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USING MODERN DIAGNOSTIC METHODS FOR TECHNOLOGICAL DISCIPLINE ASSESSMENT OF MAIZE SILAGE

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The paper focuses on the analysis of compliance with the technological discipline in silage quality assessment based on sampling the silage wall using thermal imaging and penetrometer method for silage compaction. Experimental measurements were done in a selected company, which has built a silage trough with a capacity of 6,624 m^3, in which the maize (hybrid KWS – KALIFF FAO 440) with a 36% solids content was ensiled. A thermal camera ThermoPro TM TP8S IR and cone penetrometer Eijkelkamp were used for measurements. The results obtained suggest that also undesirable heating was found in the sampling area, since the maximum temperature at some places in the depth of 0.5 m reached a temperature of 36.4 °C. According to regression and correlation analysis, we found direct linear relationship between penetration resistance and penetration depth in a 6 m and 1.5 m height (R = 0.938 respectively R = 0.970).

Keywords: maize silage; penetration resistance; compaction; thermography; heating

Silage is preserved fodder which is characterized by low pH (3.7 to 5.0) according to dry matter content to form the organic acids, especially lactic acid, generated by fermentation of saccharides of low molecular weight (Doležal et al., 2006). If we want to harvest silage maize at the time with the highest nutritional value, to store and close silage clamps, it is necessary to well organize all operations (Bouška et al., 2006). It is required that silage troughs were filled as soon as possible, the ensiled mass must be air-tight, closed as soon as possible with plastic foil to create an anaerobic environment. Compression, influenced by the length of chop, significantly determines the quality of the fermentation process, the level of losses, preventing heat damage and silage hygienic quality (Doležal et al., 2006). Well compressed silage has a temperature comparable with air temperature; higher temperature is indicating incorrect compression – silage contains a lot of air. Prolonged temperature exposure, higher than 35 °C, creates irreversible bonds between saccharides and nitrogen substances, thereby reducing their fermentation.

Any interruption of silage or inadequate compaction is visually noticeable in the silage profile, e.g. by caramelized light brown to dark brown layer. In insufficiently compacted silage layers, as much air may be closed as sufficient for their getting mouldy. These mouldy deposits found in the silage profile cannot be practically removed (in comparison to the surface layer), and toxic mycotoxins are becoming part of fodder ration (Bouška et al., 2006). The proof of good silage management and subsequent handling is its temperature. It should never exceed 20 °C. If temperature exceeds 20 °C, it is not suitable for dairy cattle (even in summer).

Literature sources indicate that the self-heating of maize silage to 30 °C increases the losses caused by anaerobic fermentation of silage by 1.7% of dry matter per day. As prevention from undesirable heating, it is necessary to follow the technological discipline of silage (filling rate, application of additives, mass compaction, rate and covering of silage troughs) (Rajčáková, 2008).

The main observed problems are residues after milling and residues of air containing silage pushed back to the silage wall. Thus layered material begins to warm up, which means nutrient losses. These losses are 3% for each 10 °C temperature increase per day (http://www.zea.cz/vyziva-zvirat/lze-vyrabet-mleko-levneji-dil-vii/).

The thermal camera is used for detecting the temperature increase, silage quality and problems of silage wall, which at first sight upon arrival in the silo is not visible (http://www.zea.cz/konzervanty/termokamera-v-jame/). According to Reszler (2010), an infrared thermometer is more affordable.

The paper is focused on the analysis of compliance with the technological discipline in silage quality assessment based on sampling the silage wall using thermal imaging and penetrometer method for silage compaction.

Material and methods

Experimental measurements were done in the selected company, which has built a silage trough with a capacity of 6,624 m^3, in which the maize (hybrid KWS – KALIFF FAO 440) with the 36% solids content was ensiled.

Cutting work was done with a harvester CLAAS JAGUAR 850, and compacting was done with heavy weights based on railway wagon wheels. After compacting, the silage trough was hermetically closed with two silage foils and loaded with old tyres.

