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Abstract

Silage density is an important factor in silage making. High density of silage in a silo implies a higher storing capacity and a high density of silage can also decrease the risk of dry matter losses due to air penetration into the silage. However, the density is often difficult to measure under practical conditions. In this study a method based on weighing drilled silage samples was evaluated. The method was tested on bunker silos with mainly grass/clover silage in four different farms in mid-Sweden. The drilled samples were collected by two methods: drilling by a 23.2 mm diameter drill (Stickit) and a 39.8 mm diameter drill (JTI). As the Stickit was a new device it was used twice for sampling. The resulting densities (calculated from the weight of the drilled samples and the volume of the hole in the silage created by the sampling) was compared with the densities derived from weighing silage blocks of 300-500 kg fresh weight using silo block-cutters with 1.5 to 2.3 meters width. The results showed that the correlation between the drilling methods was high and that both the JTI and the Stickit drill estimated the fresh weight density, the dry matter density and the dry matter content of silage blocks satisfactory. It was further concluded that the dry matter density depends on the dry matter content and the depth on which the sample is taken. The drilling operation must therefore represent the full silo depth to be able to estimate the density of the entire silo.

Key words: Bunker silo, Density, Dry matter content, JTI, Silage, Stickit

Contents

Introduction

Silage is a common way of storing forage and the forages are fermented in an anaerobic environment. The most common crops used as silage are grasses, legumes and whole crop cereals (McDonald *et al*., 2002). It is stored in different types of silos and fed the animals throughout the year. There are different designs of silos such as; tower silos, bunker silos and bag silos. The advantages to store forage as silage are: it can preserve most of the nutrients of forage, less influence by weather condition compared to hay production, high palatability and digestibility. During the fermentation the acid content increases and reaches a level that can inhibit the growth of some unfavorable bacteria. By adding chemical additives or favorable lactic acid bacteria the ensiling process can be controlled or enhanced.

When the forage is stored in silos the dry matter (DM) loss can be at a range of 12%-16% with good management. Many practices, such as to harvest the forage at optimum moisture content and high yields of sugars, to practice intensive compaction to limit oxygen content in the silo, and to exert high removal rate at feeding can decrease the dry matter losses (Holmes and Muck, 2007). The typical recommended dry matter content of forage for ensiling is 25% to 35% in bunker silos. Silage effluent and clostridial fermentation are the main problems of ensiling low DM content forage. The effluent can result in reduced feed value because the plant juice consists of dissolved nutrients and the amount of losses increase with the increase of moisture content. Clostridial bacteria produce butyric acid, ammonia and amines during fermentation and reduce palatability of the silage, and probably increase the risk of ketosis for lactating dairy cows. Spores of *Clostridium tyrobutyricum* can also be transferred into the milk and cause inferior product quality, mainly bad cheese. For example, the growth of *Clostridium* can lead to excessive gas production and peculiar smell in semihard cheese (Vissers *et al*., 2007). To avoid this, a sufficiently low pH is desired as it inhibits the growth of this bacteria and bad fermentation caused by unfavorable bacteria is rare when the forage is harvested under good conditions. The high-end of the DM range is determined by the susceptibility of the forage to aerobic spoilage loss. Drier forage is more porous and more oxygen is allowed access into the silo and increased the aerobic spoilage loss (Bolton and Holmes, 2006).

Respiration and fermentation are the two main causes of losses if the crops are dry enough to avoid effluent. Lactic acid bacteria and some other microorganisms utilize sugars and other substrates and produce carbon dioxide gas and contribute to the fermentation losses. The loss by lactic acid bacteria is about 1% to 4% and is always considered unavoidable (McDonald *et al.,* 1991). The losses by other microorganisms, such as clostridia, can be limited by controlling the dry matter content of the forage. Respiration loss has two subcategories: plant respiration and microbial respiration. Plant respiration is active a short time after the crop is cut, typically until the crop is filled into the silo and the environment turns from aerobic to anaerobic. Most other losses are from microbial respiration where the activities of microorganisms utilize oxygen and produce carbon dioxide gas. This process is limited by good sealing (Holmes and Muck, 2007).

The density of a silo on a commercial farm is variable (Ruppel *et al.*, 1995). A high density of a silo can minimize the DM losses and reduce the costs of storage. It is important to have a high density in a silo for two main reasons; the porosity of the silage and the capacity of the silo (Bolton and Holmes, 2006). Porosity is determined by density and DM content of the silage, and it affects how much air can enter into the silo and subsequently cause spoilage during storage and feedout. According to research by Ruppel (1992), the dry matter loss of alfalfa silage was decreasing when the density was increased. A minimum dry matter density of 240 kg DM/m^3 (15 lbs DM/ft^3) was recommended by Holmes and Muck (2004) as a reasonable density to attain and to reduce excessive losses of dry matter.

The factors that can increase the density of silage are increased self-compaction by its own weight especially in tower silos, pressure by tractor weight in bunker silos or bag rotor in round bales. Density is also increased by increasing the moisture content (Holmes and Muck, 2007). In a bunker silo, the dry matter density of silage is directly related to the weight of packing tractor, packing time, silage depth and the dry matter content of the silage (Muck and Holmes, 2000). As a summary of many studies related to density in tower or bunker silos Holmes and Muck (2006) stated the following:

- Dry matter density of silage is higher near the bottom than at the top (Muck and Holmes, 2000; Visser, 2005; Craig and Roth, 2005; D’Amours and Savoie, 2004; Oelberg *et al.*, 2005).
- Dry matter density in the centre of a bunker silo is higher than next to the wall (Visser, 2005; Craig and Roth, 2005; D’Amours and Savoie, 2004; Oelberg *et al.*, 2005).
- Reducing layer thickness before packing, increasing the weight of the packing tractor and the number of tractors can increase the dry matter density of the silage (Muck and Holmes, 2000; Visser, 2005; Craig and Roth, 2005; D’Amours and Savoie, 2004; Oelberg *et al.*, 2005).

The study

In our study three methods were used to collect samples for measuring the density of silage in different layers in bunker silos at commercial farms. Blocks of 300-500 kg was collected by a silage cutter machine from the bunker silos. From these blocks, samples were taken by two different core samplers: an older and well established drill, JTI, with rather wide diameter (39.8 mm) and heavy to operate (Nilsson et al, 1986); and a newer type of drill that was narrower in diameter (23.2 mm) and easier to operate, named Stickit. Stickit was developed by the company Ekolag AB, Björklinge, Sweden.

By weighing and analyzing the drill cores the fresh weight density, dry matter content and dry matter density were calculated and compared to the same values of the complete blocks. The values from the complete blocks were used as the reference. The study also delivered information on the relation between DM density and DM content and height in bunker silos.

Literature review

Harvest

The process of making silage begins with harvesting a fresh forage crop from the field. The stage of plant maturity and DM content are two factors that usually determine the time to harvest forages for silage. The DM content generally increase as maturity advances and the nutrient content of the plants decline rapidly after a certain maturity level. To optimize both nutrient content and fermentation of the forages the recommendation for Lucerne (*Medicago sativa Linn*) is to harvest at mid bud and wilt to 30%-35% DM content. It is recommended to harvest unprocessed corn for silage between 1/2 to 2/3 milkline at the DM content 30%-35% (Johnson and Harrison, 2001). The nutrient content of corn silage can change by varying cutting height within a certain maturity (Johnson and Harrison, 2001). In a study, Quaife (2000) found that if around 51 cm of the lower part of the stover were left unharvested, it resulted in silage with higher starch content and lower fiber content compared to a 10 cm cutting height (Table 1).

