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Dry matter losses from different silo structures

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Introduction

Major research resources have been spent to improve the ensiling process. The ultimate objective is to accomplish a secure preservation of the ensiled material with limited changes in nutrients and a high hygienic standard of the end-product. However, the problem of silage heating up after opening and during unloading is evident on many farms. This problem leads to rapid deterioration of feed quality, large losses and sometimes situations where a considerable amount of silage must be discarded. Heating does not always occur, but takes place in a seemingly haphazard way on different farms and in different years. Presence of air in the silo is a prerequisite for heating and yeast starts the process in most cases (Wilkinson & Davies, 2013), which always leads to losses of organic matter and the production of carbon dioxide and heat. A set of experiments, funded by the Swedish Farmers´ Foundation for Agricultural Research, have been carried out in laboratory scale silos to study the effect of air ingress during fermentation (Spörndly & Persson, 2015a) and during unloading silos (Spörndly & Nylund, 2016) as well as the effect of yeast prevalence on crops at commercial farms (Spörndly & Persson, 2015b). Temperature measurements have also been performed in full-scale bunker silos to monitor ongoing processes during the ensiling and unloading phases (Spörndly & Nylund, 2016). The present study reports dry matter (DM) losses measured by silo balances and chemical analyses from different types of silo structures at commercial farms.

Materials and methods

Losses during ensiling, storing and unloading of mainly grass-clover crops were studied on 12 farms. During the study, a total of 12 bunker silos, 6 tube silos, 3 tower silos and 60 round bales in duplicate were monitored (Table 1). In-going green crops (mostly grass/clover leys) for ensiling in large silos were weighed by an axel weighing kit (Dini Argeo s.r.l, Italy) with four load cells with a limit of 10000 kg each and an accuracy (d-value) of 5 kg. Unloaded silage was weighed by the farmers using on-farm mixer wagon scales. Both the axel weighing kit and the mixer wagon balances were calibrated using a pair of beam load cells (Flintec SB5, Flintab AB, Sweden) of with a limit of 1020 kg each and an accuracy (combined error) of 0.5 kg. This Flintab scale was also used for weighing round bales before and after storage. Samples from in-going crops were taken from each wagon before the crop was loaded into the bunker, tube or tower silos. For round bales, samples of in-going material was taken from every second bale. At unloading the big silos, samples were taken three times per week and for round bales, the same bales sampled in the beginning were sampled at opening. All samples were frozen at -18ºC and dry matter was determined on each individual sample by drying for16 h in 60ºC and weighed hot. For silage samples, a correction for volatiles was applied, using the regression: 0.99 x g DM/kg +10 (Åkerlind et al, 2011). All DM analyses were made on the individual samples and DM losses were calculated by recalculating dry weight to corresponding quantity of wet weight. Analysis of ash, crude protein (CP), pH and metabolizable energy for ruminants (ME) was performed on 8-20 pooled samples per silo, depending on silo size. Ash was analysed by incineration at 550°C for 5 h, CP as Kjeldahl-N x 6.25 determined with a Kjeltec 1030 (Foss A/S, Denmark) and ME was estimated from in vitro organic matter digestibility (Lindgren, 1979). For statistical calculations, the Mixed procedure and Pearson correlation procedure of the SAS package were used (SAS 9.4, SAS institute Inc., Cary, NC, USA) with silo type and farm as fixed independent variables.

Results and discussion

Silo balance for all measured silos are in Table 1. The DM content in the bunker silos was in average 33.0%, in the tube silos 30.8%, in the tower silos 26.9% and in the round bales 53.9%. Silo balances in fresh weight (kg out of the silos minus kg into the silos) were mainly negative. However, in three cases with bunker silos, silo balance were positive.

Table 1 Silo balances for bunker silos, tube silos, tower silos and round bales.