Measurements were done just before removing the fodder (24 hours after last removing, because the dairy

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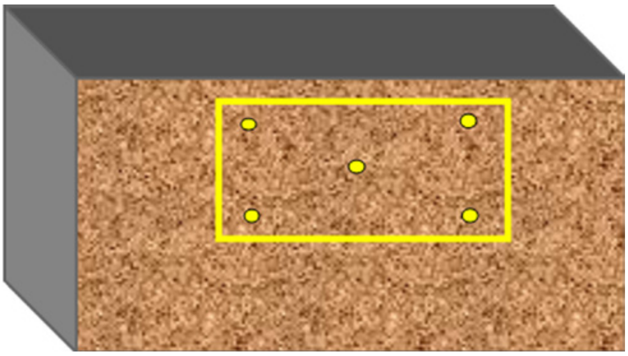

Figure 1 Marked boundaries of monitoring points on the sampling silage wall

cattle is fed once per day), and immediately after removing the fodder. Silage clamps are used in farm for removing the fodder. A metal frame with the dimensions 1.0 × 0.5 m was prepared before the measurement. The frame was installed into the silage where temperature was measured by using the thermal camera. The average surface temperature and minimum respectively maximum temperature was measured in the selected area.

The following places in the silage trough were measured and evaluated:

- Fodder surface after removing the foil (height 6 m) – before removal.
- Sampling silage wall (height 1.5 m) – at a depth of 0.5 m after removal.

Measuring device and processing of thermographs

The thermal imaging camera ThermoPro TM TP8S IR is a high-quality equipment. Temperature profiles were evaluated using special software.

Measurement of silage compaction with penetrometer method

Silage penetration resistance (compaction) was measured with using the cone penetrometer. The working principle of the cone penetrometer is to press the metal cone with the ground area 1 cm^2 and angle 60° perpendicular to the measured surface (velocity 3 cm.s^{-1}), with using the same pressure on both handles. Penetrologger's measuring range is 0 – 10 MPa. During measurements, penetration depth is recorded by an ultrasonic sensor. The maximum force is 1,000 N and the resolution of force is 1 N. The communication between the penetrometer and the computer is provided with communication ports (https://en.eijkelkamp.com/products/field-measurement-equipment/penetrologger-set-a.html).

In each enclosed area with the dimensions 1.0 m × 0.5 m, 5 penetrations had been measured and then average values for each measured area (Figure 1) have been calculated. Experimental measurements were performed in the direction identical to the direction of fodder compression. The results were evaluated with regression and correlation analysis. A similar method was also used for determination of winter wheat straw bales compression (Korenko et al., 2013).

The penetration images were made of measured values. The peaks of curves could be read at a depth of 35 cm. The measurements were carried out in winter when the outside air temperature was 2 °C and relative humidity 55%.

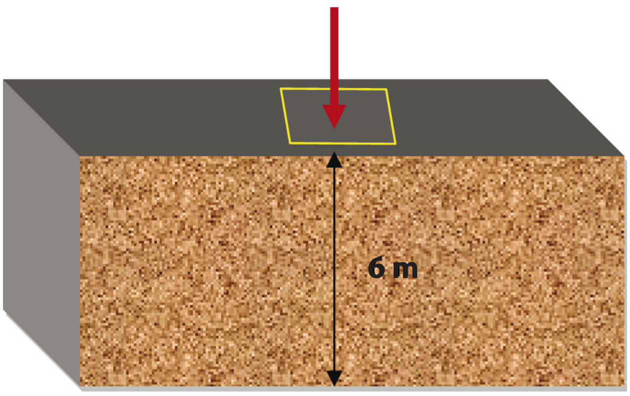

Figure 2 Measured area before fodder removal

Results and discussion

A) Fodder surface after removing the foil (height 6 m) – penetration resistance was measured in the direction identical to the direction of fodder compression. Measurement was done before fodder removal (Figure 2).

Results show that the average temperature of measured area before removal was -0.6 °C, the minimum temperature was -2.4 °C, and the maximum temperature was 5.1 °C (Table 1).