Table 1. Nutrient content of corn silage harvested with different cutting heights (Quaife, 2000)

Cutting Height (cm)	Yield (tons/acre 30% DM)	Acid Detergent Fiber (% DM)	Starch (% DM)
10.1	29.8	22.1	28.4
20.3	28.4	21.6	29.3
50.8	26.6	20.6	31.1

The nutritive value of corn silage can also be altered by mechanically processing the crop. The energy content of unprocessed corn silage increase until two-thirds milkline, and starts to decline as maturity advances to blackline. However, the nutritive value of processed corn silage seems to increase at all maturity stages, compared to unprocessed corn silage. The fiber digestibility increased by shearing when the plants passed through the rollers of the harvester at harvest in early maturity of corn. At advanced maturities, the starch digestibility of corn increased due to cracking of the kernels which altered the starch matrix in the kernel (Johnson and Harrison, 2001).

It is important to harvest forage at the right stage of maturity and moisture content. The reasons are: (1) to maximize the silage mass density, (2) to minimize the dry matter loss. In addition, forages with proper moisture content can reduce or eliminate seepage (Jones *et al*., 2004). Seepage of silage juice can occur when the forage is harvested at moisture content above 70% (Bolton and Holmes, 2006). It is a significant loss of soluble nutrients.

The mass density and dry matter density of silage are related to the moisture content of forage (Jones *et al.,* 2004). The moisture content of forage is lower when it is harvested at advanced maturity. Drier forage tends to be more difficult to compress (Wood, 1971; Daynard *et al*., 1978). In a study by Daynard *et al*. (1978), double pressure was required to achieve the same density when the dry matter content of maize increased from 270 g/kg to 300 g/kg.

Silage fermentation and management

Silage is forage that has fermented in an anaerobic environment where microbes present in the crop produce acids, mainly lactic acid that reduces the pH of the forage. These microbes (bacteria) consume the soluble carbohydrates in the forages to produce the lactic acid. There are four phases in silage fermentation (Johnson and Harrison, 2001). During the first phase, microbes in the forage consume oxygen and the pH starts to drop. In the second phase fermentation starts, the number of microbes (anaerobic group of bacteria) increases, lactic acid is produced by the activities of these microbes and pH decrease. The third phase is a stable phase with minimal biological activities. Silage will remain in this phase until it is exposed to oxygen. Feedout is referred to as the fourth phase. The silo is then opened and oxygen infiltrates into the silage. This may cause the growth of microorganisms such as yeast and molds that thrive in aerobic environment and the increase of these microorganisms will reduce the nutritive value of forages and may also lead to health problems in animals (Johnson and Harrison, 2001). Due to these problems, it is important to get from the first phase to the stable phase as quickly as possible and minimize oxygen exposure when making silage. The silage management factors are mostly focused on effective fermentation and limiting the oxygen exposure at feedout. Good silage management practices can avoid undesirable DM loss, for example filling a tower silo rapidly, and spreading the forage in thin layers and drive over it with heavy tractors packing it tightly when filling a bunker silo (Holmes and Muck, 2000).

Type of silo

Silo types used at the farms varies, ranging from small plastic bags to large towers built by steel, concrete or wood. In tower silos, forage is packed by the weight of the materials above and the silage near to the top has lower density (Holmes and Muck, 2000). Silage conserved as big bales that are wrapped in plastic film sometimes have the problem that bales do not seal well and get punctured. The technical development of balers is intensive and modern balers chop the material and also make the wrapping while picking up the crop for the next bale. Balers thereby effectively produce the ready packed and sealed “silo” instantly already at harvest. Internationally, the most common type of silo used is the bunker silo which is consisting of 2-3 meters high solid walls (Holmes & Muck, 2004). The surface of the silo is covered with some plastic sheeting and weighted with some materials when the silo is full.

Importance of the density of silage

Many factors can affect the quality of silage, for example, forage species, harvest time, oxygen exposure, filling and packing techniques of bunker silos and some other management practices. One of the most important factors is the density of the silage. A higher density means that more silage can be stored in a silo and dry matter losses during storage decrease, as well as the annual cost in commercial farms.

A high density in a silo is important for two main reasons. First, the density and dry matter content determine the porosity of the silage. Second, a higher density means a higher storage capacity of the silo (Martin *et al*., 2004). Table 2 shows the results of a study on dry matter loss related to density for Lucerne silage measured by Ruppel (1992).

Table 2. Dry matter loss related to density of silage in bunker silo (Ruppel, 1992)

Density (kg DM/m^3)	160	224	240	256	288	352
Dry matter loss, 180 days (%)	20.2	16.8	15.9	15.1	13.4	10.0

The storage capacity of a silo also relate to the density of silage. A fact that is often neglected is that knowledge about the density is required in order to estimate the quantity of silage stored in the silo. This is needed when planning the daily consumption and to plan for the emptying of the silo. As forages are normally not weighed or measured at harvest, the density is also used for estimation of the yield (Holmes, 2008).

Dry matter losses of silage are caused by growing microbial populations in an aerobic environment. Yeasts, molds and acetic acid bacteria degrade soluble substrates of grass initializing aerobic deterioration (Muck *et al*., 1991; Spoelstra *et al*., 1988; Middelhoven *et al*., 1988). Oxygen must come into silage to allow the aerobic microorganisms to grow and cause deterioration (Williams, 1994). Diffusion (Pitt, 1986) and permeation (Parsons, 1991) are considered to be the mechanisms of oxygen penetration. Diffusion is affected by variation of oxygen concentration and permeation is affected by the difference of pressure.

Silage density can be increased by increased packing at silo filling. This technique limits the amount of oxygen in the silo and the amount of aerobic microbes in the forage will be lower. Consequently, the plant respiration can be prevented. Furthermore, at the time that the forage is re-exposed to oxygen, the time taken to rise the temperature due to increased aerobic deterioration will be longer if silage density is high (Johnson and

Harrison, 2001).

Materials and methods

This study was initiated to determine fresh and dry matter silage density of bunker silos in four farms; Lövsta, Kårsta, Focksta and Ola, during November in 2011. The farms were situated near Uppsala in Sweden at about N 60° and E 17°. The effects of two different drill sizes, Stickit and JTI were also compared at the same time. Table 3 shows the specification of the silos and some information about the four farms.

Table 3. Specifications of the silos and some other information of the farms included in the study

	Lövsta	Kårsta	Focksta	Ola
Silo (length/width/height)	43/7.95/3	41/10.4/2.98	30/7.4/3	42/12.96/3
Drilling Date	2011-11-08	2011-11-11	2011-11-15	2011-11-18
Weight of packing machine (tonne)	15*	14+9 rotor	14	14 +10 rotor
Silo filling, period	Unknown	12th July	Unknown	20th July
Materials	Grass/Clover crops	Grass/Clover crops/Whole crop of cereal**	Grass/Clover crops	Grass/Clover crops

*The information about the rotor is unsure.

