Systems Management, Components and Nutrients*, 38-59, NRAES-116, Ithaca, NY: NRAES.
7. Kennedy, S.J. 1987. Alternative silage making. *Irish Grassl. Anim. Prod. Assoc. J.* 21: 146.
8. McGechan, M.B. 1990. A review of losses arising during conservation of grass forage: Part 2, storage losses. *J. Agric. Engng. Res.* 45(1): 1-30.
9. Muck, R.E. and J.T. Dickerson. 1988. Storage temperature effects on proteolysis in alfalfa silage. *Trans. ASAE* 31(4):1005-1009.
10. Muck, R.E. and B.J. Holmes. 2000. Factors affecting bunker silo densities. *Appl. Engr. Agric.* 15(6): 613-619.
11. Pitt, R.E. and R. E. Muck. 1993. A diffusion model of aerobic deterioration at the exposed face of bunker silos. *J. Agric. Engng. Res.* 55: 11-26.
12. Ruppel, K.A. 1992. Effect of Bunker Silo Management on Hay Crop Nutrient Preservation. M.S. Thesis. Cornell University, Ithaca, NY.
13. Ruppel, K.A., R.E. Pitt, L.E. Chase and D.M. Galton. 1995. Bunker Silo Management and Its Relationship to Forage Preservation on Dairy Farms. *J. Dairy Sci.* 78:141-153.
14. Rony, D.D., G. Dupuis, and G. Pelletier. 1984. Digestibility by sheep and performance of steers fed silages stored in tower silos and silo press bags. *Can. J. Anim. Sci.* 64(2): 357-364.
15. Shinnars, K.J. 2001. Personal Communication. Biological Systems Engineering Dept., University of Wisconsin-Madison.
16. Shinnars, K.J., R.E. Muck, R.G. Koegel, and R.J. Straub. 1994. Silage characteristics as affected by length-of-cut. ASAE Paper No. 94-1524. St. Joseph, MI: ASAE.
17. Wallentine, M.V. 1993. Silage storage systems in the arid west. In *Silage Production from Seed to Animal*, 124-133, NRAES-67, Ithaca, NY: NRAES.