*Avrupa Bilim ve Teknoloji Dergisi*
*Sayı 17, S. 744-749, Aralık 2019*
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***Araştırma Makalesi***

www.ejosat.com ISSN:2148-2683

*European Journal of Science and Technology*
*No. 17, pp. 744-749, December 2019*
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***Research Article***

# Examination of the Measurement Methods Used to Determine the Silage Density in Small Farm

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(İlk Geliş Tarihi 30 Eylül 2019 ve Kabul Tarihi 13 Kasım 2019)

(**DOI:** 10.31590/ejosat.625909)

**ATIF/REFERENCE:** Şahin, M. & Tan, F. (2019). Examination of the Measurement Methods Used to Determine the Silage Density in Small Farm. *Avrupa Bilim ve Teknoloji Dergisi*, (17), 744-749.

**Abstract**

The aim of this study was to determine the density of the compacted material in pile-type silo under field conditions and to compare different measurement methods. Three different methods (core sampling-M2,M3,M4,M5; penetrometer-M6 and control method-M1) were used for density measurement. The density measurements of the corn silage were made during the ensiling (stage-I) and at the feeding (stage-II). The results showed that different results were obtained in density measurement methods both stages. In all methods, measurements taken from 0.40 m-layer thickness were always denser than at the measurement taken from 1.20 m-layer thickness by 21.75% in stage-I, 32.96% in stage-II. Linear regression models were determined between the methods and the M6 method both stages. Methods were statically significant. M4 from the core sampling method and M6 are recommended because they are practical for small farms in field conditions.

**Anahtar Keywords:** Density, Penetrometer, Corn, Silage, Pile-type silo, Density measurement.

# Küçük İşletmelerde Silaj Yoğunluğunu Belirlemek Amacıyla Kullanılan Ölçüm Metotlarının İncelenmesi

**Öz**

Bu çalışmanın amacı saha koşullarında yığın tip silaj yapımında sıkıştırılan materyalin yoğunluğunu belirlemek ve farklı ölçüm metotlarını karşılaştırmaktır. Yoğunluk ölçümleri için üç farklı ölçüm yöntemi ( Örnekleme M2, M3, M4,M5; penetrometre-M6; ve kontrol yöntemi) kullanılmıştır. Mısır silajında yoğunluk ölçümleri silolama sırasında (Aşama-I) ve yemleme sırasında (Aşama-II) yapılmıştır. Sonuçlar her iki aşamada da farklı yoğunluk değerleri göstermiştir. Bütün metotlarda 0.40 m den alınan ölçümler, 1.20 m kalınlığında alınan örneklere göre; aşama-I de % 21.75, aşama-II' de ise % 32.96 daha fazla yoğunluk değerine sahip olduğu saptanmıştır. Her iki aşamada da M6 yöntemi i ile diğer yöntemler arasında lineer olarak bir regrasyon modeli belirlenmiştir. Yöntemler istatistiki açıdan önemli bulunmuştur. Çalışma sonuçlarına göre; örnekleme metotlarından M4 ve penetrometre ölçüm yöntemi olan-M6 tarla koşullarında ufak işletmeler için pratik ölçüm tekniği olmaları nedeniyle önerilen yöntemler olmuştur.

**Kelimeler:** Yoğunluk, Penetrometre, Mısır, Yığın silo, Yoğunluk ölçüm.

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# 1. Introduction

The density of the silage is the most important factor affected the quality of silage. For good quality silage, it is desirable to have a high density. But, the density of silage is highly variable, especially in pile-type silos (Roy et al. 2001). Heterogeneous density in the silo is a major problem in terms of silage quality (Latsch 2014). There are many factors that affect the silage density. These are the weight of the compression equipment used (Muck and Holmes 2000, Ruppel et al. 1995), pressure (Savoie et al. 2004, Tan et al. 2018), the layer thickness, number of layers, silage height (D'Amours and Savoie 2005), the compression time (Roy et al. 2001, Ruppel 1993), and the operator experience (Tan et al. 2018). Other factors such as tire pressure, crop and particle size were not correlated with density (Holmes and Muck 2000). Ruppel et al. (1995) and Holmes (2008) indicated a linear relationship between density and DM loss. Pitt and Muck (1993) also reported DM loss was reduced as silage density increased.

