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DENSITY OF SILAGE STORED IN HORIZONTAL SILOS

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A b s t r a c t. The objective of this study was to identify the effect of silage density on quality and efficiency of crop preservation. Feed quality is reduced in loosely packed silos because of decreased dry mater and nutrient losses from aerobic deterioration. Adequate packing in the silo to attain the minimum recommended density of dry matter is a challenge. This study estimates how packing tractor weight, silage dry matter, rate of fill and blade layer work together to effect dry matter density. Increasing packing tractor weight, number of packing tractors and reducing layer thickness result in increased dry matter density. High density in horizontal silos minimises losses and reduces storage costs. High density reduces the porosity of the crop and a higher density increases the storage capacity of the silo. Density increased from top to bottom of horizontal silos and significant difference in silage densities across the face of the pile are noted. Lower densities are consistently registered along silo walls, therefore extra attention should be paid to packing along the silo walls. Using a heavy tractor with narrow tyres could be a way to reduce feed losses. Only an experienced operator should be employed to pack along a wall with a heavy tractor. Silage should not be packed too high or too steep, as that could increase the likelihood of rolling the packing tractor over. Silage density in horizontal silo is most strongly influenced by packing layer thickness (L), tractor weight (m_v), packing time per ton as-fed (t_u) and dry matter content (DM). Muck and Holmes (2000) proposed that the relationship between these four factors forms the packing factor (PF). Silage density is moreover influenced by delivery rate, moisture content, dimensions of the horizontal silo and particle length.

K e y w o r d s: horizontal silo, silage, packing, density.

INTRODUCTION

Ensiling is a growing practice for the conservation of crops (Wilkinson and Toivonen 2005a, Muck and Kung 2007). Second primary option of crop storing is haymaking. Countries with predominantly dry climates, such as the United States and Australia, preserve most of their forages as hay. In contrast, most northern

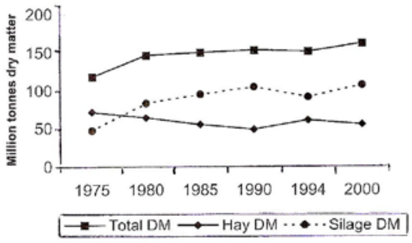


Fig. 1. Estimated production values of silage and hay DM in Western Europe: 1975 to 2000 (Wilkinson 2005b)

European countries storage forages as silage due to their wet climates. Estimated figures of silage and hay DM produced in Western Europe are shown in Figure 1. There has been a steady increase in silage production since 1975.

Density of the silage mass is the most important factor influencing silage quality (Ruppel *et al.*1995, Craig and Roth 2005). In more densely packed silage porosity is decreased, more air is pressed out, which will reduce spoilage and dry matter loss. This allows also that more dry matter can be stored in the same volume, thus reducing the cost of additional storage capacity. Silage density is one of the major factors in anaerobic fermentation and aerobic stability (Woolford 1990, Zaharia *et al.* 2009, Orosz *et al*. 2006). The packing process should be done continuously throughout the filling time.

Optimally, forage should be packed at the rate of 1 to 4 minutes per tonne of forage (McAllister and Hristov 2000). Packing rate lower than 1 minute per tonne of forage may indicate that forage is being delivered to the horizontal silo too quickly. Packing density is maximised by using a packing tractor with tyres applying the greatest weight per unit of surface area. Densities decrease with wetter crops. Pitt (1983) showed temperature rise in tightly sealed silos increased with dry matter content and low bulk density. The effect of packing density on dry matter losses in corn silage after 180 days ensiling is shown in Table 1.