**the whole crop cereals was in the bottom of the silo.

The same self-propelled forage harvester "Claas Jaguar" was used in the four farms.

Materials

- Silage samples were collected from bunker silos at four farms; Lövsta, Kårsta, Focksta and Ola
- Drilling machine, drill "Stickit" 23.2 mm inner diameter (Figure 1) and drill "JTI" 39.8 mm inner diameter (Figure 2), extension for Stickit, rubber pad,
- Silo block-cutter machine, container for weighing block

Figure 1. Stickit-drill and extension Photo: Claes Jonsson.

Figure 2. Front of JTI-drill. Photo: Claes Jonsson

Methods

The work began with determining the center position of the block in the silo. Then samples were collected by drilling with the two different core samplers from the top of the silo and the drilling depth was measured. After drilling, a silage cutter was used to take out the block and put it in a container to weigh the fresh weight of the block. The width, length and height of the block were measured at the same time. The procedure was repeated again until the bottom of the silo was reached.

In Lövsta and Focksta farms, blocks were collected at four levels of the bunker silo, and at Kårsta and Ola farms blocks were collected from five levels. In farm Kårsta, the bottom block was a whole crop silage block and the other four were forage silage blocks. Table 4 indicates the position of each block that was taken from the silos and regarded as the center-block.

Table 4. Position of the center block collected in bunker silos at the farms

	Lövsta	Kårsta	Focksta	Ola
From the opening end of the silo (m)	32	20	16.5	9.3
From the 'left' wall of the silo (m)	6.2	3	5	4.45
Height of upper level block from the bottom of the silo (m)	2.25	2.82	2.65	3.03
Planned block height (cm)	65	60	60	60

A 23.2 mm diameter Stickit and a 39.8 mm diameter JTI were used to drill into the block of the silage at 3 locations. One of them was drilled by JTI and the other two were drilled by Stickit. The Stickit was a new method so we repeated sampling with it two times. Stickit 1 and Stickit 2 was just a repetition of the same method. The locations of sample collecting sites were determined by a rubber pad with holes on it (Figure 3 and 4). The planned drilling depths of the two instruments were 15 cm (Stickit) and 25cm (JTI). The drilling depth of each sample depended on the planned height of the block and the Stickit needed extensions to collect samples with the increase of drilling depth. The block-cutter machine was used to cut out the block and separate it from the silo after having collected the three drilling samples, and the block was then weighed. The whole block of silage was weighed by using a big container and an electric scale (Figure 11). The length, width and height of the blocks were measured for calculating the volume of each block. The volume of drilling sample was determined by the diameters of JTI and Stickit and drilling depth of each sample. The procedure was then repeated until four or five blocks had been cut and the bottom level of the silo was reached. The volume of each block depended on the silage cutter machine that was normally used in the farm (Table 5). Bunker silo surfaces and silage block cutters used at the different farms are presented in Figures 5 to 11.

Figure 3. Rubber pad for determination of the the positions of drilling. Photo: Claes Jonsson

Figure 4. Positions of drilling in the silage after drilling. Photo: Ruonan Wang

Figure 5. Collecting blocks in Lövsta. Photo: Ruonan Wang

Figure 6. Silo in farm Kårsta. Photo: Ruonan Wang


2011/11/15

Figure 7. Silo in farm Focksta. Photo: Ruonan Wang


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Figure 8. Silo in farm Ola. Photo: Claes Jonsson

Table 5. Block cutter machine that was used at each of the farms, width of block cutter in parentheses

	Lövsta	Kårsta	Focksta	Ola
Block-cutter machine	Ri-Mach (2 m)	Ålö Silocut (2.3 m)	Ålö Silocut (1.5 m)	Ålö Silocut (2.3 m)

Figure 9. Block-cutter machine used at Lövsta. Photo: Claes Jonsson

Figure 10. Block-cutter machine used at Focksta. Photo: Claes Jonsson

Figure 11. Block-cutter machine used at Ola, and the container used for weighing the blocks. Photo: Claes Jonsson

Measurements performed at the laboratory and calculations:

- Weighing the fresh weight of the drilled samples and calculating the fresh matter density of silage
- The samples were then dried at 65°C for > 10 hours to make sure that the samples are dried enough and weighed warm
- Calculating the DM content, dry matter density of each block and the average values of DM content and dry matter density of silage in each farm from the values achieved.

Silage density was calculated by dividing the silage weight (fresh and dry) by the volume of samples and blocks. DM content was calculated by the following formula:

DM content (%) = dry weight / fresh weight * 100

The value of DM content of the whole block was calculated by the average of the three samples drilled by Stickit and JTI.

There able to compare farms with different numbers of blocks, results were reported as three layers; top, mid, and bottom. At farms where four blocks were sampled the mean of the two middle layers were used as mid layer. At farms where five blocks were sampled, the mean of the three middle layers were used as mid layer.

Statistical analysis

Statistical analysis was performed by SAS (SAS institute, Cary, NC, USA, version 9.1). Pearson correlation coefficients of drilling tools effects among farms and among different layers within a silo both for fresh matter density and dry matter density were calculated, and if $P < 0.05$ the correlation was regarded as statistically significant. The two measurements of the Stickit method was treated as two repeated measurements named Stickit 1 and Stickit 2.

Standard deviation, represented by the symbol sigma (σ), is commonly used to measure the dispersion in statistical analysis. The standard deviation of a data set is the square root of its variance. It shows the variation of the values from the mean value of the population. A high standard deviation indicates the data points are spread in a large range of values. On the other hand, a low standard deviation shows that the data points are very close to the mean value of the data set.

The Pearson correlation coefficient is used to measure the correlation between two variables in statistics.

To study the effect of which depth (layer) the sample was taken from and the influence of the DM content on dry matter density, the following model was used in SAS with general linear models procedure:

$$y_{ijkl} = \mu + \alpha_i + \beta_j + \gamma_k + e_{ijkl}$$

Where *α* is the effect of farm, *ß* is the effect of DM, *γ* is the effect of layer and *e* is the residual effect. Farm and layer was treated as class variables. Where interaction among dry matter content and dry matter density was significant it was included in the model.

The P-value less than the significant level and the result is said to be significant. The common significant levels are 0.05 and 0.01.

Results

Block height and drilling depth

Comparing the values of block heights and drilling depths between the four farms, data from Focksta was a little bit higher than data from the other three farms (Table 6).

Table 6. Difference between mean block height and drilling depth in four farms

	Lövsta	Kårsta	Focksta	Ola
Mean block height (cm)	58.5	55.0	64.8	59.8
Mean drilling depth (cm)	60.3	56.1	58.9	60.5
Difference (cm) between block height and drilling depth	1.8	1.1	5.9	0.7

Fresh matter density

Lövsta had the highest average fresh matter density compared to the other three farms. The mean values of fresh matter density at different layers are shown in Figure 12. Figure 13 to 15 shows the fresh matter density of the three layers with different sampling methods. The average of fresh matter density in all four farms is showed in Table 7.