Different methods can be used to calculate the density. Norell et al. (2013) compared three methods (Core sampling, calculator and feed-out methods) for estimating silage density on different farms. They have proposed the core sampling and calculator method for estimating storage dry matter losses and evaluating alternative ensiling management practices. Hoffmann and Geyer (2014) used radiometric method to determine the density of the ensiled material during the compaction drives. They have reported that this method is cost-effective if the number of dairy cows exceeds 135 cows, not for small livestock enterprises. Latsch and Sauter (2013) reported good results with drilling cylinder to underestimate density in grass silage. High penetration resistance ($Ncm^{-2}$) is considered as a high compression and high density (Medvedev 2009). Roy et al. (2001) stated that small farms the higher silage density in small farms is very difficult as they do not have access to heavy compaction vehicles. Penetrometer method was used by Sun et al (2009) to determine the bale density. Li et al. (2016) developed that a penetrometer-based mapping system for visualizing silage density. They have reported that this system may be beneficial to estimate the risk of aerobic degradation potential in silos.

This study was initiated to compare different measurement methods for determining the density of silage in pile-type silo for small farms and to determine the relationship between the methods used.

# 2. Material and Method

## 2.1. Experimental Design

The main parameters recorded during this study are given in Table 1. The second crop of maize was harvested and the chopped material was ensiled in the pile-type silo.

*Table 1. The Main Parameters*

| | | |
|---|---|---|
| Corn type | | Pioneer ® P2948W |
| Harvest date (Ensiling date) | | November 2, 2017 |
| Measurement date of the stage-I | | November 2, 2017 |
| Measurement date of the stage-II | | Feb. 14, March 10,April 2,2018 |
| Dry matter content (%) | Stage-I | 32 |
| | Stage-II | 28, 27, 26.3 |
| Mean chop length (mm) | | 12 |
| Tractor type | | John Deere 6230 |
| Tractor mass (t) | | 4.6 |
| Front tire size | | 380/85R24 |
| Rear tire size | | 420/85R38 |
| Tire pressure front/rear (bar) | | 2/2.3 |
| Layer thickness (m) I-II-III | | 0.40-0.80-1.20 |
| Silo size (m) | | 12x4.5x1.6 |

Trials were performed in two stages; stage-I; during the ensiling period, stage-II, during the feeding period. The measurements at the stage-II, were performed on three different days depending on the opening day of the silo. The first measurement was carried out in the front region of the silo, the second measurement in the middle region of the silo and the third measurement in the rear region of the silo. A single tractor was used to compact the silage material. Dry matter contents of the samples were determined according to standard method S358.2 (ASAE 2002).

## 2.2. Density Measurement

Density measurements were made at three height levels of the silo both at the ensiling stage (stage-I) and at the feeding stage (stage-II). In silo, were identified 27 measurement points to measure density of silage. These points were shown in Figure 1. There are 9 measuring points in each layer of the silo. Measurements were made at a similar point for each method. Density measurements in the stage-I were completed during the filling period in all measurement points. In Stage II, the densities were measured and calculated on three different days depending on the opening day. At stage II, measurements on first measurement day (Feb. 14): A1....A9 in the measurement points; on the second day (March 10): B1.....B9 in the measurement points; on the third day (April 2,2018): C1..... C9 in the measurement points were done.

