Journal of Agricultural Science and Food Technology
Vol. 2 (11), pp. 180-188, December, 2016
ISSN: 2465-7522
Full Length Research Paper
http://pearlresearchjournals.org/journals/jasft/index.html

Effects of Different Bulk Densities on *Zea mays* Silage Characteristics, Temperature Profiles, CO_2-and O_2- Concentrations in Small Scale Silos during Aerobic Exposure

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Accepted 25 November, 2016

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ABSTRACT

In this study, effects of different bulk densities on the Maize (*Zea mays*) silage characteristics, temperature, CO_2- and O_2- gases in small silos during the aerobic exposure were investigated. The method described in Jungbluth et al. (2016) was used. For this, 8 buckets (65.3 l) were filled with 40 kg FM (218.7 kg DM m^{-3}; n=4) or 50 kg FM (273.4 kg DM m^{-3}; n=4) of maize silage. Temperature was measured to observe heating resulting from microbial activity. Similarly, gas samples were taken and analyzed by gas chromatography during reheating. Reheating was observed in every bucket. Temperature increases were higher (p=0.05) in the low-density treatment. Gas measurements showed CO_2 flowing out and O_2 diffusing into the buckets after opening. 24 h later, CO_2 concentrations reached their minimum when O_2 values reached their maximum. The CO_2 minimum was followed by an increase in concentration, whereas O_2 concentrations decreased. The reason for this change, happening immediately before reheating started, is microbial respiration, consuming O_2 and producing CO_2. The reheating process had no effect on the nutrient categories, crude ash, crude fibre, crude fat, neutral detergent fibre (aNDFom), and starch or on the pH value. Higher crude protein and metabolizable energy content(s) were found in the high-density treatment after reheating and dry matter losses between 0.58 and 4.38% were found and were tendentially higher in the low-density treatment. Therefore in agricultural practice it is recommended to reach high bulk densities in silage to preserve staple feed and it´s quality.

Keywords: Maize (*Zea mays*) Silage, Oxygen Induced Deterioration, Density and Reheating.

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INTRODUCTION

The importance of silage as a livestock feed is tremendous and has continuously grown (Woolford, 1984). Today, apart from alfalfa (*Medicago sativa*) and various grasses, maize is the most important substrate for ensiling (Weinberg and Ashbell, 2002). Nowadays, the process of silage production is fully understood; therefore, the conditions needed to obtain high silage quality are well defined, and the risk of poor silage quality is thereby minimized (Woolford, 1984). However, in agricultural practice it seems to be difficult to meet these requirements. The aerobic deterioration of silage is still a worldwide problem for quality of livestock´s feed and profitability of farms (Tobacco et al., 2011; Muck, 1988). Additionally, from the viewpoint of economically successful biogas production, dry matter (DM) and energy losses must be reduced to the minimum (Reinhold and Peyker, 2007). On farms, the diffusion of oxygen into silage is unpreventable. Even in well-sealed silos small amounts diffuse inside the

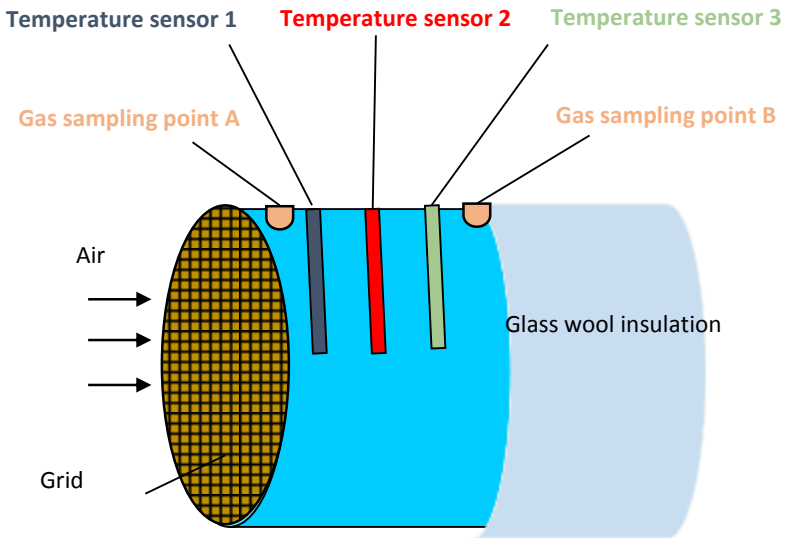

Figure 1. Schematic illustration of the experimental setup (modified from Jungbluth et al., 2016).

material, this inflowing oxygen is metabolized by microorganisms. A process, which proceeds along with DM losses. During the feed-out period, there is even more oxygen diffusing into the silage, leading to an increase in aerobic microbial metabolism. As a result heating of the silage and further losses of DM may occur (Rotz, 2003; Wilkinson and Davies, 2012; Pitt and Muck, 1993). The density and porosity of silage are the main physical factors affecting the amount of oxygen diffusing into the silage (Wilkinson and Davies, 2012).