Table 1. Dry matter loss as influenced by silage density (Ruppel 1992)

Density (kg m^{-3})	DM loss at 180 days, % of the DM ensiled
160.2	20.2
224.3	16.8
240.3	15.9
256.3	15.1
288.4	13.4
352.4	10.0

Factors affecting silage densities stored in horizontal silo

Factors that affect silage density stored in horizontal silos are highly variable and not well recognised. Extensive researches on silage storing in bunker silo were made mainly in USA Universities: Wisconsin (Conway 2008), Cornell (Craig 2008), California (Silva-del-Rio 2010a and b), Kansas (Bolsen, 2000), Pennstate (Lee 2011) and Florida (Adesogan and Newman 2010). Silage density in horizontal silos is correlated with the following factors (D’Amours and Savoie 2005, Holmes and Muck 2000): moisture content of the silage, tractor weight, wheel pressure, silage delivery rate (tons h^{-1}), harvest time per day, depth of silage, maximum silage height, crop maturity, chop length, silage dry matter content, silage packing layer thickness and silo dimensions. Dual wheels can provide additional weight and stability. Wetter forage compacts more easily, but can be prone to seepage and, opposite to drier forage, is more difficult to pack and keep compacted (Charley 2008).

Multiple layers of plastic on the top and sidewalls with adequate weighting can allow higher digestible silage (Griswold 2011). Producers drape plastic over the walls before filling, then lay plastic toward the centre of the bunker and cover the entire pile with a second layer of plastic to reduce air and moisture entry on the sides and the top of the bunk.

The range of densities and DM contents in hay crop and corn silages are shown in Table 2. Density was measured by the coring method with 50 mm diameter corer (Holmes 1996, Holmes and Muck 2008 b), taking cores at approximately 1.20 m above the floor of the silo at four locations cross the silage feedout face (Fig. 2). Determination procedure steps of silage density by this method (Holmes 2008a): core sample at face to depth of 0.305 m at multiple sites, weigh samples, dry samples, weigh dry samples and calculate core density and average. Dry matter densities obtained by core sampling are shown in Table 3. Other procedures of density measurement on silage was given by Schemel *et al*. (2006). Table 4 lists some of the research and demonstration projects conducted to investigate factors affecting silage density in tower and bunker silo. Vokey (2002) found that density and silage quality increased with depth down to 1.83 m from the silage top surface (Tab. 5).

Table 2. Density summary of silage core samples collected from 168 horizontal silos (Holmes and Muck 1999)

Silage characteristic	Haycrop silage (87 silos)			Corn silage (81 silos)		
	Average	Range	Standard deviation	Average	Range	Standard deviation
Dry matter (%)	42	24-67	9.5	34	25-46	4.80
Wet density (kg m^{-3})	593	208-977	1.9	593	368-961	8.3
Dry density (kg m^{-3})	237	106-434	3.8	237	125-378	2.9
Average particle size (mm)	13.0	7.6-30.5	0.2	10.2	7.6-17.8	0.1

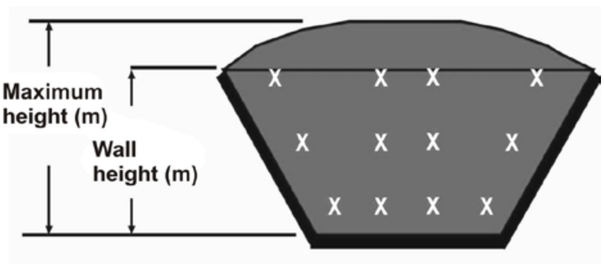


Fig. 2. Suggested coring locations (Holmes 2008a)

Table 3. Alfalfa silage dry matter density by height above floor for lx and 2x tractor (Muck *et al*. 2004)

Sampling date Dec. 18, 2003			Sampling date Feb. 3, 2004		
Height above floor (m)	1x	2x	Height above floor (m)	1x	2x
	Density (kg DM m^{-3})				
0.49	370.1	362.1	0.49	298.0	301.2
1.19	2S2.0	293.2	1.10	357.2	324.4
1.89	269.1	246.7	1.58	225.9	270.7
2.59	169.8	225.9	2.19	253.1	304.4
3.29*	168.2	185. 1	2.71*	163.4	195.4
Average	253.1	262.7	Average	259.5	27S.7

* 0.49 m below cop surface of silage.