Table 7. The average fresh matter density (FMD) at different layers and mean fresh matter density (including all sampling methods) in the four farms (standard deviation within parentheses)

	N	Lövsta	Kårsta	Fockista	Ola
Mean FMD, kg/m^3	4	887 (121.3)	809 (88.5)	730 (129.3)	804 (95.7)
FMD of top layer, kg/m^3	4	741 (57.2)	687 (41.3)	547 (47.5)	648 (49.1)
FMD of middle layer, kg/m^3	4	918 (57.4)	871 (42.8)	758 (65.8)	834 (53.9)
FMD of bottom layer, kg/m^3	4	970 (149.2)	745 (19.9)	858 (52.6)	868 (56.7)

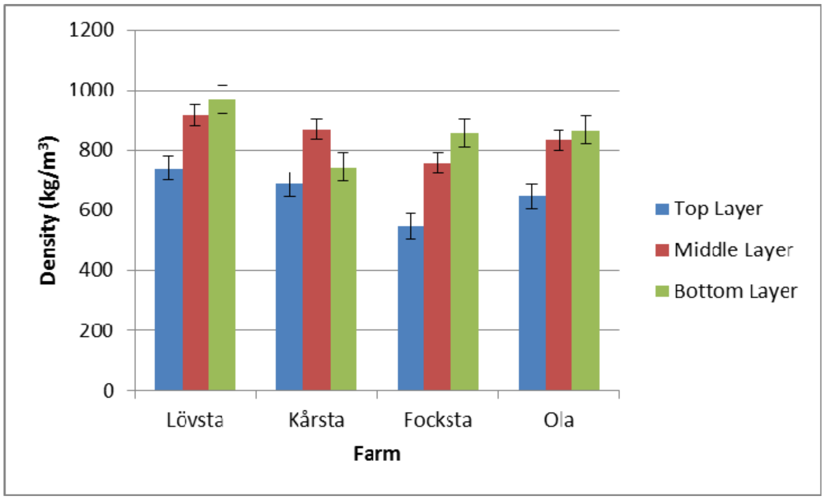


Figure 12. Mean fresh matter density of different layers (including all sampling methods) in the four farms.

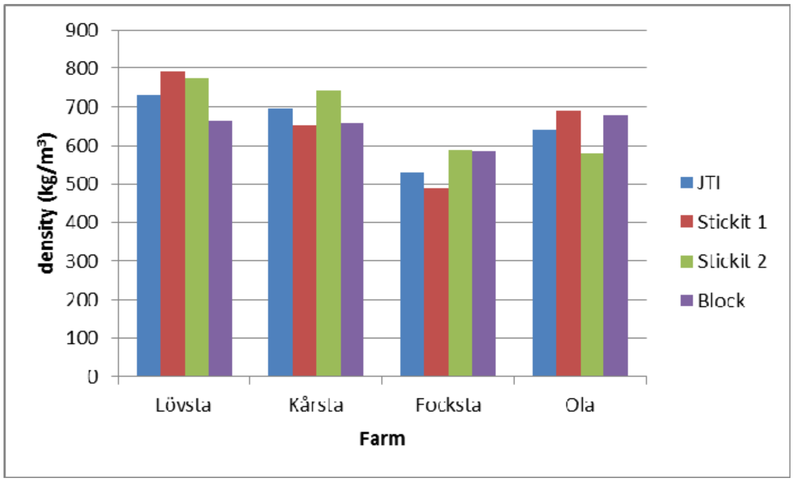


Figure 13. Fresh matter density of the top layer in the four farms using the different sampling methods

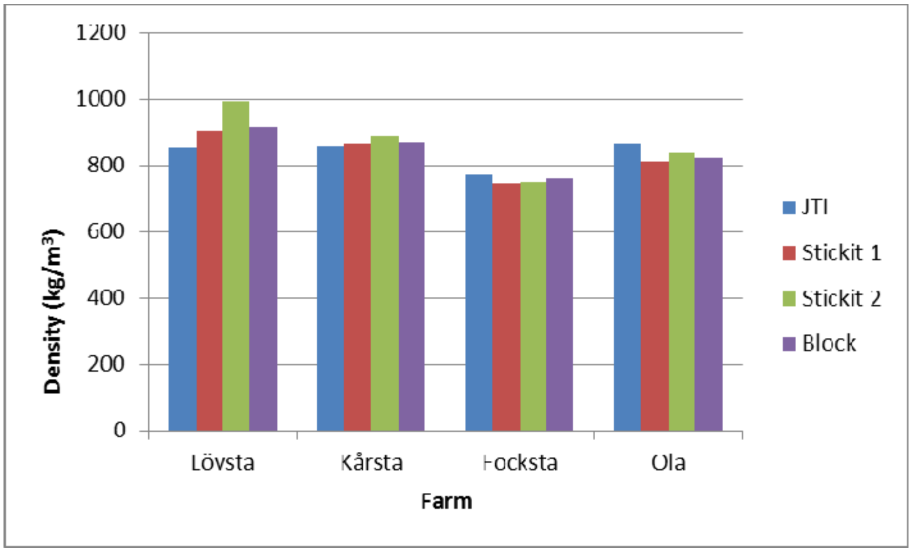


Figure14. Fresh matter density of middle layers in the four farms using the different sampling methods.

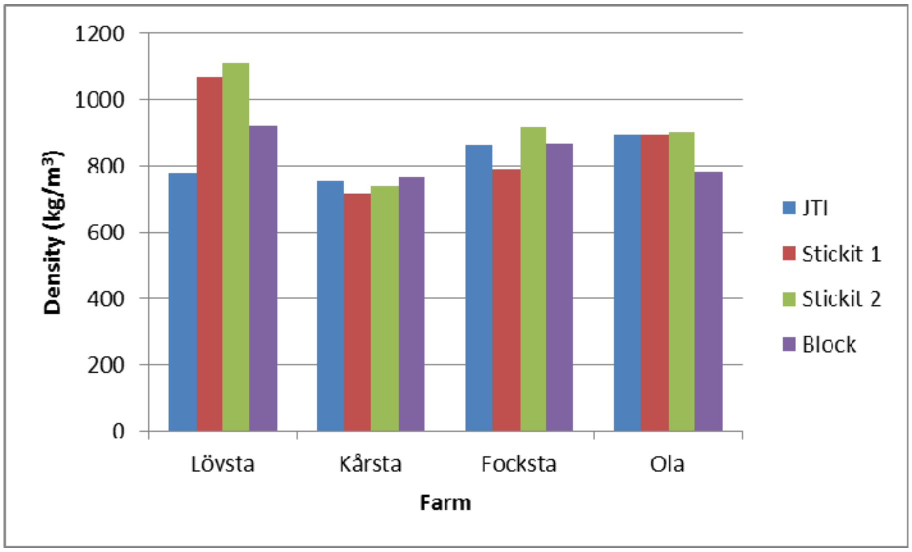


Figure15. Fresh matter density of bottom layers in the four farms using the different sampling methods.