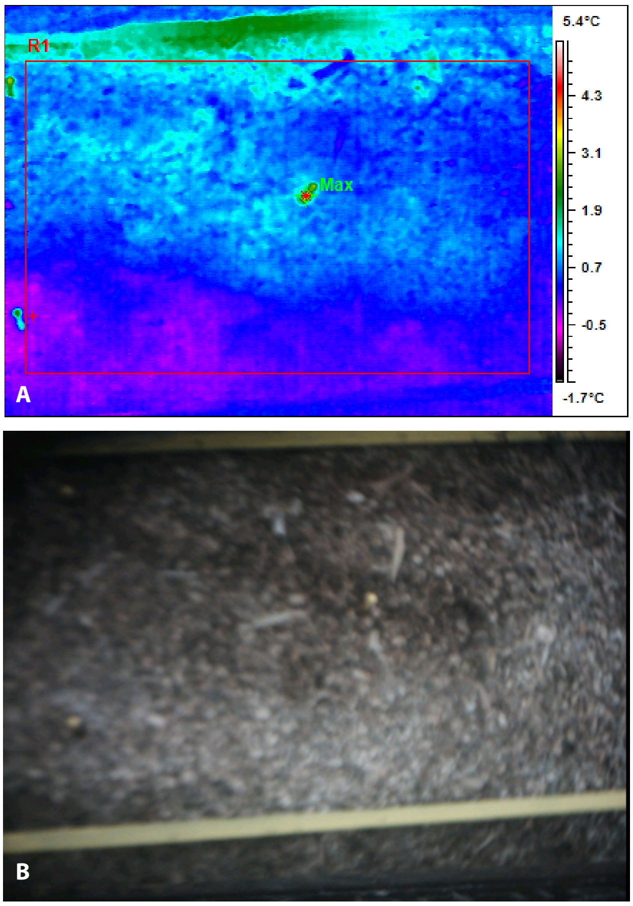

Figure 3 a) Thermal image, b) Real image

Table 1 Temperature of maize silage

Parameter	Height 6 m	Height 1.5 m
	value (before removal)	value (after removal)
Average temperature	-0.6°C	28.0
Maximum temperature	5.1°C	36.4
Minimum temperature	-2.4°C	13.0

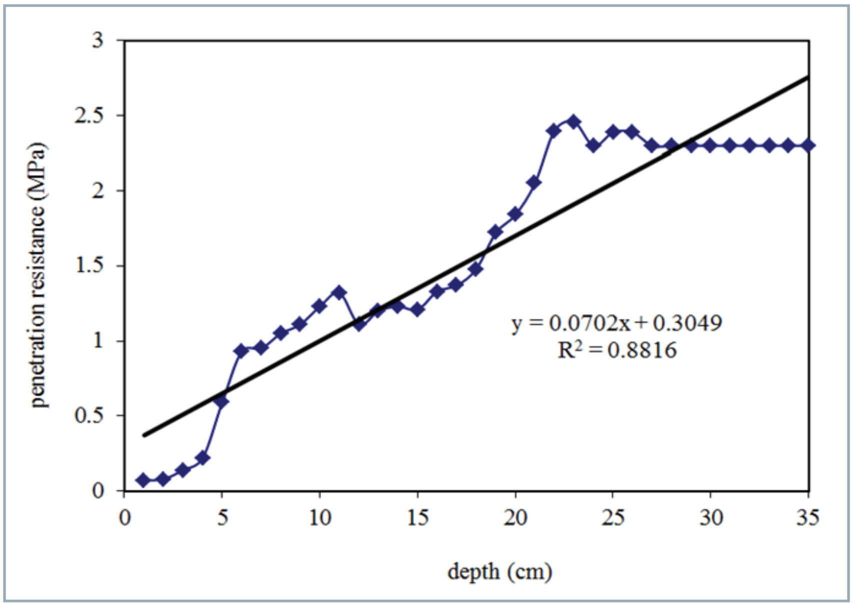

Figure 4 The relationship between penetration resistance and the depth of cone rod penetration