Table 4. Factors influencing dry matter density (Holmes 2006)

Reference / Factors influencing DM Density	Messer & Hawkins 1977a	Messer & Hawkins 1977b	Pitt 1983	Negi *et al*. 1984	Jofriet & Zhao 1990	McGechan 1990	Darby & Jofriet 1993	Ruppel *et al*. 1995	Muck & Holmes 2000	Bernier –Roy *et al*. 2001	Johnson *et al*. 2002	Vokey 2002	Muck *et al*. 2004b	Savoie *et al*. 2004	D'Amours & Savoie 2004	Visser 2005	Craig & Roth 2005
Depth in storage		o	+			+	o		+			+			+	+	+
Distance from storage wall/edge			+												+	+	+
Distance from feedout face															+		
DM content	o	o	–	+		+			+	+			+	o			
Packing time/ frequency						o/+		+	+	+			o	o			
Surface area								+						+			
Tractor weight	+	+			+		+	+	+								
Pressure				+						+			+	+			

Layer thickness									–	–			o	–			
Grain percentage															+		
Corn maturity	o					–					–						
Particle size	o	o				–			o		–		–				
Crop type	+	+							o	+			+				
Processing											+			o			
Storage type																+	
Surface cover												+					
Dual wheel									o								
Overfilling storage																	–

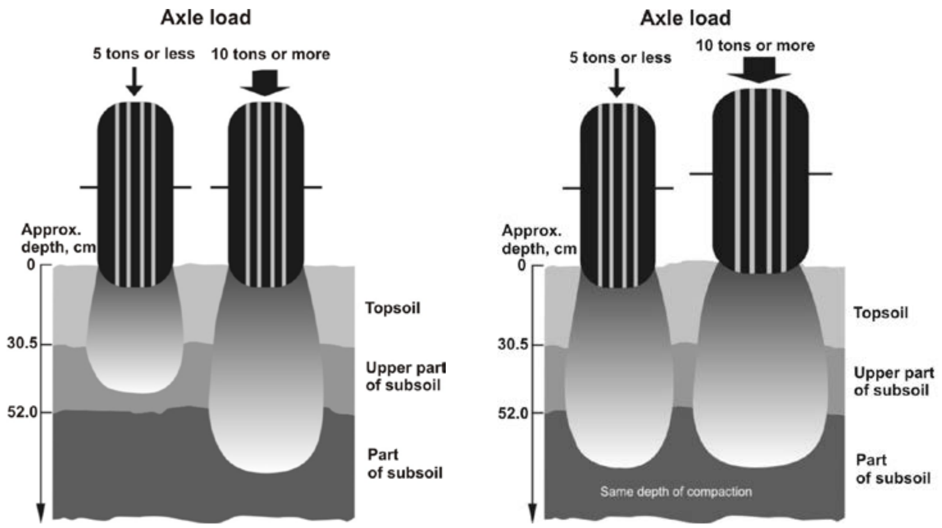
+ Positive impact; – Negative impact; o Considered but no impact observed.

Table 5. Effect of depth from top and covering of bunker silos (Vokey 2002)

Silage depth (m)	Uncovered	Covered
	Density (kg DM m^{-3})	
0.30	141.0	176.2
0.91	221.1	197.0
1.83	241.9	227.5

Soil and silage compaction effects are created very similarly. There exist two principles of silage compaction. According to the first principle (axle load effect) – a heavier axle load compacts more and deeper than a lighter weight (Fig. 3), and the second principle (surface area effect), bunker being filled using concave formation to allow edge compaction (Kaiser *et al.* 2004).

Investigations of Vokey (2002), Craig (2004), Craig and Roth (2005) have shown that silage density depends on location in horizontal silos (Tab. 6). Differences of density were found to depend on the level of the pile (effect of level) with the highest density value in the bottom level, followed by the middle level and then the top (Fig. 4a). Significant difference in densities was also found to depend on the position in horizontal silo. Positions, at each level, were noted as 1, 2, 3, 4 from the left to the right, with the lower silage densities in the outside edge values than the interior (Fig. 4b).



a b

Fig. 3. Principles of compaction (Craig and Griswold 2008): a) first principle – axle load effect, b) second principle – surface area effect

Table 6. Average bunker silo silage dry matter density by depth (Craig and Roth 2005)

Level within bunker	Average density (kg DM m^{-3})	
	2004	2005
Top	179.4	190.6
Middle	206.7	222.7
Bottom	224.3	241.9