In combination with airtight coverage, high compaction is the primary factor influencing the prevention and reduction of energy losses (Muck, 1988; Maack et al., 2007). By reducing the energy and feed losses, the efficiency and sustainability of agricultural production can be improved. It means that loses of the DM in maize silage can be reduced by a higher bulk density and feed-out rate (Köhler et al., 2013). In addition to fermentation biology, bulk density plays an important role in farm management because it affects the capacity of the silo and thereby the costs to farmers for the storage of a given quantity plant material (Muck et al., 2003). A given size of a silo can include more silage if this material is higher compacted. And new-built silos can be constructed to be smaller if there is the opportunity of high compaction. Therefore the main aim of the study was to investigate the effect of the physical factor 'bulk density' on silage under aerobic conditions. The silage characteristics investigated were the temperature development during oxygen influence (1), the concentrations of CO_2 and O_2 (2) and DM, energy and nutritional losses (3) during the reheating of the maize silage. The basic hypothesis was that higher density leads to slower temperature rise and consequently lower losses. The concentrations of CO_2 and O_2 were expected to change due to microbial respiration expressed in a CO_2 increase and an O_2 decrease.

MATERIALS AND METHODS

The measurement trial was performed under laboratory conditions at the research facilities of the Institute of Agricultural Engineering of the University of Bonn, Germany in 2014. All the experimental steps were done according Jungbluth et al. (2016). Four polyethylene buckets with a volume of 65 l were filled with 40 kg maize silage (low-density treatment, 218 kg DM m^{-3}) and another 4 with 50 kg (high-density treatment, 273 kg DM m^{-3}) maize silage, corresponding to densities slightly lower and higher, respectively, than those that are recommended by Honig (1987). The maize silage had been produced at Frankenforst, the research centre for animal production at Bonn University (Geographical coordinates: 7° 12' 22'' E, 50° 42' 49'' N). The cultivar used in the trials was Canon and had been harvested in autumn 2013. The samples were taken from a clamp silo that contained silage with DM contents varying between 356 g kg^{-1} and 358 g kg^{-1}, as found in the samples taken from the area of the silo used in the experiment. After filling, the buckets were resealed using an airtight cover with a rubber seal and clamping ring and were laid on their sides. During the experimental period, gas samples were taken twice per day and temperature was measured (resistor-based sensors and data logger ALMEMO®, Ahlborn Mess- und Regeltechnik GmbH, Holzkirchen, Germany) four times in each hour during the experiment. Gas analyses and temperature measurements were done according to Jungbluth et al. (2016). Each bucket had been weighed before and after the experimental period to quantify the weight losses that occurred during reheating. To start the inflow of oxygen, the buckets were opened, as shown in Figure 1, so that the air could diffuse into the unsealed buckets unhindered, which gives the microorganisms the opportunity to start aerobic metabolism. To prevent the resulting heat from