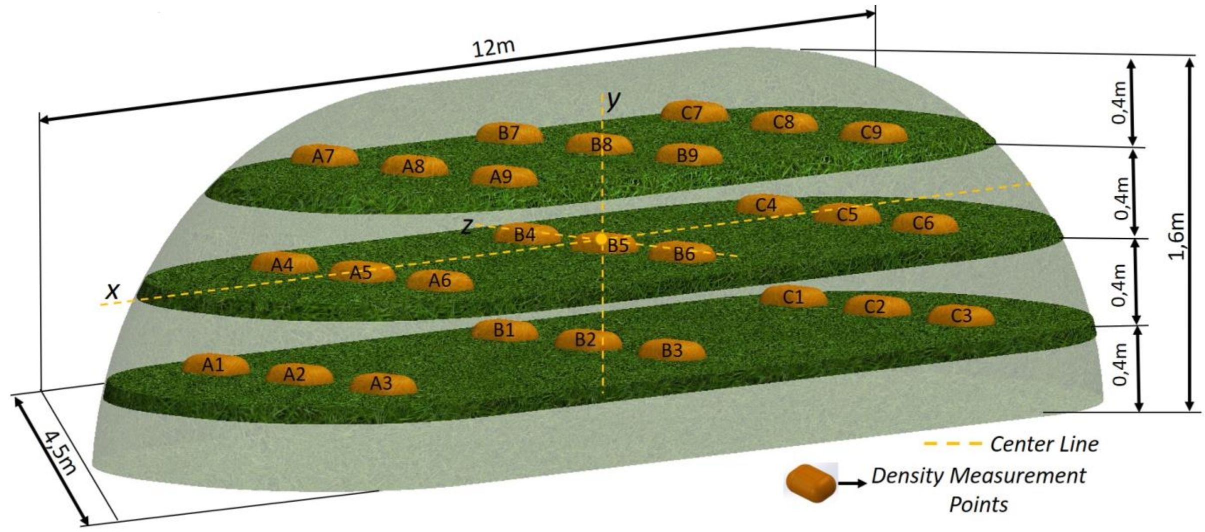


*Figure 1. The Density Measurement Points in Pile-Type Silo*

Three different methods (control method-M1; core sampling-M2,M3,M4,M5 and penetrometer-M6) were used to measure the density of corn silage in pile-type silo. The density of the samples taken in the control method were measured under laboratory conditions (Cai et al. 1997). The core sampling is the standard method (Norell et al. 2013). Samples were taken by four different core samplers from pre-determined measurement points of the silo in core sampling method (Table 2). The volume of the samples taken in core sampling was determined by four different core samplers. In the method M2, the cylinder used to take samples has a narrower diameter while M3 has a wider diameter. In Method M4, the sampler with square cross-section used to take samples has a smaller volume and M5 has a larger volume.

*Table 2. Properties of The Core Samplers*

| | **M2** | **M3** | **M4** | **M5** |
|---|---|---|---|---|
| Type | cube | cube | cylinder | cylinder |
| Diameter | narrow | wide | narrow | wide |
| Volume | small | big | small | big |
| ($m^3$) | 0.008 | 0.016 | 0.0078 | 0.016 |

In M6 method, penetrometer (Ejkelkamp) was used for density measurements (Fig. 2). Technical specifications of the penetrometer were given in Table 3. The hardness indicating the level of compaction of the material was measured as kg $m^{-2}$ by penetrometer. M6 method has a practical use. Therefore, according to other methods, its usability for density estimation will also be examined.

*Table 3. Technical Specifications of The Penetrometer*

| **Technical specifications** | |
|---|---|
| Operational temperature | 0-50 °C |
| Operational humudity | Water-resistant |
| Max. penetration force | 1000 N |
| Total length measuring rod | 0.97 m |
| Memory | 1500 measurements |

*Figure 2. Ejkelkamp Penetrometer*

The mass and volume of the silage were measured for calculating the density of each sample. The density of silage material is calculated by equation (1).

$$\rho = \frac{m}{v} \tag{1}$$

Where, ρ is ensiling material density, kg m$^{-3}$; *m* is mass of the ensiling material filling, kg; *v* is volume, m$^{-3}$ (Wang 2012). The density of the material both stage-I and stage-II in a small livestock farm was calculated.