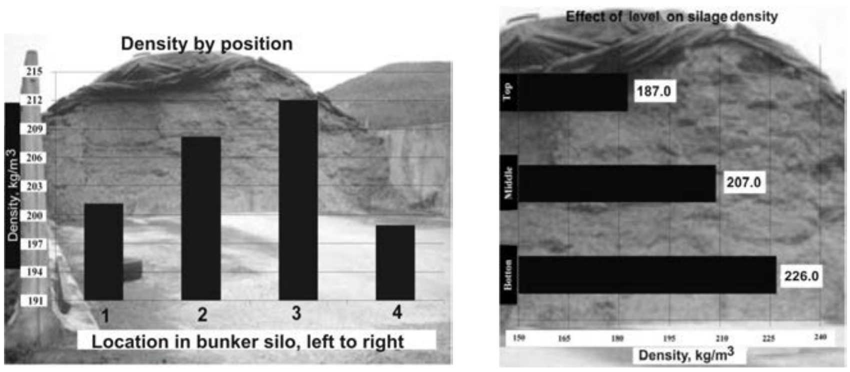


Fig. 4. Density of corn silage in bunker silo according to studies (Craig 2004): a) depending on location in bunker silo, b) depending on level of considered level

Determination of dry matter density by Muck and Holmes model

Horizontal silo DM density as a function of packing and height may be calculated as (Savoie *et al*. 2004):

$$\rho = \left[136 + 0.42\left(\frac{m_v}{L}\sqrt{10 t_u DM}\right)\right](0.818 + 0.045H), \tag{1}$$

where: ρ – average DM density, kg DM m^{-3}, L – initial layer thickness of the crop when spread (but unpacked) in the silo, t_u – compacting time per ton of wet crop, h t^{-1}, H – average silage height: (height at wall + height at centre)/2, m,

$$\frac{m_v}{L}\sqrt{10 t_u DM} \text{ – packing factor,} \tag{2}$$

m_v – proportioned average tractor weight (tons), for all tractors packing silage; DM – dry matter content, (decimal), g kg^{-1}; N – number of tractor-packing equivalents, where N=1 when one tractor is packing continuously during the filling time process. This value can be fractional, reflecting one or more tractors packing intermittently. For example, if one tractor packs continuously during the silo-filling process and another packs 50% of the filling time, N = 1 + 0.5 = 1.5. If there is only one packing tractor and it packs for 11 hr day^{-1} and the silo is filled 10 hr/day, then N = 11/10 = 1.1.

Example according to Holmes and Muck (2000)

Horizontal silo of 12.00 m width and 3.05 m high at sidewalls is packed to a maximum depth of 4.27 m at the centre. The 35% dry matter content silage is delivered to the silo at the rate of 100 tons as-fed, per hour. Silage packed by two tractors.

One packing tractor of mass of 11.34 tons distributes continuously silage of 0.305 m layer thickness, and a second tractor of mass of 6.804 tons also packs continuously. Thus the average packing tractor weight is: m_v = (11.340 + 6.804) : 2 = 9.072 tons. But if tractor #1 packs 90% of filling time and tractor #2 is used for 50% of the time, the proportioned average tractor weight is: (11.340·0.9 + 6.804·0.5) · [90/(90 + 50)] = 8.748 t.

Assuming a triangular-shaped cross section above the 3.05 m walls height and 4.27 m as maximum silage depth in the silo centre , the average silage depth is:

$$H = (3.05 + 4.27) : 2 = 3.66 \text{ m}$$

where: tractor weight m_v = 9.072 tons, packing layer thickness L = 0.305 m, crop delivery rate to the silo C = 100 tons as-fed, per hour, dry matter content 35%.

The packing factor from Eq. (2):

$$\mathrm{PF}=\frac{9.072}{0.305}\sqrt{2\times 10\times \frac{35}{100}}=29.75\times 2.65=78.84$$

and dry matter density from Eq. (1):

$$\rho = [136 + 0.42\cdot 78.84]\cdot(0.818 + 0.446\cdot 3.66) = 16620 \text{ kg m}^{-3}$$