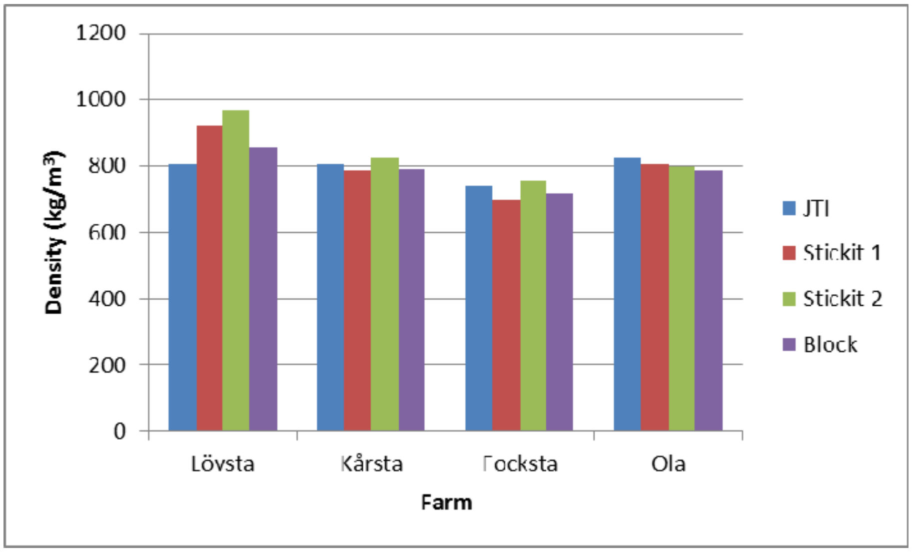


Figure16. Average values of fresh matter density of all layers drilled by JTI, Stickit 1 and 2, and the density of the whole block in the four farms.

The density of fresh matter increased from top to bottom in most farms except from Kårsta, where the density of the bottom layer was lower compared to the middle layer, and the Kårsta bottom layer also had the lowest fresh matter density of all bottom layers at the four farms. Different material used for ensiling in the bottom layer of Kårsta might be the reason for this. We also found that it was easier to drill the bottom layer compared to the other layers when we working in Kårsta. Lövsta had the highest density at every layer among all farms.

The correlation results showed that in different layers, the fresh matter density of samples that were drilled by Stickit 1 and 2 were strongly correlated (Table 8). The fresh matter density in samples drilled by JTI, Stickit 1 and 2 were all well correlated to the density of the whole block. The correlation between JTI and Stickit 1and between JTI and Stickit 2 were lower compared to the correlation among block and drilling methods (Table 8).

Table 8. Pearson correlation coefficients of fresh matter density between JTI, Stickit 1, Stickit 2 and block (including data from all layers)

	N	JTI and Block	Stickit 1 and Block	Stickit 2 and Block	JTI and Stickit 1	JTI and Stickit 2	Stickit1 and Stickit 2
Pearson Correlation Coefficient	18	0.80	0.85	0.89	0.74	0.73	0.91
P value		<0. 0001	<0. 0001	<0. 0001	0. 0005	0. 0006	<0. 0001

Dry matter content

Average dry matter content of each farm and the range of dry matter content in different layers in the four farms are shown in Table 9.

Table 9. The mean dry matter content (data from all drilling methods) of silage from the four farms

	Lövsta	Kårsta	Focksta	Ola
DM content (%)	23.8	30.6	31.5	31.2
MIN/MAX	22.4/25.0	25.8/35.9	25.2/37.1	26.4/36.4

In farm Kårsta, the DM content of bottom layer with whole crop cereals was much higher than the other layers in Kårsta. Mean DM content of silage was highest at Focksta and lowest at Lövsta. The DM content of samples collected by JTI and Stickit 1 and 2 were strongly correlated (Table 10).

Table 10. The Pearson correlation coefficient of DM content between JTI, Stickit 1, Stickit 2 (including data from all farms)

	JTI and Stickit 1	JTI and Stickit 2	Stickit1 and Stickit 2
Pearson Correlation Coefficient	0.94	0.97	0.97
P value	<0. 0001	<0. 0001	<0. 0001

Dry matter density

The average dry matter density of Lövsta was the lowest and farm Kårsta had the highest dry matter density among the four farms. The values of DM density were increasing from top to bottom in the silos of all farms except Fockstа. In Fockstа, the middle layer had the highest DM density. Table 11 and Figure 20 show the values of the average dry matter density in different layers and the mean DM density of the silo.

Table 11. The average dry matter density (DMD) in different layers of the silos and mean dry matter density of the four farms, data from all sampling methods included (standard deviation within parentheses)

	N	Lövsta	Kårsta	Fockstа	Ola
Mean DMD,	4	212	257	226	250
kg DM/m^3		(35.8)	(22.7)	(31.2)	(37.6)
DMD of top	4	166	221	185	208
layer, kg DM/m^3		(13.8)	(14.1)	(12.9)	(15.1)
DMD of middle	4	219	266	252	249
layer, kg DM/m^3		(14.4)	(14.1)	(11.7)	(29.7)
DMD of bottom	4	242	267	217	296
layer, kg DM/m^3		(39.4)	(13.2)	(16.4)	(19.4)

Figure 17 shows the mean dry matter density of different layers on the four farms. Figure 18 to 20 show the dry matter density at the different layers of silos using different sampling methods. Finally, Figure 21 shows the silo dry matter density as an average of all layers at each farm.

