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Influence of Dry Matter Content, Bulk Density and Particle Size on Silage Porosity

Previous methods of measuring silage pore volume required a sample from the undisturbed silage core. For the "pore volume determination-Bonn, version 1", which was developed in Bonn, uncompacted substratum is used, which is pressed to the desired density in the measuring equipment. This prevents changes in the pore volume during sampling and transportation. Based on the data collected a formula has been developed to calculate the pore volume of maize silage.

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Keywords

Silage, pore volume, bulk density, pore volume determination

Animal feeding has become in recent years increasing competitition by the cultivation of renewable energy crops. The increasing demand for raw material production as well as the global increase in demand for foodstuffs has lead to an increase in the prices of grain and bought-in fodder. One possibility of reducing the expenditure in bought-in fodder exists in the improvement of the quality of farm-produced fodder. It is not sufficient just to harvest high quality fodder – the fodder must remain as a high quality input until the time of consumption. For this reason the successful storage of fodder crops is of the highest importance both as regards animal husbandry and energy production.

Definition of the problem and related aims

The most widely used method of fodder crop conservation is ensiling. Silage is the result of anaerobic conservation of damp harvested material. The availability of oxygen in silage is deleterious and leads to secondary fermentation. This results in a considerable loss of energy, nutrients, vitamins and dry matter [11, 7]. Secondary fermentation is frequently accompanied by the formation of moulds and mycotoxins, with consequent negative effects on animal health [11]. The work of [10] shows however that in practice secondary fermentation due to insufficiently compressed silage material is very common. In theory it is possible to prevent the ingress of air by comprehensively covering the silage with an impermeable membrane. In practice the efficacy of this is questionable [5]. There is an ever-present danger of damage to the membrane e.g. by birds, resulting in spoilage of the silage [12]. Another problem arises when the silage pit is opened for extraction of silage as fodder, resulting in the formation of a cutting surface, through which air can penetrate into the unused silage [9]. A poor filling and and extraction technolgy can lead to heightened levels of air ingress [7]. Pores in the silage contain a high proportion of CO_2, which has a higher density than air. At the start of the fermentation process the CO_2 concentration in the pores can be as high as 90 %. Later the CO_2 concentration declines to 20 %. This is however sufficient as a cause for the gas movement [6]. As well as diffusion, the permeability of the silage plays a role. If the silage material is sufficiently compressed during filling the silage pit, then the pore volume is small.

A small pore volume indicates high resistance to gas flow. An optimal resistance reduces the gas flow to at most 20 l $h^{-1}m^{-2}$ and at the same time ensures that air penetrates no further than 1 m into the silage [1].

The objective of this diploma project is ascertaining a formula that can be used to estimate the pore volume within maize silage. In the course of this project a measurement technique was developed that provides the most exact estimation possible of pore volumes in silage material. This enables research to be carried out on the influence of dry matter content, bulk density and particle size upon the pore volume.

Material and method

In order to measure the pore volume the "Bonn Pore Volume Estimation Version 1" (PVB-B1) method was developed and used. This involves a further development of the method for ascertaining pore volumes as described by [8]. [8] used an extraction method to obtain the silage sample. The PVB-B1 method involves the compression of the loose silage material directly in the measuring method with the help of a material testing method. The material to be tested can be weighed to a high degree of precision on scales and it can be compressed exactly to the desired sample volume. This guarantees the avoidance of sample transport and sample extraction related changes to the pore volume.

Calibrated measurements

For checking measurement accuracy the material testing machine cylinder serves as a replacement for the silage volume. The moving downwards of the piston reduces the air space. The basis of this method is the fact that the air-impregnated bodies do not need to be distributed equally. In this way it is possible to check that the values found by using the PVB-B1 method are correct by considering the relationship of mass to volume. The porosity measurements found by the PVB-

B1 method had a median deviation of 1.2 % from the actual values. The maximum deviation from the actual porosity value was 3.7 %.

Description of the samples

The substrate samples that were investigated comprised freshly cut fodder maize. The maize was frozen after being harvested. The samples varied both in cut length and in dry matter content. Dry matter content was ascertained after 16 hours of drying at 105 °C in a drying chamber.

The effective particle size was found through the use of an electronic sieve tower that allowed differentiation between 8 different values. The samples were dried for twelve hours at 100 °C and 100 g sieved for three minutes – after each three second run time a one second pause followed. The fractions were then weighed and the dry matter percentage calculated [2, 3].