Since this DM density is less than 225 kg m^{-3} as the recommend ideal value, both tractors weight was increased by adding 2.722 t and packing layer thickness was decreased from 0.305 m to 0.1525 m.
Thus:

$$m_v = (14.06+ 9.526)/2 =11.79 \text{ t}$$

$$\mathrm{PF} = \frac{11.794}{0.1525}\times 2.65 = 205.0$$

and

$$\rho = (1363 + 0.42\cdot 2050)\cdot 0.981 = 2224 \text{ kg m}^{-3}$$

Methods for increasing packing factor

Methods for increasing the packing factor and thus the dry matter density are given by Holmes and Muck (2000) and Craig and Roth (2005) and they rely on: reduced delivery rate of crop to the silo and increasing the total time spent packing per tonne of forage, adding weight to the packing tractor(s), using more packing tractors, increasing dry matter content by allowing longer crop field drying time, increasing depth of silage results in additional weight and other given above.

Influence of packing factor on dry matter density is shown in Figure 5.

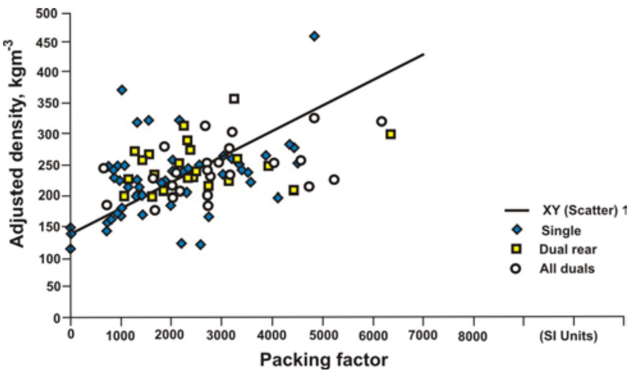


Fig. 5. Dry matter density as related to the packing factor and use of dual wheel on packing tractors (Muck and Holmes 2000)

CONCLUSION

The factors that have a major effect on silage densities in horizontal silos include the tractor weight, total spent packing time per ton, layer thickness, forage delivery rate and, to a lesser extent, particle length and height of silo. Concrete walls should be sloped and air tight. Filling and compaction should be continuous throughout the silage making period. Packing density of minimum of 225 kg m^{-3} is essential for high silage value. Silage dry matter density can be well estimated by the model of Muck and Holmes. Producers who are very interested in silage density, modify their management practices.

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GĘSTOŚĆ KISZONKI SKŁADOWANEJ W SILOSIE POZIOMYM

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Streszczenie. Celem pracy jest przedstawienie wpływu gęstości kiszonki na jakość i efektywność zakiszania zielonki. Jakość paszy ulega zmniejszeniu w silosach jeśli jest ona niewystarczająco upakowana z uwagi na zmniejszenie się suchej masy i wartości odżywczych spowodowanymi reakcjami aerobowymi. Odpowiednie upakowanie w celu osiągnięcia zalecanej gęstości suchej masy jest wyzwaniem dla rolnika. W opracowaniu niniejszym podano wpływ na gęstość suchej masy takich czynników jak: masa traktora upakowującego, zawartość suchej masy, szybkość napełniania i grubość układanej warstwy zielonki. Zwiększając masę traktora upakowującego, ich liczbę oraz zmniejszając grubość układanej warstwy suchej masy w rezultacie otrzymuje się zwiększenie gęstości składowanej suchej masy. Wysoka gęstość kiszonki w silosie poziomym minimalizuje straty paszy i zmniejsza koszt jej składowania. Gęstość taka zmniejsza porowatość a w jej rezultacie wzrasta pojemność składowania w silosie. Gęstość kiszonki w przekroju silosu wzrasta od góry do dołu, jak również ma miejsce zróżnicowany rozkład gęstości w kierunku poziomym. Na szczególną uwagę zasługuje upakowywanie kiszonki wzdłuż ścian przy zastosowaniu traktorów z wąskimi kołami o dużej masie. Aby uniknąć stoczenia się traktora, kiszonka nie powinna być składowana ani zbyt wysoko bądź zbyt stromo. W pracy omówiono ponadto znaczenie wpływu takich czynników jak: wilgotność, wymiary silosu, stopień rozdrobnienia zielonki, warunki pogodowe podczas napełniania silosu i czas upakowywania jednej tony zielonki.

Słowa kluczowe: silos poziomy, kiszonka, upakowywanie, gęstość.