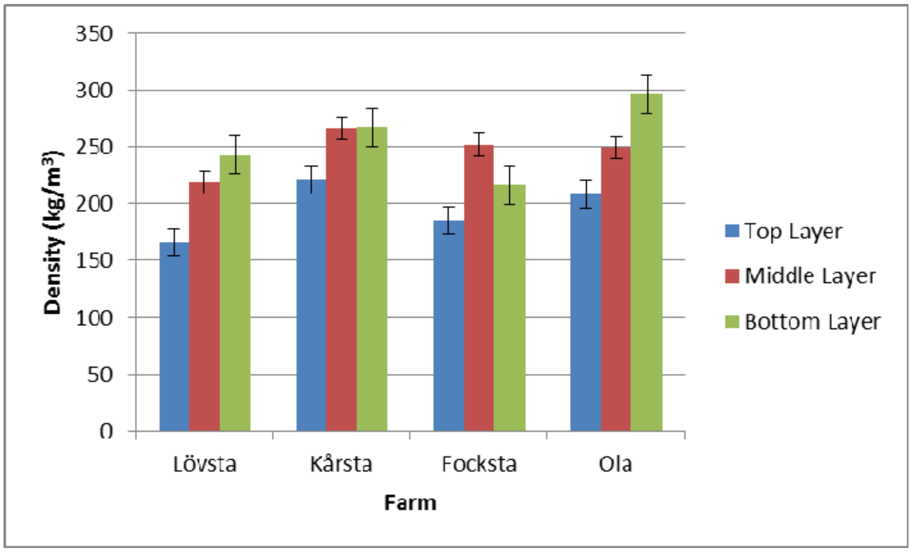


Figure17. Mean dry matter density of different layer in four farms

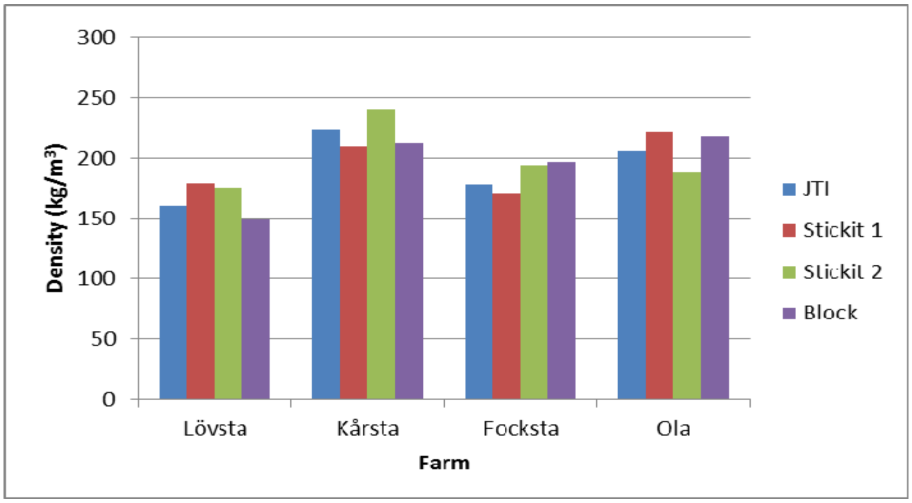


Figure18. Dry matter density of top layer in the four farms

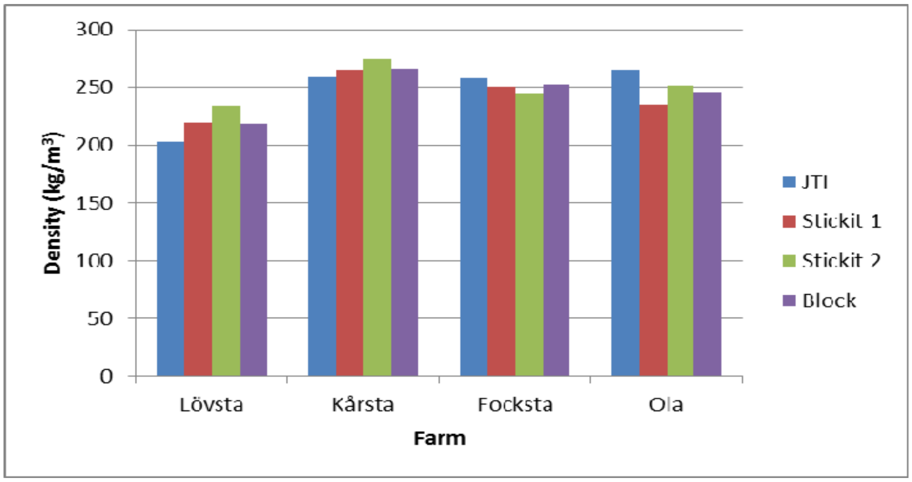


Figure19. Dry matter density of middle layer in the four farms

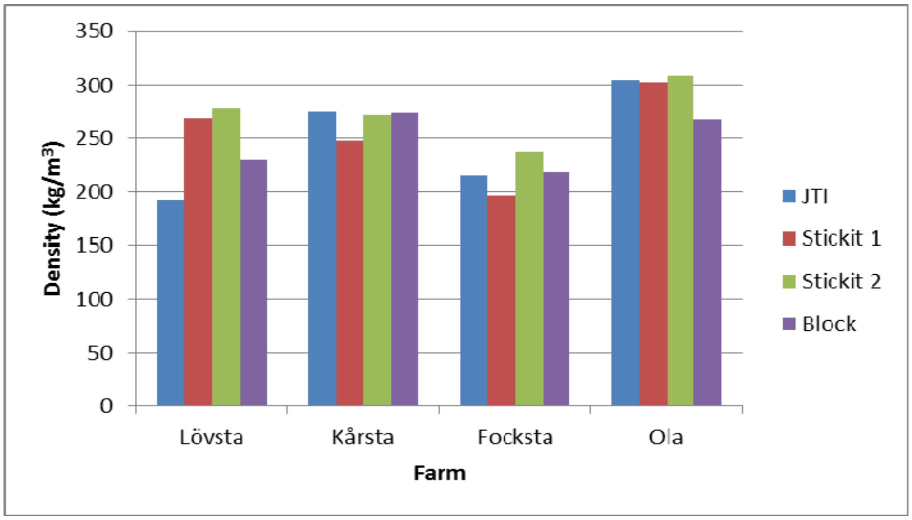


Figure20. Dry matter density of bottom layer in four farms

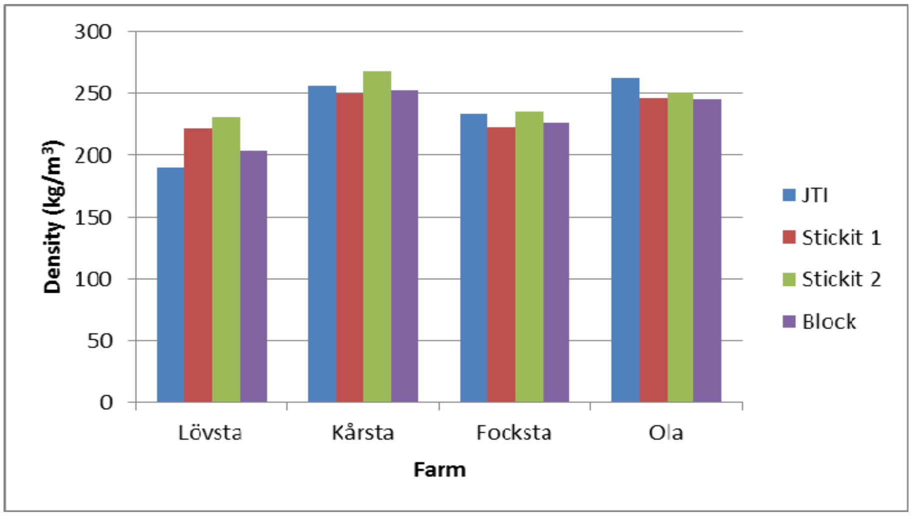


Figure 21. Mean dry matter density of samples drilled by JTI, Stickit 1 and 2, and the density of block

The correlations between drilling methods JTI, Stickit 1 and 2 and the whole block for DM density were significant. The DM density measured with the Stickit method showed as good correlation with the block as did the JTI method. The highest correlation was, as expected between Stickit 1 and Stickit 2 indicating a good repeatability of the method (Table 12).

Table 12. The Pearson correlation coefficients for dry matter density between JTI, Stickit 1, Stickit 2 and block, data including all layers and all farms

	N	JTI and Block	Stickit 1 and Block	Stickit 2 and Block	JTI and Stickit 1	JTI and Stickit 2	Stickit1 and Stickit 2
Pearson Correlation Coefficient (P value)	18	0.85 <0. 0001	0.86 <0. 0001	0.85 <0. 0001	0.73 0.0005	0.74 0. 0004	0.88 <0. 0001

Density estimation with different methods

In Figures 22 to 24 the full regressions for the dry matter density between the JTI sampling method (Figure 22) and the Stickit 1 and 2 sampling method (Figure 23 and 24) are plotted against the block dry matter density. The estimate by the JTI drill balances at 240 kg DM/m^3 where it equals the block DM density. At 300 kg DM/m^3 the JTI method underestimates with 18 kg DM/m^3 and at 200 kg DM/m^3 it overestimates with 10 kg DM/m^3. The Stickit 1 balances at 240 kg DM/m^3 with an underestimation of 12 kg DM/m^3 at 300 kg DM/m^3 and overestimation of 8 kg DM/m^3 at 200 kg DM/m^3. The Stickit 2 underestimates with 9 kg DM/m^3 at 240 kg

DM/m^3 with an underestimation of 21 kg DM/m^3 at 300 kg DM/m^3 and balances at 200 kg DM/m^3.