## 2.3. Statistical Analysis

In this study, to evaluate any statistical significance between measurement method and density in pile silo, the data was analyzed by using the one-way ANOVA employing SPSS (version 18.0). Minimum level of significance was 5%. Means were compared by the Duncan test. While M1, M2, M3 and M4 methods were tested among themselves, M6 was tested in itself. The relationship between the methods was analyzed by using a linear regression model.

# 3. Results and Discussion

Table 4 and Table 5 indicates the density values of the whole-chopped corn measured during the stage-I and stage-II according to the methods. There were a significant effect (P<0.05) of layer thickness and locations on density at all methods both stage. Significant differences were observed for both layer thickness (vertical) and locations (horizontal) layers. The highest density values were determined at 120 cm layer thickness while the lowest density values were determined at 40 cm layer thickness in all methods. Muck and Holmes (2000) also found a negative correlation between layer thickness and density. The highest densities were M1, M4, M5, M2 and M3 respectively.

*Table 4. Density Values of The Whole-Chopped Corn Measured During The Stage-I*

| | M1 | M2 | M3 | M4 | M5 | Mean | M6 |
|---|---|---|---|---|---|---|---|
| LT | | | kg m$^{-3}$ | | | | kg m$^{-2}$ |
| 120 | 871.75 | 852.25 | 810.27 | 867.01 | 862.22 | 852.70 $^{A}$ | 5.02 $^{a}$ |
| 80 | 818.42 | 723.75 | 628.96 | 808.58 | 781.80 | 752.30 $^{B}$ | 4.02 $^{b}$ |
| 40 | 766.41 | 566.55 | 518.89 | 764.40 | 720.05 | 667.26 $^{C}$ | 3.72 $^{c}$ |
| Location | | | | | | | |
| Right | 795.37 | 684.89 | 625.83 | 794.83 | 763.00 | 732.78 $^{C}$ | 4.23 $^{b}$ |
| Center | 821.70 | 721.33 | 659.09 | 819.82 | 794.87 | 763.36 $^{B}$ | 4.23 $^{b}$ |
| Left | 839.51 | 736.32 | 673.21 | 825.34 | 806.20 | 776.12 $^{A}$ | 4.30 $^{a}$ |
| Mean | 818.86 $^{a}$ | 714.18 $^{c}$ | 652.71 $^{d}$ | 813.33 $^{a}$ | 788.02 $^{b}$ | | 4.25 |

AB Mean with different superscript within a column differ for M1,M2,M3,M4 and M5at $p < 0.05$.
a,b Mean with different superscript within a column differ for M6at $p < 0.05$.
LT, Layer thickness; M1, control method; M2, core sampling method with narrow volume cube; M3. core sampling method with wide volume cube; M4, core sampling method with narrow volume cylinder; M5, core sampling method with wide volume cylinder; M6, penetrometer method.

*Table 5. Density Values of The Whole-Chopped Corn Measured During The Stage-II*

| | M1 | M2 | M3 | M4 | M5 | Mean | M6 |
|---|---|---|---|---|---|---|---|
| LT | | | kg m$^{-3}$ | | | | kg m$^{-2}$ |
| 120 | 598.25 | 510.75 | 488.58 | 529.41 | 498.32 | 525.06 $^{A}$ | 4.45 $^{a}$ |
| 80 | 532.12 | 432.37 | 322.52 | 450.32 | 418.99 | 431.26 $^{B}$ | 3.66 $^{b}$ |
| 40 | 496.63 | 341.55 | 207.63 | 373.24 | 314.56 | 346.72 $^{C}$ | 3.00 $^{c}$ |
| Location | | | | | | | |
| Right | 520.99 | 404.30 | 321.41 | 433.93 | 398.73 | 415.87 $^{C}$ | 3.66 $^{b}$ |
| Center | 550.81 | 435.68 | 345.77 | 455.33 | 416.05 | 440.73 $^{B}$ | 3.72 $^{a}$ |
| Left | 555.19 | 444.68 | 351.56 | 463.70 | 417.11 | 446.45 $^{A}$ | 3.73 $^{a}$ |
| Mean | 542.33 $^{a}$ | 428.22 $^{c}$ | 339.58 $^{e}$ | 450.99 $^{b}$ | 410.63 $^{d}$ | | 3.70 |