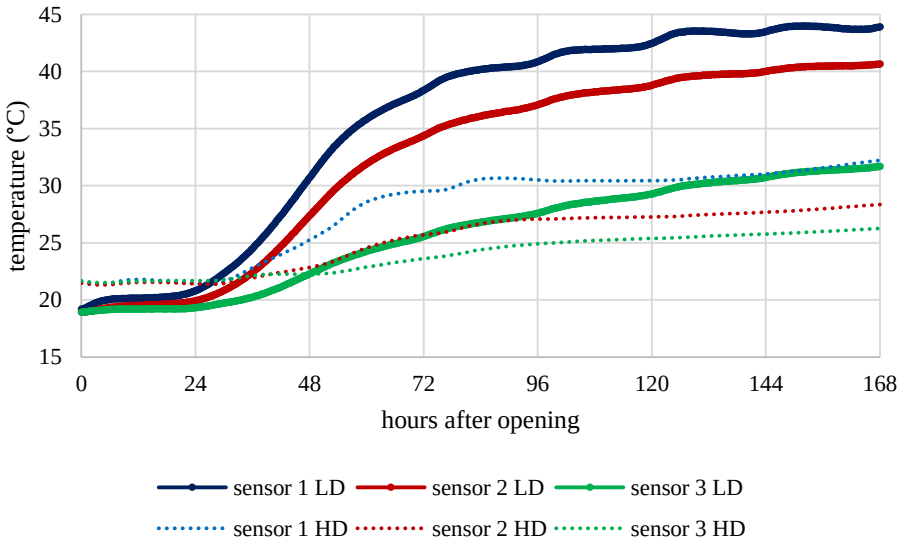

Figure 2. Courses of temperature measured in buckets: One LD and one HD bucket, including three sensors each.

dissipating, the buckets were thermally insulated with glass wool (100 mm, λ = 0.04 W K^{-1} m^{-1}).

The glass wool covered the whole bucket and is implied in Figure 1, which gives a schematic overview of the experimental setup. After the buckets were opened, silage samples were taken through each open surface. After the entire experiment, three samples were taken from every bucket: one from the upper third, one from the middle third and one from the lower third. Each of these three samples was taken by drilling through the centre of the opened bucket with a drilling tube. All the samples were sent to an external laboratory (LKS Landwirtschaftliche Kommunikations– und Servicegesellschaft mbH, Lichtenwalde, Germany), which is accredited in accordance to DIN EN ISO/IEC 17025 and certified according to DIN ISO 9001 to analyze the feed components by near infrared spectroscopy (NIRS). The experiment was conducted twice at different times, each time using a group of four buckets: two of the high-density treatment and two of the low-density treatment to exclude the risk of random influences. At the end of the experiment the buckets were put in an upright position to take thermographic images using a thermal imaging camera (Variocam, InfratecnfraTec GmbH, Dresden Germany) and the IRBIS ® 3 software (Variocam, InfratecnfraTec GmbH, Dresden Germany). The data were evaluated using IBM SPSS Statistics version 22 as described in Jungbluth et al. (2016). First Kolmogorov-Smirnov-Test was conducted to examine if the measured data follows normal distribution. After this requirement was fulfilled, t-tests were used to compare the two different experimental groups (HD and LD) to each other and analysis of variance was used to compare the three different sensors to each other. The statistical significance was determined by Tukey test. Differences of means < 0.05 (P<0.05) were accepted to be significant. Differences of means <0.001 (p< 0.001) were accepted to be highly significant.

RESULTS

Reheating was observed in each of the eight buckets. The course of reheating represented in Figure 2 shows a characteristically temperature development. It shows mean values for each hour of the experiment, calculated for each sensor of two buckets (one is low-density treatment and one is high-density treatment). Obtained temperature increase were significantly higher (p=0.05) in the buckets containing silage of low density compared with those containing silage of high density. The calculated daily mean temperature values did not differ significantly between the high- and low-density treatments during the first two days of the experiment (T_0-phase). Starting on the third day of the experiment, the calculated daily mean temperature values differed significantly between the high- and low-density treatments. On the 5th and 6th day of the experiment, the daily means of the temperatures measured by sensor 2 were significantly (p=0.001) different between the high- and low-density treatments. On the 6th and 7th day of the experiment, the daily means of the temperatures measured by sensor 3 were significantly (p=0.001) different between the high- and low-density treatments. The maximum temperature value was observed in a low-density treatment bucket, in which the temperature rose from 19.2°C to 44.0°C in 151.75 h (6thday of the experiment), as measured by sensor 1. The minimum temperature value was observed in a high-density treatment bucket, in which the temperature