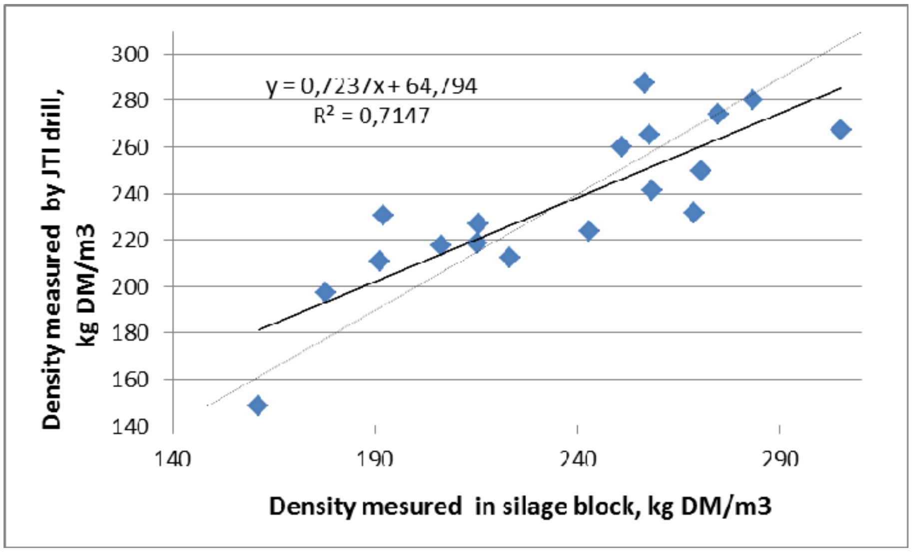


Figure 22. The regression of dry matter density in samples taken with JTI-method compared to the block dry matter density. The continuous line is the regression line and the dotted line is the ideal where y=x.

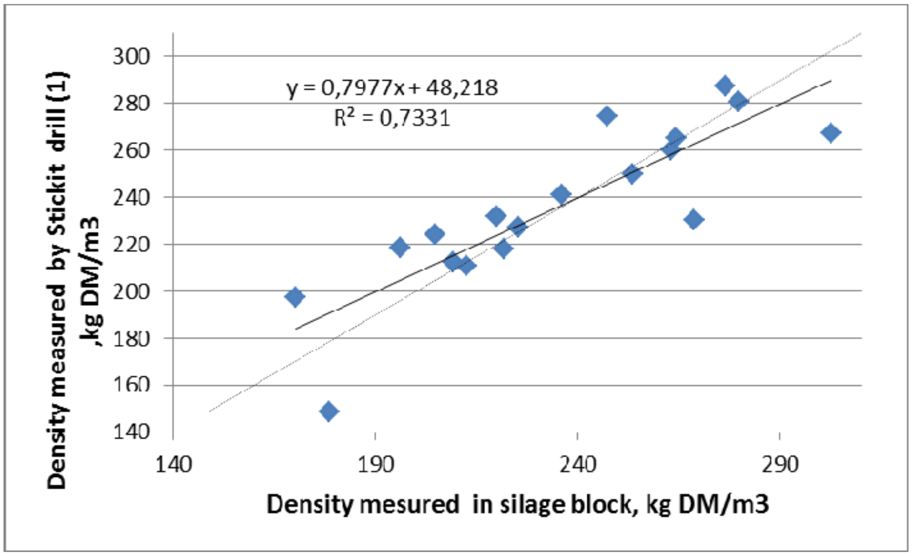


Figure 23. The regression of dry matter density in samples taken with Stickit-method 1 compared to the block dry matter density. The continuous line is the regression and the dotted line is the ideal where y=x.