AB Mean with different superscript within a column differ for M1,M2,M3,M4 and M5at $p < 0.05$.
a,b Mean with different superscript within a column differ for M6at $p < 0.05$.
LT, Layer thickness; M1, control method; M2, core sampling method with narrow volume cube; M3. core sampling method with wide volume cube; M4, core sampling method with narrow volume cylinder; M5, core sampling method with wide volume cylinder; M6, penetrometer method.

The lowest density was measured in M3 method. In the present study, density of silage in stage-I ranged from 652.71 kg m$^{-3}$ to 818.86 kg m$^{-3}$, which were lower than the values found by Li et al. (2016). This can be explained by the less compaction during ensiling. In M4 method, the closest values to M1 method were obtained both stages. The density of silage at 40 cm layer thickness was 11.31 %, 21.75 % lower than at the 80 cm and 120 cm layer thickness, respectively. The highest density values were determined at left location (776.12 kg $m^{-3}$) in all methods while the lowest density values were determined at right location (732.78 kg $m^{-3}$). The density of silage at left location was 5.59 %, 1.65 % higher than the right and center location, respectively.

In the present study, density of silage in stage-II ranged from 339.58 kg $m^{-3}$ to 542.33 kg $m^{-3}$. The highest densities in stage-II were M1, M4, M2, M5 and M3, respectively. The density of silage at 40 cm layer thickness was 17.86 %, 33.96 % lower than at the 80 cm and 120 cm layer thickness, respectively. According to locations, all methods except Method 6 were found to be in a statistically different group. The highest density values were observed at left location (446.45 kg $m^{-3}$) in all methods while the lowest density values were determined at right location (415.87 kg $m^{-3}$). The mean density of silage at left location was 6.85 %, 1.28 % higher than the right and center location, respectively. In M6, similar values were measured in the right and center locations and at left location was 1.63% higher than right and center locations.

Our results showed that mean density of 120 cm layer thickness (bottom layer) was higher than 80 cm and 40 cm layer thicknesses in all methods including the M6. The values were found higher than the value (434 kg $m^{-3}$) mentioned by Muck and Holmes (2000). The highest density were 818.86 kg $m^{-3}$ and 542.33 kg $m^{-3}$ in the M1 method both stages. The density of silage in the M4 was 0.68 %, 16.84% lower than the M1 at stage-I and II, respectively. The densities in our study were within the range found for pile-type silos. Regression models according to the methods were shown in Table 6. The correlations and standard deviation values between methods were shown in Table 7. According to the results, the correlation between density measured and methods was significant ($P<0.01$).

*Table 6. Linear Regression Models According to The Methods*

| **Methods** | **Stage-I** | **$R^2$** | **Stage-II** | **$R^2$** |
|---|---|---|---|---|
| M1 | y = 498.257 + 75.339 (M6) | 0.713 | y = 278.990 + 71.031 (M6) | 0.863 |
| M2 | y = -125.559 + 197.329 (M6) | 0.851 | y = -4.844 + 116.812 (M6) | 0.941 |
| M3 | y = -258.061 + 214.020 (M6) | 0.953 | y = -377.813 + 193.503 (M6) | 0.985 |
| M4 | y = 496.593 + 74.430 (M6) | 0.863 | y = 51.076 + 107.870 (M6) | 0.966 |
| M5 | y = 349.786 + 102.981 (M6) | 0.876 | y = -54.746 + 125.526 (M6) | 0.968 |

M1, control method; M2, core sampling method with narrow volume cube; M3. core sampling method with wide volume cube; M4, core sampling method with narrow volume cylinder; M5, core sampling method with wide volume cylinder; M6, penetrometer method.

