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Improved bulk density determination of silage round bales from penetrometer data

Bulk density plays an important role for silage quality. For the determination of the bulk density and its variability in round bales penetrometers are used, among other methods. However, the commonly used data analyses provide insufficient information in terms of site-specific interpretation. In this study, the conventional technique was expanded by two-dimensional data analysis (map-based analysis).

Keywords
Silage, bulk density, penetrometer, forage quality

Abstract
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3 figures, 17 references

The bulk density of silage round bales are of importance for several reasons. With increasing bulk density the costs of transportation as well as the specific requirement of film and yard per kg of silage decreases. Conservation success of silage is also affected by bulk density. On the basis of a high bulk density, a low porosity is achieved and the risk of reheating is reduced. (10, 11, 16, 5, 13, 4, 3, 15). A well compacted round bale is characterized by equal bulk density disposition, which provides for form stability of the bale. According to previous studies, bulk density and form stability are determined by compacting-technique and other factors such as cut length, layer thickness, dry matter content and harvest time (7, 8, 14, 10). In general, two types of round balers are used in practise: fixed chamber balers and variable chamber balers.

Fig. 1

Penetrometer in operating position

Several techniques used to determine silage quality, such as the Geo-radar, microwave scatter probe, sinking depth detector, ultrasonic sensor, film pressure cell, near infrared spectroscopy, γ-ray and penetrometer have been tested (5). These techniques are – depending on their operation mode – divided into invasive and non-invasive methods.

Among the non-invasive instruments, none but the Geo-radar and γ-ray have adequate penetration ability to allow scanning the inside of bales (5, 9). Despite the risk associated with radiation and complicated calibration procedures, some operators accept radiometric measuring methods as appropriate due to the accuracy of their measurements. Among various invasive instruments, the penetrometer has particular advantages over other techniques since it provides reliable data and can be calibrated easily (12).

Previous studies have focused mainly on statistical analysis and penetration course analysis to quantify silage density. In fact, statistical analysis is a not-dimensional data process and is therefore unable to characterize site-specific variations.

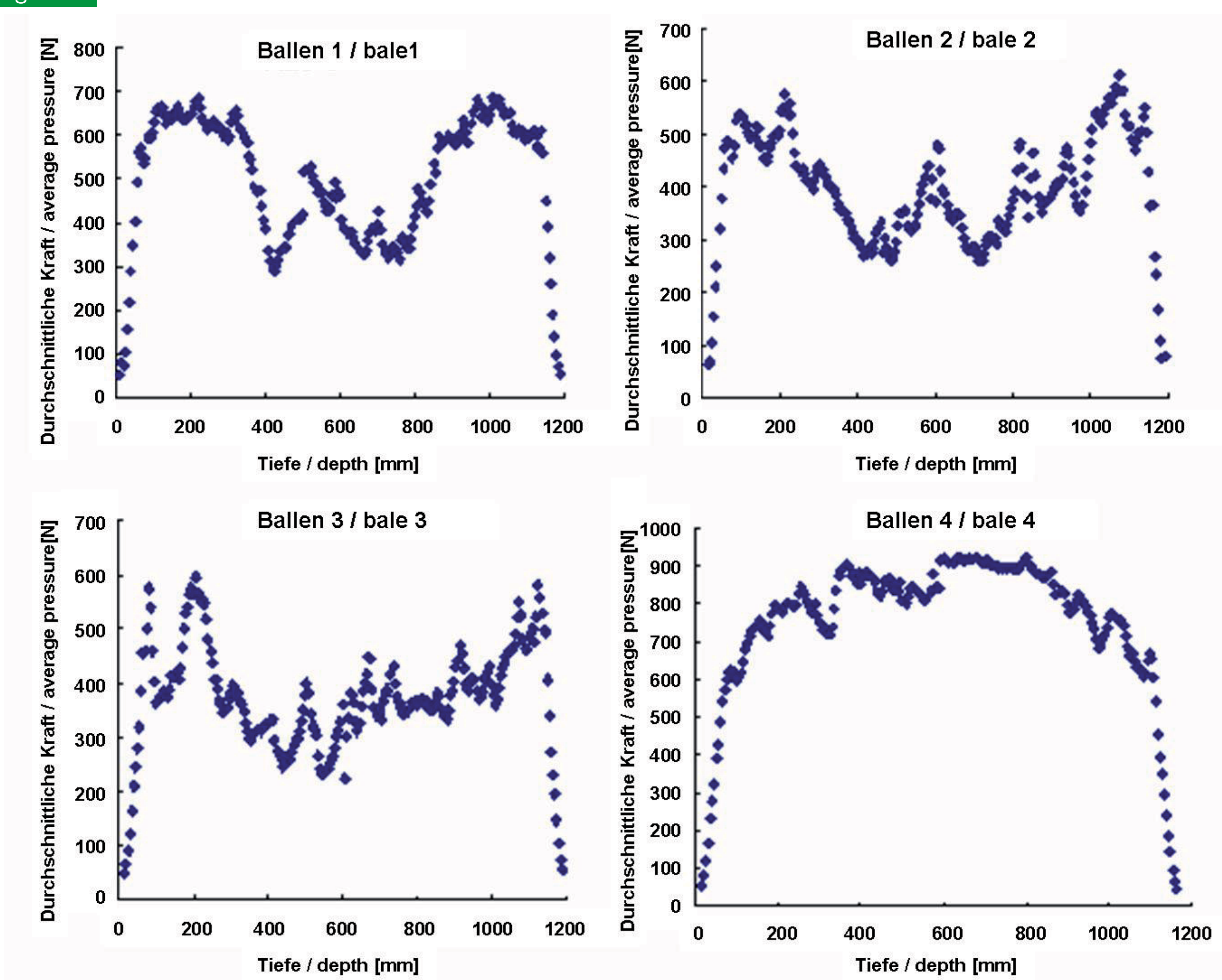
Penetration course analysis requires information regarding penetration resistance versus depth. In single-dimensional representation the illustration of results is restricted.