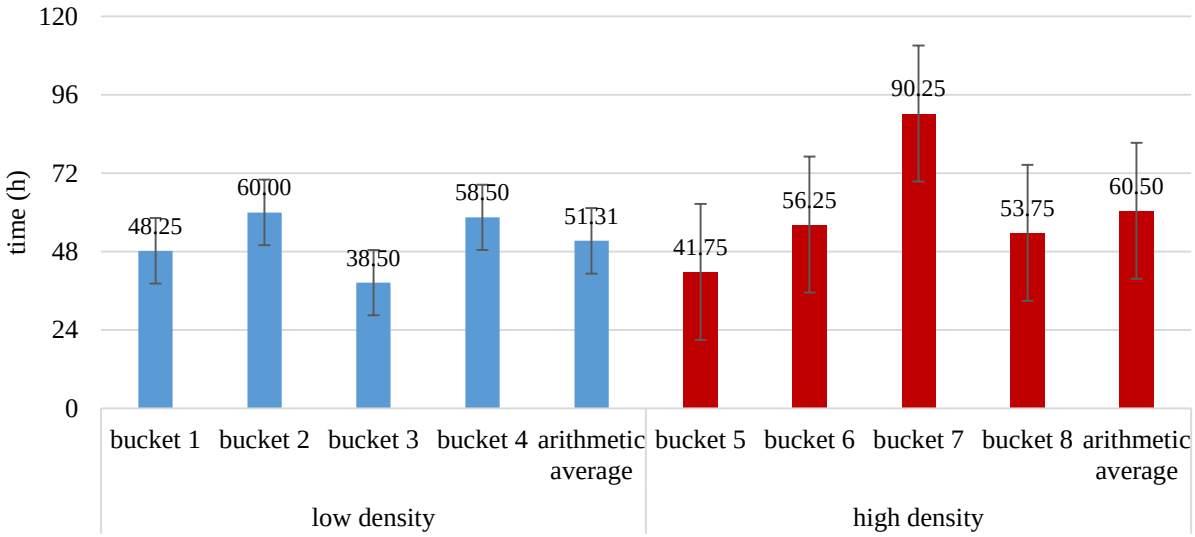

Figure 3. Length of T1-phase (h) by silage density and bucket until reheating, measured as the time at which multiple sensors within a bucket of silage detected a temperature difference of 5 K.

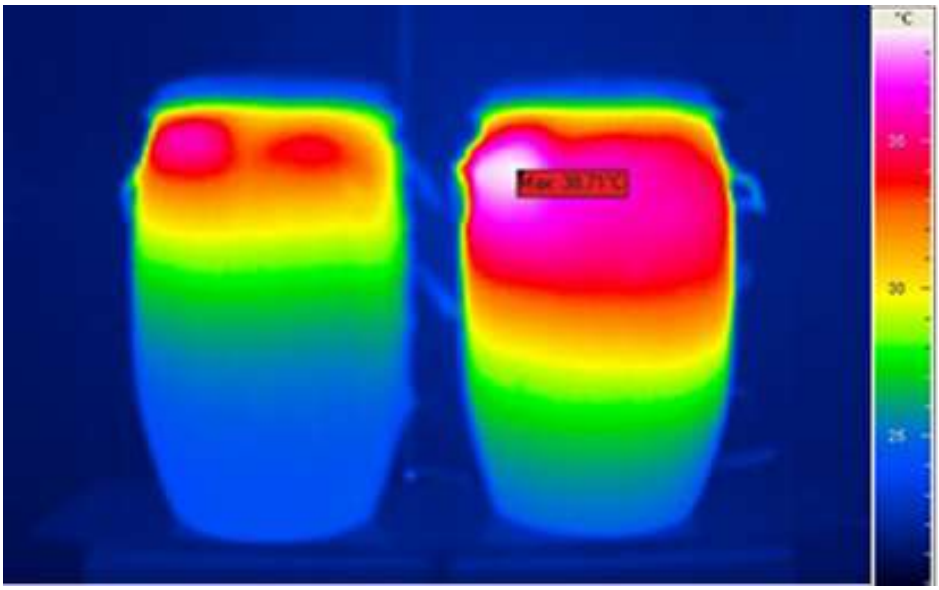

Figure 4. Thermographic image of one high-density treatment bucket (left) and one low-density treatment bucket (right) obtained on the last day of the experimental period (day 7).

measured by sensor 1 increased from 21.4°C up to 32.2°C in 168 h (7th day of the experiment). The courses of temperature measured in these buckets are shown in Figure 2.

In most of the buckets of the low-density treatment, all sensors within single buckets recorded reheating on the same day or within a period of 24 h. In the high-density treatment, the temperature difference between the sensor positions within each single bucket was much greater. In every high-density treatment bucket, sensor 3 measured reheating two days later than the day indicated by sensor 1. Figure 3 shows the time in hours (T_1-phase) until multiple sensors measured a temperature difference of 5 K within each bucket, which is the time until reheating. (Reheating according to this definition was reached in the low-density treatment buckets after 24 to 72 h of the experimental period. In comparison, the high-density treatment buckets were reheated after 24 to 96 h of the experimental period. Figure 4 shows a thermographic representation of two buckets, one low-density treatment bucket and one high-density treatment bucket. The image has been taken at the end of the seven-day experiment to