The relationship between M6 method and other methods was investigated. In both stages, the linear relationship between the methods was highest. In all methods, $R^2$ determination coefficient was higher in the stage-II than in the stage-I. The highest coefficient ($R^2$) between M6 method and other methods was found in M3 method ($R^2$=0.953 and $R^2$=0.985) at stage-I and II, respectively. According to the control method; the lowest density was determined by M3 method. With the M6 method it is possible to determine a density value that is 20% lower than the control method. Instead of core sampling method, the penetrometer could be used for measuring when density needs to be calculated for small farm.

*Table 7. Correlations Between Methods*

| **Methods** | **M1** | **M2** | **M3** | **M4** | **M5** | **M6** | **Std.Dv.** |
|---|---|---|---|---|---|---|---|
| **Stage-I** | | | | | | | |
| M1 | 1 | 0.908** | 0.906** | 0.924** | 0.933** | 0.844** | 50.67 |
| M2 | 0.908** | 1 | 0.978** | 0.974** | 0.979** | 0.923** | 121.46 |
| M3 | 0.906** | 0.978** | 1 | 0.977** | 0.984** | 0.976** | 124.50 |
| M4 | 0.924** | 0.974** | 0.977** | 1 | 0.990** | 0.929** | 45.51 |
| M5 | 0.933** | 0.979** | 0.984** | 0.990** | 1 | 0.936** | 62.49 |
| M6 | 0.844** | 0.923** | 0.976** | 0.929** | 0.936 | 1 | 0.57 |
| **Stage-II** | | | | | | | |
| M1 | 1 | 0.959** | 0.955** | 0.965** | 0.932** | 0.929** | 46.52 |
| M2 | 0.959** | 1 | 0.973** | 0.993** | 0.983** | 0.970** | 73.26 |
| M3 | 0.955** | 0.973** | 1 | 0.984** | 0.980** | 0.992** | 118.61 |
| M4 | 0.955** | 0.993** | 0.984** | 1 | 0.983** | 0.983** | 66.75 |
| M5 | 0.932** | 0.983** | 0.980** | 0.983** | 1 | 0.984** | 77.62 |
| M6 | 0.929** | 0.970** | 0.992** | 0.983** | 0.984 | 1 | 0.61 |

**significant at $P<0.01$ (2-tailed).

M1, control method; M2, core sampling method with narrow volume cube; M3. core sampling method with wide volume cube; M4, core sampling method with narrow volume cylinder; M5, core sampling method with wide volume cylinder; M6, penetrometer method.

Densities were positively correlated with the measurement methods. All methods in the stage-II had a higher correlations and lower standard deviation compared to the stage-I. This can largely be explained by the absence of spaces between the materials. The highest correlations with control was found at M5 and at M4 in stage-I, at M4 in stage-II. According to the results of this study, M4 method is recommended to determine the density at the small farms. Among the core sampling methods, M4 was the most practical and easiest method to measure density under field conditions. Core sampling method is also recommended for assessing silage density by Holmes (2008).

# 4. Conclusion

Results indicate that in order to determine the silage density in small farms, all methods tested in this study can be used for density measurement including penetrometer method. Penetrometer method (M6) is the best method for fast and accurate measuring of density. If small farms do not have a penetrometer, M4 sampling method may be recommended for density measurement.

# 5. Acknowledgment

This study; It was produced from a MSc. thesis by Mustafa ŞAHİN at the Institute of Natural and Applied Sciences, Tekırdag Namık Kemal University.

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