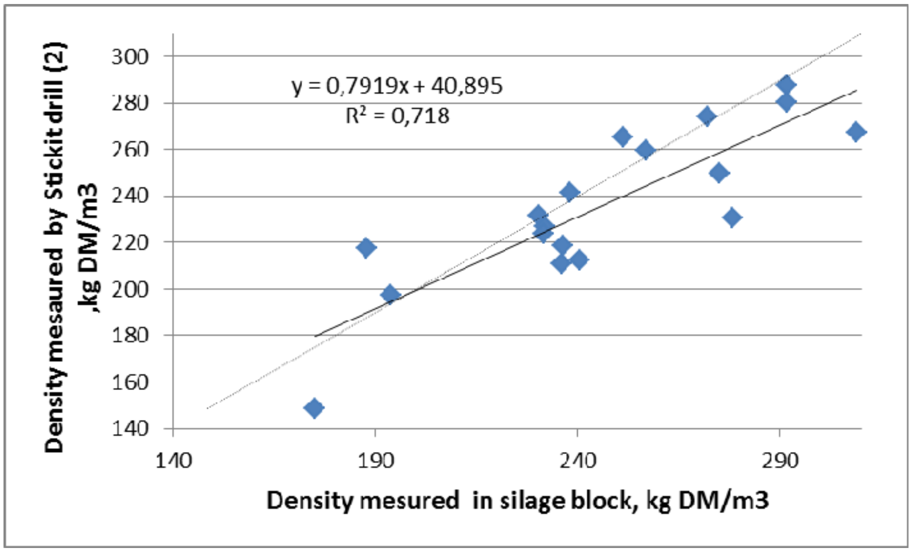


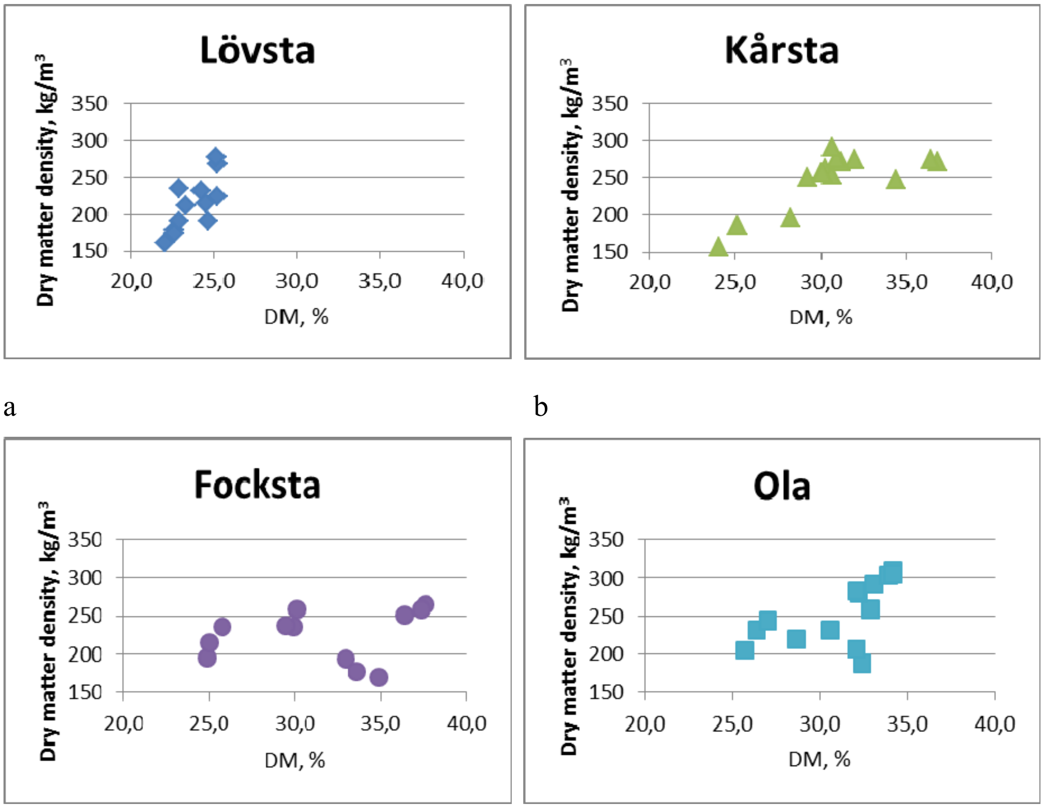
Figure 24. The regression of dry matter density in samples taken with Stickit-method 2 compared to the block dry matter density. The continuous line is the regression and the dotted line is the ideal where y=x.

From these three figures, we got the regression coefficients (R^2) of dry matter density measured by two drilling methods and the block, and they were 0.7147 (JTI), 0.7331 (Stickit 1) and 0.718 (Stickit 2) respectively. It seemed that the dry matter density measured by the two drilling methods correlated well to dry matter density measured in the silage block. Furthermore, we used SAS-GLM procedure as statistical analysis. The SAS-GLM procedure is a method uses least squares to fit a general linear model. According to the results, the correlation between dry matter density measured by two drilling methods (JTI and Stickit) and block was significant ($P<0.0001$).

Table 13. The mean values of fresh matter density, DM content and dry matter density of 18 blocks by all methods

	In block	By JTI	By Stickit	
			Stickit 1	Stickit 2
Fresh matter density, kg /m^3	797	795.	801	834
DM content, %	29.5	29.6	29.2	29.5
Dry matter density, kg DM/m^3	235	236	235	246

Figure 25a-d illustrates the relation between DM content and the dry matter density of silage in the four farms. As the results showed in these figures, the dry matter content of silage and dry matter density almost had the same trend. As DM content increased, so did DM density in the four farms in our study.



a b

c d

Figure 25a-d. Plots of dry matter content and dry matter density in silage at the four farms included in the study.

According to the results of the GLM (General Linear Model) procedure the model including farm, layer and DM content were factors having an effect on the block DM density (*P*=0.0004). The effect of farm was barely significant (*P*=0.0542), the effect of layer was significant (*P*=0.0014) and the effect of DM content was significant (*P*=0.0043) on the dry matter density of a block. The Least Square Means (LSM) of the block dry matter density in different layers and farms are shown in Tables 14 and 15.

Table 14. Least square means of block dry matter density in different layers at farms Lövsta, Kårsta (5 layers), Focksta and Ola (4 layers).

Layer	Density, kg DM/m^3
1	198.1^a
2	238.5^b
3	242.1^b
4	259.5^b
5	236.3^b

$^{a,\ b)}$ Means with different superscripts differ at $P<0.05$

Table 15. Least square means of block dry matter density in different layers at farms Lövsta, Kårsta, Focksta and Ola.

Farm	Density, kg DM/m^3
1	230.8^b
2	251.2^a
3	221.4^b
4	236.2^b

$^{a,b)}$Means with different superscripts differ at $P<0.005$

Discussion

The results of our study showed that the density of silage in a bunker silo was commonly higher near to bottom than towards the top in the center part of the silo. The different methods used for collecting samples by drilling for measurements of density were well correlated with the density measured on whole blocks. Instead of cutting a whole block, any of the two drilling tools JTI and Stickit could be used for sampling when density needs to be calculated. Both were effective in collecting samples and the Stickit was easier to operate. Referring to one sample got in a block compared with the whole block, the average volume of samples collected by Stickit and JTI was only 0.06% and 0.18% of the volume of the block. The correctness of estimating the dry matter density might be higher by using JTI for sampling.

Dry matter density of a block can be affected by the layer (height in the silo) and the DM content of the block in our study. In this study, the dry matter content and dry matter density nearly have the same trend but a few results were different. In farm Kårsta, dry matter density of silage in the bottom layer was not so high however the dry matter content was higher than that of other layers. Different materials used for ensiling might be the reason for that. The whole crop cereal used in Kårsta might be harvested at an advanced maturity stage. The DM content of plant increased as they developed (Cherney and Marten, 1982). The silage in the top layer in farm Focksta also had a high DM content and lower dry matter density compared to the other layers. The reason for that was not well understood. It is probably that the upper layer silage was not packed tightly. The drilling can identify the differences in DM density that exists between the different layers in our results. Therefore the whole silo depth has to be drilled in order to estimate the whole silo DM density.

There are some experiences that need to be discussed in our study that may influence the results. In this study, the variations in dry matter content can be caused by effluent being produced as we drilled deeper and deeper. Also, we found the knife of the block-cutter to be slightly imperfect and silage effluent was present on the knife, as well as in the middle layer at Focksta. The effluent could not be collected and that might affect the results. In these four farms, the upper blocks in the silo were often uneven in hardness, which could have contributed to inaccurate depths of boreholes.

The materials that were used for ensiling might affect the fresh matter density of silage. In farm Kårsta, the bottom layer of the bunker was filled with whole crop of cereals and we noticed that this block was loose and it was easier to collect samples by JTI and Stickit compared to the other four blocks which were filled with forages. Our results also showed that mean fresh matter density of the bottom layer was lower than that of mid layer. The reason for this might be that the whole crop cereal was harvested at advanced maturity which results in harder kernels and structural changes in the cell wall of the stem, also it is more difficult to compact this kind of plant material in a silo compared to plants harvested at early maturity (Kennely and Weinberg, 2003).

The measurement of the blocks' weight does not feel completely secure because of the silage effluent we missed. It seems different cutting positions of blocks and assessments of carry over effects from neighboring blocks are needed. Further, this study was performed on only four farms. The average variation in DM content among the silos was low in our study although quite a large variation between different layers and blocks was observed. It would be valuable if the different drilling equipments could be tested in silages differing more in dry matter content.

From the results of our study, we propose that when the farmer or adviser takes samples for nutritional analysis he/she may gain important information of the density by weighing the core sample taken by drilling instead of collecting and weighing complete blocks. The findings of Nilsson et. al. 1986, that the JTI drill gave adequate samples, was confirmed and the study also showed that it can be replaced by the more easily operated Stickit drill. However, in order to to ensure the relationship between variation of DM content and dry matter density of silage in bunker silos more experiments are needed. Therefore it is advised to take samples in order to estimate the silage density and total silage quantity in a silo.

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