Results

The evaluation of results has shown, as expected, that by increasing the bulk density the pore volume is reduced. The volume of the "No air fraction" in contrast increased with a greater bulk density. This demonstrates that, as well as the bulk density, the dry matter content of the silage has a significant influence on the porosity.

Comparing the two silages in *Figure 1* it is to be seen that a difference in dry matter content of 10 percentage points has an effect on the pore volume. Silage with a 39 % dry matter content has with a bulk density of 150 kg m^{-3} a median porosity of 66.1 %. Silage with a 29 % dry matter content has with the same bulk density a median porosity of 54.4 %. This is a difference of 11.7 %.

The difference increases with the increasing of the bulk density. With a bulk density of 230 kg m-3 silage with a dry matter content of 39 % has a porosity of 47.6 % and silage with 29 % dry matter content a median porosity of 28.4 %. This is a difference of 19.2 percentage points.

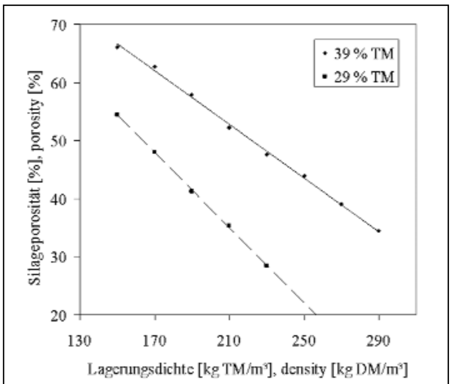

Fig. 1: Two silages with extremely different DM-contents

Taking account of the pore volumes at the same density, no differences could be established between silages with differing particle size.

Regression analysis

Multiple regression was used to analyse more exactly the influencing factors of bulk density and dry matter content. 885 measurement values were analysed. Particle size was ignored, because it had already been proved that in the case of maize silage for a given bulk density the cut length had no influence on the pore volume. Overall, 98 % of the porosity variance could be ascribed to the "Dry matter content" and "Density" variables. It was shown that bulk density had, by a factor of 2.383, a greater influence than dry matter content.

Equation 1: Estimation of pore volumes in maize silage

$$VP = 1{,}733 \cdot TMG - 0{,}256 \cdot \rho + 39{,}778$$

Where

VP = Pore volume in %

TMG = Dry matter content in %

ρ = Bulk density in kg dry-matter m^{-3}

Using this formula the porosity of maize silage can be calculated when the dry matter content and bulk density are known. This is a simple method that can be used in practice to calculate porosity, however it is recommended that the bulk density is ascertained using the method as described by [4]. The formula should only be used for maize silage, because it is based on maize silage porosity values and not all silage material demonstrates the same characteristics under compression.

Conclusion and prospects

Even a complicated silage cutting technique, as, for example, described by [8] is no guarantee that changes can be avoided at the cutting face. The possibility of damage to the sample during transport also cannot be ruled out when using the sample extraction device of [8].

The method used in this project has the distinct advantage that the silage material to be researched is first compressed in the laboratory. In consequence there is absolute certainty that no transport or sample extraction related, damage has occurred to the sample.

With the method it is not currently possible to measure the porosity of silage having a low dry-matter content, and at the same time a higher density. A future aim should be to make technical alterations to the method so that water can flow away unhindered during the compression process. Taking into account the volume of water flowing away, it should be possible to estimate the pore volume of very wet silage.

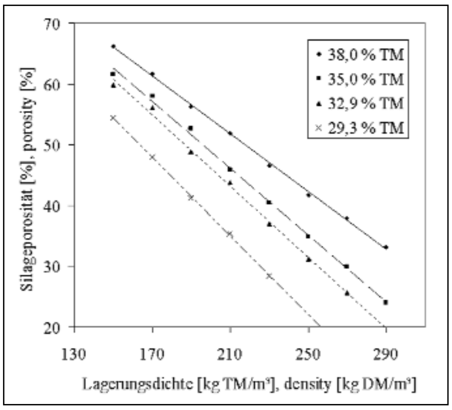

Fig. 2: Porosity of silages

Partial automation of some stages is imaginable. For example the sequence of opening and closing the single air valve could be automatically controlled. This would help to obviate the risk of operator errors and simplify the estimation process.

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