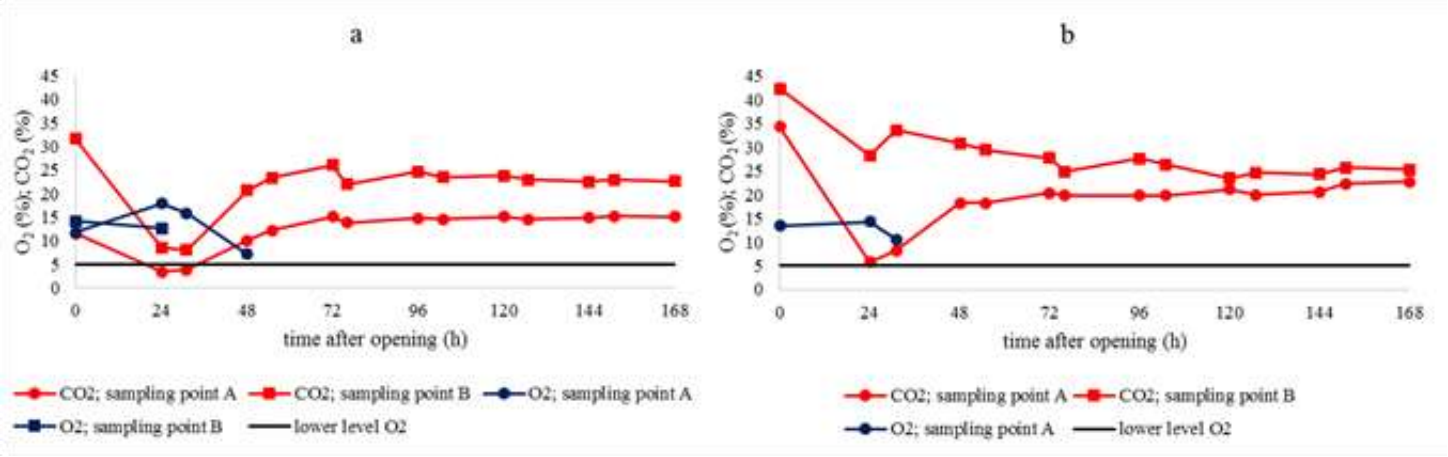

Figure 5. Mean CO_2 and O_2 concentrations measured in gas samples from a) low- and b) high-density treatment buckets (O_2 concentrations below 5% (= lower level) could not be analyzed).

visualize the status of heat moving into the material. The figure illustrates the area and position of the hotspot, which had penetrated deeper into the material of lower density. The measured CO_2 concentrations are displayed in Figure 5 for the low-density treatment buckets and in Figure 4 for the high-density treatment buckets. Figure 5 also shows the measured O_2 concentrations, which increase after opening of the buckets and decrease again in the T_0-phase. After T_0-phase O_2-concentrations decreased below 5%, which is the lower level that can be analysed by the standard method. O_2 concentrations were higher in the samples taken at sampling point A than those taken at sampling point B.

In the high-density, variation of O_2 concentrations at sampling point B could not be determined, because they fell below the lower level. CO_2 concentrations were lower in the samples originating from sampling point A compared with those originating from sampling point B. In the first samples taken at the beginning of the experiment, CO_2 concentrations were higher than those measured at the second experimental day. Afterwards, the CO_2 concentrations rose until they reached a level lower than the initial value, which persists for the rest of the experimental period. The analyses of the silage samples which are represented in Table 1, showed that the bucket-ensiled material tended to dry after re-ensiling compared with silage from clamp silo; especially in the high-density treatment buckets, as shown by the analyses of the samples taken directly after opening the buckets before reheating started. Furthermore, the data indicated that none of the nutrient values which included those for; crude ash, crude protein, crude fibre, crude fat, starch and neutral detergent fibre determined on an organic matter basis (aNDFom), changed significantly as a result of the re-ensiling process. The pH value was higher in the buckets after re-ensiling. The energy content was not changed significantly after re-ensiling. Table 1 shows the analytical state of the silage samples based on the DM before and after reheating. The analyses of the silage samples showed that the low-density buckets lost more moisture compared with the high-density treatment, as shown by the analyses of the samples taken after reheating.