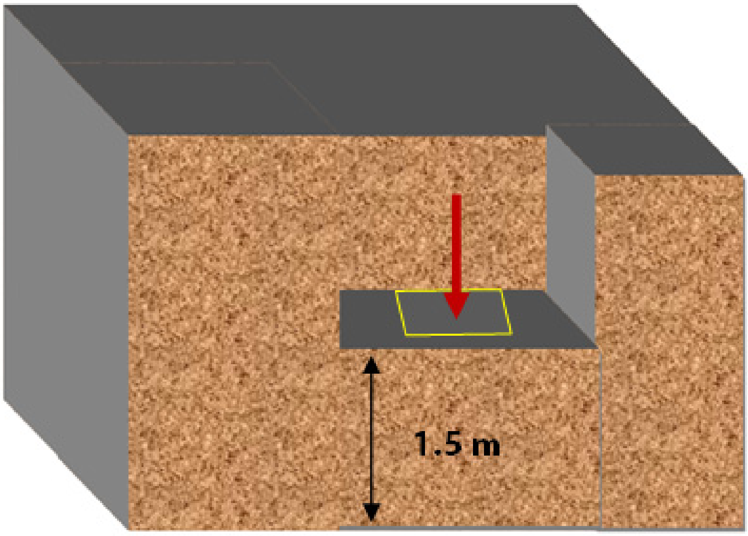

Figure 5 Measured area after fodder removal

Figure 4 shows that there was an increase in the average values of penetration resistance (2.46 MPa) to a deph of 23 cm. Regression coefficient *R* (0.938) is interpreted as a direct linear relationship between penetration resistance and the depth of cone rod penetration into the silage mass. The coefficient of determination R^2 (0.88) indicates that 88% of penetration resistance variability depends on depth. The F significance determines the model suitability: the value is below (7.53E-17) the significance level (0.05), the model has been selected properly, and it is suitable for explaining the dependence. The model equation is in the form $y = 0.30 + 0.07x$. The *P*-value (7.53E-17) was below α (0.05), which means that regression coefficient is statistically significant. When the depth of cone rod penetration into the ensiled mass increases by about 1 cm, penetration resistance will increase by about 0.07 MPa.

B) Sampling silage area (height 1.5 m) – penetration resistance was measured in the direction identical to the direction of fodder compression. Measurement was done after fodder removal (Figure 5).

Obtained results indicate that the average temperature of the measured area after fodder removal was 28.0 °C, the minimum temperature was 13.0 °C, and the maximum temperature was 36.4 °C (Table 1). The increase of average values of penetration resistance (3.88 MPa) was monitored into the depth of 35 cm (Figure 7).

Regression coefficient *R* (0.970) shows the linear regression between penetration resistance and the depth of cone rod penetration into the silage mass. The coefficient of determination R^2 (0.94) indicates that 94% penetration resistance variability depends on depth.

The F significance determines the model suitability: the value (6.09 E-22) was below (0.05), the model has been selected properly, and it is suitable for explaining the dependence. The model equation is in the form $y = 0.49 + 0.09x$. The *P*-value (6.09E-22) was below α (0.05), which means that regression coefficient is statistically significant. The model implies that when the depth of cone rod penetration into the ensiled mass increases by about 1 cm, penetration resistance will increase by about 0.09 MPa.

The study presents the possibilities of using modern diagnostic methods for heating detection, primarily because of insufficient compaction. Incorrectly compacted silage due to the presence of air is more prone to undesirable type of fermentation, lower aerobic fermentation and secondary fermentation (Rajčáková, 2007). A temperature increase of 15 °C corresponds to 1.5% netto energy loss per day (http://www.schaumann.cz/ke-stazeni/produktove-letaky/prednaska-bioplyn-schaumann.pdf).