Farm	Green crop weighed in. kg fresh	DM.%	Silo balance, out - in, kg fresh	DM loss as discarded, %	DM loss total, %	DM loss excl. discarded, %	Total, ME loss, %	Total CP loss, %
				Bunker silos				
1	328000	21.5	-16467	1.6	3.1	1.5	3.2	3.1
2	442220	36.4	-36727	2.8	18.1	15.3	12.6	18.1
1	369120	35.6	-8495	0.7	3.4	2.7	4.5	3.4
1	160870	39.6	4950	1.3	7.8	6.5	9.5	7.8
2	488900	35.6	-22215	3.6	16.0	12.4	14.9	16.0
2	403720	39.6	15672	1.5	14.7	13.2	16.7	14.7
3	272720	23.7	-23104	0.9	7.7	6.8	13.8	7.7
4	892659	31/36	-28857	0.8	6.4	5.6	5.7	6.4
5	422680	33.6	-25264	1.4	21.7	20.2	23.4	21.7
6	1235830	24.0	-147166	1.8	15.0	13.2	18.6	15.0
7	119220	33.4	-5938	9.8	29.2	19.4		
7	165060	39.7	5218	14.8	26.2	11.4	23.9	16.5
	Bunker silos - mean			**3.4**	**14.1**	**10.7**	**13.3**	**11.9**
	Bunker silos - SD			**4.4**	**8.7**	**6.1**	**7.1**	**6.4**
				Tube silos				
8	492020	30.4	-55326	0.1	18.4	18.3	15.0	18.4
9	328460	28.6	10378	0.8	-2.1	-2.9	-2.5	-2.1
9	154360	29.8	4470	0.7	4.5	3.7	4.2	4.5
10	169080	40.0	-4673	9.6	8.5	-1.0		8.5
7	143720	32.4	-23898	0.0	21.7	21.7	22	22.8
7	313930	23.6	-83858	0.0	18.1	18.1		
	Tube silos - mean			**1.9**	**11.5**	**9.6**	**9.7**	**10.4**
	Tube silos - SD			**3.8**	**9.4**	**10.9**	**10.9**	**10.2**
				Tower silos				
11	394220	18.1	-128382	0.2	20.9	20.7	22.7	20.9
7	259470	33.9	-73718	0.0	24.3	24.3	22.3	24.2
7	286600	28.8	-93283	0.0	24.9	24.9	25.4	24.4
	Tower silos - mean			**0.1**	**23.4**	**23.3**	**23.5**	**23.2**
	Tower silos- SD			**0.1**	**2.2**	**2.3**	**1.7**	**2.0**
				Round bales				
12	21201	46.7	-139	0.0	1.4	1.4	0.6	1.4
7	29370	61.2	-240	0.0	0.8	0.8		
	Round bales - mean			**0.0**	**1.1**	**1.1**	**0.6**	**1.4**
	Round bales - SD			**0**	**0.4**	**0.4**		

This was interpreted as rainwater entering into the silo mass as DM contents of the silages in these silos also were lower compared to the green crop. Average precipitation during the storage time of 8 months (July – February) was 450 mm resulting in 144000 kg water falling on a bunker silo of 8 x 40 m. It is reasonable to believe that a portion of this rainwater entered the silo, if the surfaces were not perfectly tight and without a gentle slope to allow water to run off. All bunker silos were constructed with three walls. It is probable that all bunker silos were subjected to variable amounts of water leakage, indicated by average wet weight silo balance of only -3.1% compared to -14.1% for the DM balances (Table 1). The horizontal tube silo has a construction where rainwater does not enter easily. Hence, the difference between the wet weight and DM silo balance for tube silos was smaller, -8.5% compared to -11.5%. The tower silos in this study were filled with lower DM content of the fresh crop than recommended. Average fresh weight balance of tower silos was -31.2% compared to the DM silo balance of -23.4%, which indicates a substantial amount of effluent loss (not measured in this study).

Four farms participated with two silos of the same type during two different years and one farm had all four silo structures (Table 1). Therefore, a statistical analysis including also the effect of farm was possible. However, the interaction between the two could not be included in the model due to the low number of observations with different silo types on the same farm. Both the effect of silo structures and farm proved to be highly significant ($p<0.0002$) and the contrast between the silo structures are presented in Table 2.