The data also indicated that none of the nutrient concentrations in the crude ash, crude fibre, crude fat, aNDFom or starch categories changed significantly due to the reheating process. The pH value in the buckets did not change after reheating. In the high-density treatment buckets, significantly higher protein content was observed in the reheated samples compared with the samples taken before reheating. There was no similar protein increase in the low-density treatment buckets. For the high-density treatment, there was a significantly higher content of metabolizable energy in the reheated samples compared with the samples taken before reheating. There was no similar increase in the energy content for the low-density treatment. Average DM losses of 2.8% were calculated based on the data from low-density treatment and average DM losses of 1.9% were calculated based on the data from high-density treatment for the reheating period of the experiment. The minimum loss was found in a bucket from the high-density treatment, and the maximum loss was found in a low-density treatment bucket. The total DM losses due to reheating were tangentially higher in the low-density treatment.

DISCUSSION

The reheating, which was observed in the buckets during the T_1-phase was caused by the microbial activity that was induced by the entrance of oxygen into the silage vessel during the T_0-phase. The CO_2 measurements showed that the CO_2, inside the closed buckets followed a concentration gradient and flew out after the buckets were opened and at the same time O_2 diffused into the buckets (T_0-phase). After opening but before the heating process started (T_0-phase), the microorganisms especially yeasts

Table 1. Analytical state based on dry matter for silage samples from the silo on farm before filling the buckets (sample 0), from the buckets after filling (sample 1) and from the buckets after reheating for silage originating from three different sampling depth as described in Jungbluth et al. (2016) (samples 2,3 and 4); mean (standard deviation).

Treatment	Sample	Dry matter (g/kg)	Crude ash (g/kg DM)	Crude protein (g/kg DM)	Crude fibre (g/kg DM)	Ether extract (g/kg DM)	Starch (g/kg DM)	pH-value	aNDFom (g/kg DM)	ME (MJ/kg DM)	NEL (MJ/kg DM)
Silo	0	357.0 (1.1)	38.4 (2.6)	76.4 (0.8)	184.0 (3.9)	33.0 (3.6)	331.6 (12.9)	3.8 (0.03)	372.1 (13.3)	11.4 (0.1)	7.0 (0.1)
Low density	1	353.7 (12.5)	38.7 (0.7)	78.76 (2.7)	179.2 (9.0)	35.0 (3.1)	345.9 (16.9)	4.0 (0.0)	376.9 (24.2)	11.5 (0.2)	7.0 (0.1)
Low density	2	353.2 (8.4)	39.1 (2.3)	75.8 (7.0)	1843 (7.4)	34.9 (2.8)	334.6 (31.1)	4.0 (0.0)	384.8 (22.6)	11.4 (0.2)	7.0 (0.1)
Low density	3	360.5 (11.6)	38.2 (1.9)	74.9 (3.3)	1888.4 (9.9)	33.6 (1.8)	336.0 (26.7)	3.9 (0.2)	380.4 (21.0)	11.4 (0.1)	7.0 (0.1)
Low density	4	353.8 (18.8)	38.2 (2.1)	75.4 (3.8)	179.3 (6.3)	33.4 (2.4)	370.4 (18.8)	4.0 (0.2)	370.4 (24.3)	11.4 (0.2)	7.0 (0.1)
High density	1	369.9 (8.8)	37.4 (3.4)	70.8 (6.1)	185.8 (12.6)	33.2 (2.6)	360.4 (47.5)	4.0 (0.1)	386.2 (32.3)	113 (0.2)	7.0 (0.1)
High density	2	367.3 (5.5)	40.0 (3.2)	80.7 (6.0)	178.7 (10.2)	38.5 (1.7)	347.7 (17.0)	4.0 (0.2)	384.8 (41.4)	116 (0.2)	7.0 (0.2)
High density	3	366.2 (10.2)	38.1 (1.9)	79.5 (4.1)	173.5 (6.6)	36.2 (3.8)	359.8 (32.2)	4.0 (0.2)	372.5 (5.9)	116 (0.1)	7.0 (0.0)
High density	4	369.9 (13.2)	39.3 (3.3)	77.7 (7.4)	185.5 (8.3)	34.8 (1.5)	334.9 (9.9)	4.0 (0.3)	389.9 (31.5)	114 (0.1)	7.0 (0.1)

switch from an anaerobic to an aerobic metabolism. Most likely, the microorganisms were unable to immediately use the oxygen that diffused into the buckets after they were opened. As a result, there was no difference regarding the daily mean temperatures between the density treatments during the T_0-phase. This could be reasoned by the change in microbial metabolism (anaerobic → aerobic), which seemed to depend only on oxygen availability and not on the density of the silage in the buckets. The results of oxygen measurement during T_0-phase showed that oxygen was available in the first 36 to 48 h even in the high-density buckets and values even increased on the first day after opening. In the high density-buckets O_2 did not reach sampling point B in concentrations higher than 5%. According to Muck et al. (2003), the exclusion of air results in the recovery of a large amount of DM.