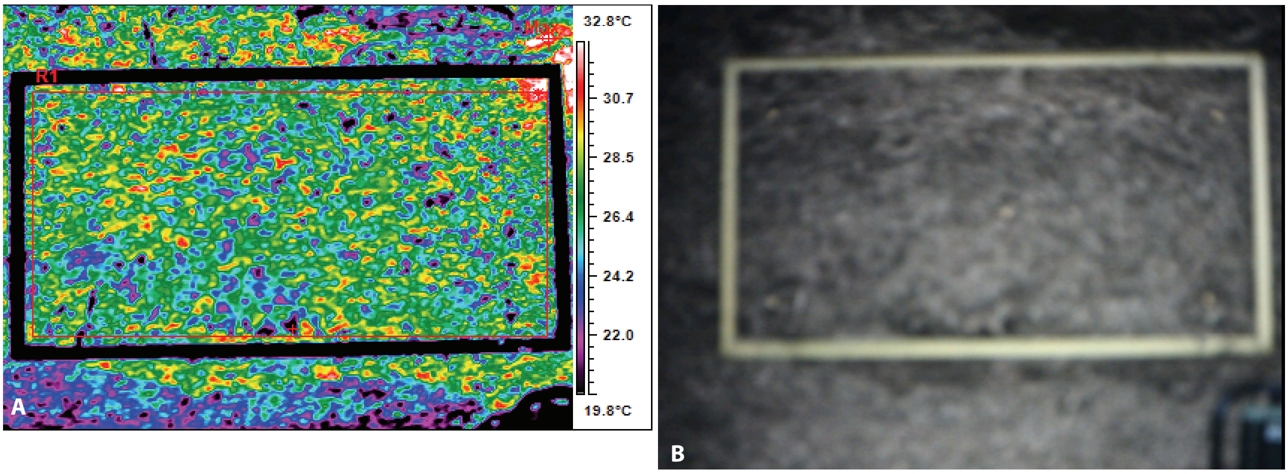

Figure 6 a) Thermal image, b) Real image

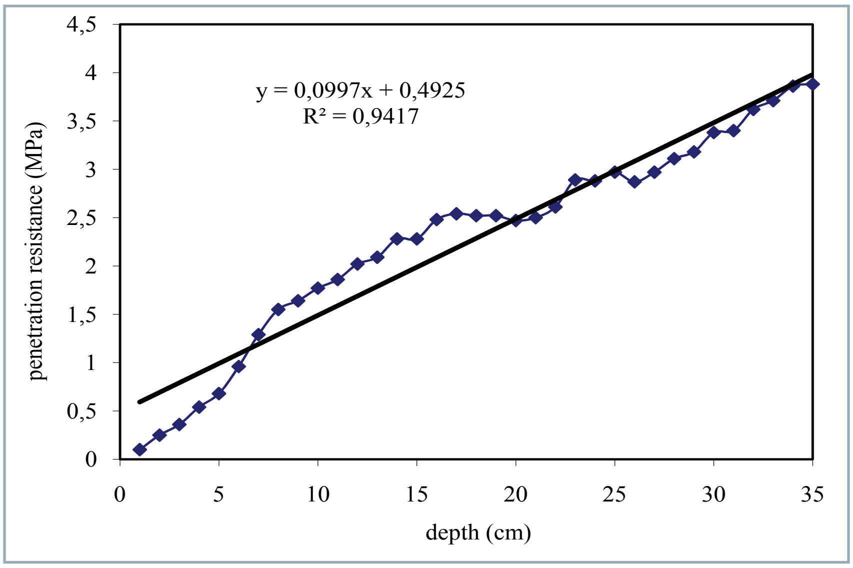

Figure 7 The relationship between penetration resistance and the depth of cone rod penetration at the height of 1.5 m

Conclusion

The paper summarises the importance of compliance with the technological discipline for silage. The obtained results show the following:

- Places with undesirable heating were detected in the sampling silage area because the maximum temperature in the depth of 0.5 m reached 36.4 °C – that is describing the insufficient silage mass compaction;
- The penetration resistance of maize silage measured before removal in the direction of compression in the height 6 m reached the maximum in the depth of 23 cm (2.46 MPa) and at the height of 1.5 m reached the maximum value in the depth of 35 cm (3.88 MPa);
- Using the regression and correlation, we observed high linear regression between penetration resistance and penetration depth at the height 6 m and 1.5 m (R = 0.938 respectively R = 0.970);
- The model equation is in the forms: $y = 0.30 + 0.07x$ or $y = 0.49 + 0.09x$; when penetration depth increases by about 1 cm, penetration resistance will increase by about 0.07 MPa or 0.09 MPa, respectively.

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