Table 2 Contrast significance levels for DM losses of four silo structures using silo type and farm as fixed variables, both significant at $p<0.0002$

Silo type	Bunker silo	Tube silo	Tower silo	Round bales
Bunker silos	-	0.0159	0.2624	<0.0001
Tube silos	0.0159	-	0.1030	0.0003
Tower silos	0.2624	0.1030	-	<0.001
Round bales	<0.0001	0.0003	<0.001	-

Results showed that the round bales had considerably lower DM losses than all the larger silo constructions. The tube silos proved to have lower losses than bunker silos but DM losses in tower silos were not different from bunker or tube silos.

The marked difference between the large silo types and the small round bale silos suggest an effect of lower seal integrity and longer unloading time of the large-scale silos. Spörndly & Persson (2015b) showed that low intensity air ingression during storage in laboratory silos resulted in a drastically higher temperature immediately after opening the silos. They also showed that the low intensity air ingression during storage hardly influenced silage quality or losses at opening of the silos. Therefore, it is possible that the great difference between large and small silo constructions arise during the long unloading time of large silos in contrast to round bale silos that are emptied the same day they are opened. Spörndly & Nylund (2016) supported this hypothesis in laboratory scale silos where the DM losses were 6% at opening but 29% after a 63-day unloading period. The average unloading time of the bunker silos in the present study was 95 days, varying from 34 to 186 days but the correlation between unloading time and loss was only 0.37 (Table 3).

Spörndly & Nylund (2016) presented detailed results of temperature development inside five bunker silos used in the present study. They registered maximum silo temperatures from 26.5 to 44.5°C with mean temperature of 23.7°C. The elevated temperature were maintained also during the winter period when the ambient temperature was far below 0°C. However, no correlation between silo temperature and total DM losses in these five silos could be observed (Table 3).

Table 3 Silo size, filling speed, unloading time, silage maximum temperature, pH at start and end of unloading time, DM loss calculated using the ash content in fresh crop and silage, and invisible DM loss (loss excluding discarded silage) using all-in/all-out method

Farm	Silo size	Filling speed,	Unloading time,	Silage max. temp.,	pH at unloading,		DM loss, calculated from ash content,	Invisible DM loss,
		ton/h	days	℃	Start	End	%	%
				Bunker silos				
1	30 x 6 x 3 m	2.4	73	28.5	3.9	4.2	1.1	1.5
2	43 x 8 x 3 m	17.8	118	26.5	4.3	4.1	-8.2	15.3
1	30 x 6 x 3 m	2.2	84	35	4.3	4.2	5.3	2.7
1	20 x 5 x 3 m	2.0	70		4.5	4.4	5.4	6.5
2	43 x 8 x 3 m	8.2	45	31.5	4.2	4.2	2.4	12.4
2	43 x 8 x 3 m	6.8	115		4.7	4.5	-2.7	13.2
3	30 x 7 x 3 m	6.5	34		3.9	3.9	2.8	6.8
4	42 x 12 x 3 m	2.9	126	44.5	4.2	4.3	10.1	5.6
5	24 x 9 x 2.4 m	2.6	69		4	4.1	-5	20.2
6	36 x 10 x 4 m	10	186		4.2	4.6	2..7	13.2
Mean			92		4.2	4.3	1.4	9.7
SD			45.0		0.3	0.2	5.4	6
				Tube silos				
8	87 x 3.3 m		41		4	3.9	6.1	18.3
9	60 x 3.3 m		94		4	3.9	-7.4	-2.9
9	30 x 3.3 m		66		4.2	4	-1.1	3.7
10	50 x 2.7 m		83		3.8	3.9	-11.5	-1
Mean			71		4	3.9	-3.5	4.5
SD			23.1		0.2	0.1	7.7	10.6
				Tower silos				
11	450 m^3		232		4.2	3.8	-9.5	20.7
				Round bales				
12	1.8 m^3		1		4.4	5.3	-10	1.4

The aerobic microbial development during unloading, started by yeast, seems likely to be the main reason to the high losses for large silo constructions. A literature review by Borreani et al (2018) compiling six farm scale silo studies also stated that it is during the feed out phase that the greatest losses occur. Chen & Weinberg (2009) showed that the rise in temperature was well correlated with increasing DM losses when laboratory silos were opened. Spörndly and Persson (2015b) also found this in studies with laboratory scale silos where green crops from seven farms were ensiled in laboratory silos. They showed that time from silo opening to start of yeast development and temperature rise was shorter if the silos were not completely airtight during the 90-d storage period. This also leading to a better survival of yeast present in the green crop. If this is the case, substrate for the yeast growth, resulting in heat production, should be mainly in the form of easily degradable carbohydrates and could also be lactic acid, if lactate assimilating yeasts are active. This was shown by Ranjit & Kung (2000) in laboratory silos, who saw a marked increase in silage pH and increased DM losses a few days after silos were opened and exposed to air. Silage pH in silos in the present study was measured throughout the unloading time. In Table 3, pH at the beginning and end of the unloading time is shown, but no change in pH was evident.