The variables that determine silage density are the liquid content, solid matter and void volume. During the process of compacting plant material, the void volume is removed by compression while the silage density increases (Muck et al., 2003). The compaction necessary to reduce the gas flow rate to less than 20 l h^{-1} m^{-2}, which is the airflow rate obtainable in well-compacted grass silage, is 225 kg DM m^{-3} for maize with a DM content of 280 g kg^{-1}. The compaction necessary for maize with a DM content of 330 g kg^{-1} is 265 kg DM m^{-3} (Honig, 1987). Because of a greater void volume and resulting greater porosity of the silage in the low-density treatment, this treatment was expected to diffuse more air compared with the high-density treatment. This expectation is confirmed by the data of oxygen measurement. More oxygen entered the low-density buckets. In contrast, the dense compaction of the silage and lesser void volume in the high-density treatment represented a stronger barrier against the diffusion of incoming air. As a result, the oxygen entered the low-density buckets more easily compared with the high-density treatment. Thus, a higher temperature rise caused by the higher amounts of oxygen metabolized by microbial respiration was observed in the low-density compared with the high-density treatment. At the same time the microbial respiration is the reason for the decrease of oxygen measured during the T1-phase. Twenty-four hours after the buckets were opened at the end of T_0-phase, the CO_2 concentrations in the gas samples taken from the buckets reached their minimum (Jungbluth et al., 2016), at the same time when O_2 values reached their maximum.

The CO_2 minimum was followed by an increase in CO_2 concentration in the gas samples during T_1-phase, whereas O_2 concentrations decreased until it was not possible to detect any more O_2 using the applied test method. The reason for this change which happened immediately before the heating process started was the respiration of microorganisms, which used O_2 and produced CO_2. The fact that less oxygen reached sampling point B compared to sampling point A means that less oxygen reached temperature sensor 3 compared to temperature sensor 1 in all of the buckets, apparently because the microorganisms utilized most of the oxygen before it could diffuse to the deeper position of sensor 3.

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The CO2 minimum was followed by an increase in CO2 concentration in the gas samples during T1-phase, whereas O2 concentrations decreased until it was not possible to detect any more O2 using the applied test method. The reason for this change which happened immediately before the heating process started was the respiration of microorganisms, which used O2 and produced CO2. The fact that less oxygen reached sampling point B compared to sampling point A means that less oxygen reached temperature sensor 3 compared to temperature sensor 1 in all of the buckets, apparently because the microorganisms utilized most of the oxygen before it could diffuse to the deeper position of sensor 3. This oxygen gradient led to a greater temperature rise in the material surrounding sensor 1 compared to that in the material surrounding sensor 2 and 3. The recent findings concerning temperature and oxygen concentrations confirm the calculated diffusion model of aerobic deterioration calculated by Pitt and Muck (1993). Likewise the temperature development as well as the course of oxygen concentrations measured by Sun et al. (2015) using oxygen sensors in silage underlines our results. The possibility of taking gas samples out of silage is also applicable on farm from clamp silos, whereas sensors are more expensive and not easy to applicate them in practice silos. The buckets in the high-density treatment showed slightly longer T1-phases than those in the low-density treatment, whereas temperatures itself differed much stronger between the density variations. This fact indicates that high density has minor impact on delay of reheating. This is confirmed because T0-phase was not significantly longer in the high density variation, but higher density had great impact on reduction of temperature during T1-phase and thereby Tmax was significantly lower in the high density treatment buckets.

The silage used in this experiment had been previously ensiled. Silage was used instead of fresh maize to make sure, that the material in the buckets has the same fermentation quality and properties to make the buckets comparable. The same experiment has been conducted with fresh shopped maize directly ensiled into buckets, to obtain information regarding changes in the material according to the influence of air using both fresh and previously ensiled silage (unpublished data). Results of this trial will be presented in prospective papers. During the process of transferring the silage from the silo to the buckets, the material lost moisture and the compaction process also led to moisture losses caused by squeezing fluid out of the silage. For these reasons, the material tended to be dryer in the high-density compared with the low-density treatment. Based on these findings, available results confirmed the prediction of Muck et al. (2003) that excessive densities increase effluent losses. The analyses of the silage samples showed that after reheating the silage in the buckets tended to be drier in the low-density than in the high-density treatment because the higher moisture content in the former treatment implies a steeper gradient in moisture content between the silage and the surrounding air. Obviously, this condition corresponds to a higher potential for moisture loss. A second and more important reason is that the evaporation rate was higher in the opened buckets in the low-density compared with the high-density treatment, as shown by the analyses of the samples taken after reheating (Table 1).

The amount of H2O produced by respiration was inadequate to compensate for the losses. The increase in pH resulted from the conversion of acetic and lactic acid into CO2 and H2O by yeasts, activated by the oxygen entering the buckets during silage transfer. The fact that

none of the nutrient concentrations in the crude ash, crude fibre, crude fat, aNDFom or starch categories changed significantly due to the reheating process are in accordance with our expectations. The higher content of metabolizable energy calculated by the silage in the high-density treatment could be explained by the higher content of protein in this silage compared with that in the low-density treatment. The higher protein content observed in the high-density compared with the low-density treatment showed that the different nutrient categories were not degraded in equal amounts. As a result, the relation of the nutrients to one another was changed by reheating in the high-density treatment because there was relatively less protein degraded compared with the other nutrients. The fact that this phenomenon was not observed in the low-density treatment implies that the higher density preserves valuable protein in the silage and results in higher energy content. The fact that there were only small or nearly no changes in the analytical categories of the silages due to oxygen might be justified by the fact that the silage used was well ensiled and the circumstances chosen, as well as the crop itself were conducive for quality silage. Garcia et al. (1989) found much greater losses in quality parameters and larger changes in nutrient categories due to oxygen infiltration, when they used alfalfa silage under circumstances that were not beneficial for quality silage. These results showed that further research is needed using valuable crops, which are less easy to ensile such as alfalfa, or grass. Also other influencing factors like parameters at ensiling should be taken into account in further research. Another interesting topic to investigate in the future is the remain of nitrogen resulting from protein degradation. Therefore, in future studies gases containing nitrogen will be included and the focus of further research should be on emissions resulting from silage.

On farm scale, Köhler et al. (2013) found that DM losses in case of maize silage averaged 10%, as measured by the total-in versus total-out procedure. Compared with the current results, the DM losses found by Köhler et al. (2013) were higher, depending on the treatment. Compared with small-scale experiments, there are more sources of losses in agricultural practice or in farm-scale operations. Rotz (2003) quantified total silo losses to range from 6% for sealed structures up to more than 15% for bunker silos. The losses described by Rotz (2003) are higher than those found in the present study. A difference between the studies in the experimental duration might be a reason for this discrepancy. (Pitt, 1986) predicted that the long-term storage losses resulting from oxygen infiltration through the silo container and into the silage mass would vary between 1 and 3% of the ensiled DM per month, as calculated with a mathematical model. Consistent with the present findings, the predicted losses by Pitt (1986) had similar magnitude. In contrast to the results obtained here with an opened system, Pitt (1986) assumed a closed silo, with oxygen infiltration occurring through the silo container into the silage mass. For that reason, the values calculated by Pitt (1986) are lower than the values reported here. According to the findings of Köhler et al. (2013), the DM losses in the low-density treatment exceeded those in the high-density treatment. The total DM losses due to reheating were tangentially higher in the low-density treatment of the present study. Contrary to the expectation, these losses were not significantly different but tended to be higher in the low-density compared with the high-density treatment. Dense compaction of plant material is one of the most important factors supporting the stability of silage by restraining the growth of microbial populations and their metabolism and thereby preserves DM, nutrients and energy during the aerobic exposure. However, dense compaction is only one factor influencing silage quality. High silage quality and aerobic stability is always a result of many factors issuing from crop, environment and management during harvest, filling, storage and feed out (Wilkinson and Davies, 2012).

Conclusion

The findings confirmed that dense compaction of plant material is an important physical factor supporting the stability of silage. High density has great impact on reduction of temperature during feed out period (Objective-1). Additionally, high density reduces microbial respiration activity in silage and can potentially reduce total mass losses (Objective-2). High silage density preserves DM, nutrients and energy during the aerobic feed-out period (Objective-3).

Acknowledgement

This study was financed by the Sino-German Center for Research Promotion (Chinesisch-Deutsches Zentrum für Wissenschaftsförderung (CDZ), Beijing, PR China) and by the German Research Foundation (Deutsche Forschungsgemeinschaft (DFG), Bonn, Germany) as a part of the project “Model-based research for the risk and prediction of silage bale deterioration suffered from aerobic impact”.

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