Aerobic microbial growth, mainly from easy degradable organic matter with end-products in the form of carbon dioxide and heat, should theoretically lead to an increased content of ash in the silage. This has been suggested as a simple indicator of DM losses in farm scale silos (Ashbell & Weinberg, 1992). They suggested that DM losses could be calculated as DM loss (%) = 1-($ash_{fresh\ crop}/ash_{silage}$). When applying this equation to the ash contents obtained in this study (Table 3), no such correlation existed between this method and the all-in/all-out method ($r<0.1$). In eight silos, the ash content was lower in the silage and in eight, it was higher.

A carefully packing during filling of bunker silos achieves a high density (kg/m^3 or kg DM/kg^3) and is a way to prevent air leaking deep into the silo mass, which limits aerobic deterioration, heating and DM losses, particularly after opening the silo (Johnson et al, 2002; Holmes & Muck, 2007). An attempt was made to measure the silage density in the present study. This was successful only at some farms and data is, therefore, not presented. However, an indication of how well the crop was compacted at filling of the bunker silos is the time the filling lasted. Dividing total mass filled into the silo with total filling time gives an estimate of kg is filled per hour. We assumed a tractor for packing was running in the silo during the filling time, except during the nights. Resulting filling speeds are presented in Table 3 and the correlation with total DM losses was 0.55. However, the 10 bunker silos included one clear outlier (Farm 5, Table 3). By excluding this farm the correlation became 0.85 ($p<0.004$), as illustrated in Figure 1.

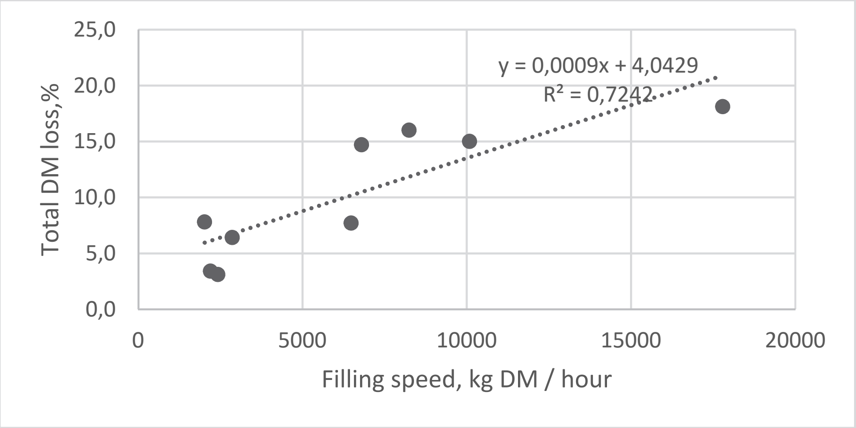

Figure 1 Total DM loss as a function of filling speed in 9 bunker silos. Hours are counted from start to end of filling, including night time hours.

Conclusions

The main difference between DM losses among silo types was a considerably lower loss in round bale silos (< 1% losses), compared to large bunker, tube and tower silos, which all averaged over 10% losses. The reason to the difference is suggested to be aerobic conditions during long unloading times of large silos. It was also suggested that the high seal integrity achievable with stretch film packages of round bales enables ensiling at high DM contents and also at moderate densities. Indirect methods for estimation of silage DM losses such as change in pre- and post-ensiling temperature did not prove useful.

A recommendation for managing bunker silos, drawn from this study, is to avoid filling the silo fast to enable a continuous compaction of the crop in thin layers. This can be done e.g. by filling two silos simultaneously instead of one after the other.

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