The objective of this research was therefore to complement the conventional penetrometer technique with map-based analysis, so that a visual validation of the bulk density becomes possible. The application of the improved method should give a better insight into the bulk density variation of round bales.

Material und Methods

Penetrometers can be operated manually or driven by a motor. In both cases a constant rate of insertion speed must be maintained even if the resistance to penetration varies (6, 17). It is difficult to achieve a constant rate of insertion speed using manually operated devices. Consequently, a motorised penetrometer was used, which was positioned over the round bales using a fork lift truck (**figure 1**).

Fig. 2



Single-dimensional results: penetration courses, averaged values of 12 measurements of bales 1 to 3: fixed chamber baler, bale 4: variable chamber baler

In this study, three round bales (Bale 1, 2, 3) were packed by a fixed chamber baler and one round bale (Bale 4) by a variable chamber baler for comparison. All bales consisted of wilted grass.

Six penetration measurements with an interval of 20 cm were undertaken on each bale. The maximum penetration depth was 60 cm, so that the cone of the penetrometer could advance to the middle of the bale. To analyse the entire bale, the bale was rotated by 180 °C and the same measurement sequence was replicated. After having taken twelve measurements for each bale, the average penetration course was calculated and brought out in one-dimensional space. Furthermore, the measured data was processed using Kriging Interpolation, so that the data could be used for digital two-dimensional representation. Finally, the software ArcGIS 9.2 was used to create a „map“ for the corresponding data

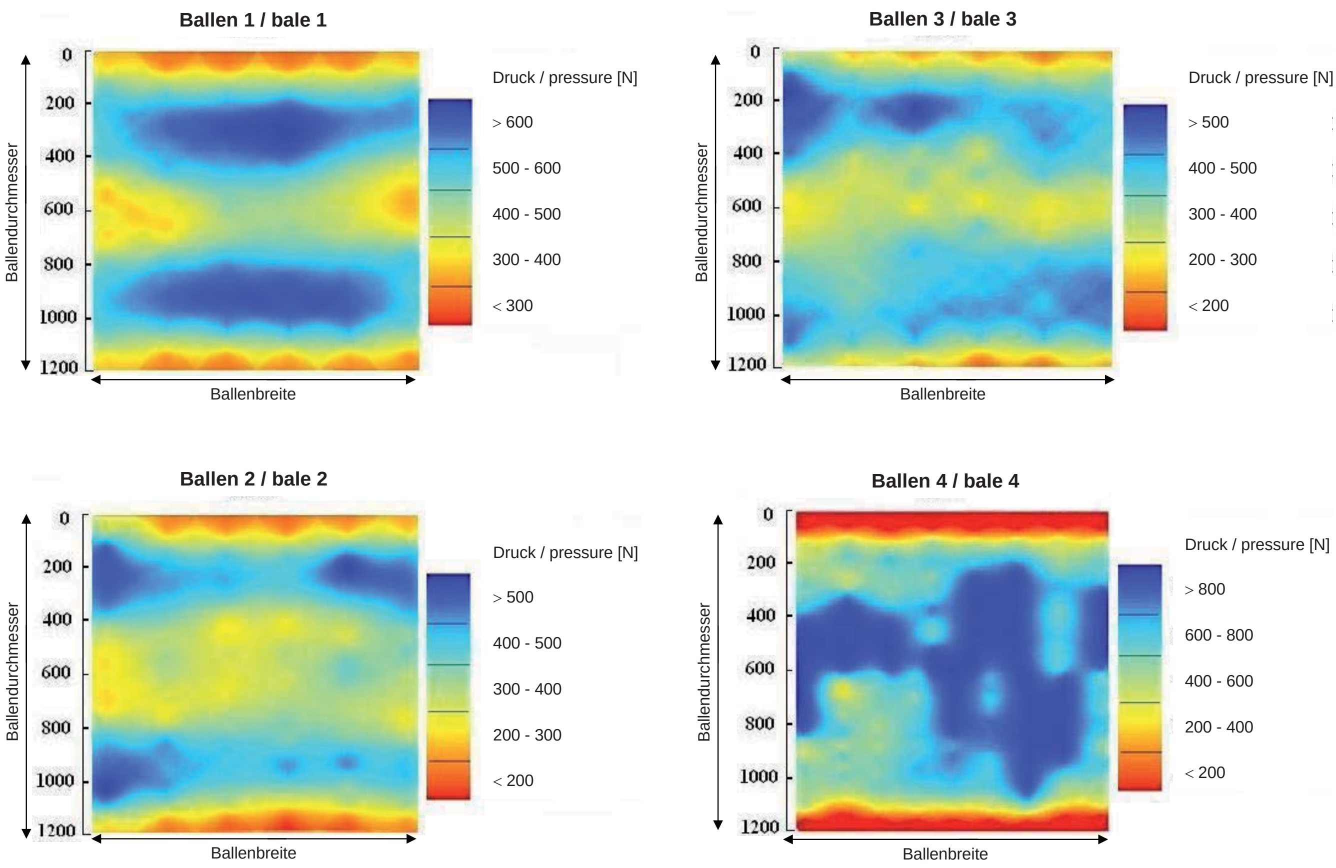
Results and discussion

Statistical analysis (not-dimensional data analysis). Among all tested bales, the mean value (721.1 N) of penetration resistance in Bale 4 was significantly higher than that of other bales. In addition, the maximal value (965.32 N) of penetration resistance also occurred in Bale 4. Both outcomes may be explained using Table 1, in which the bulk density (491 kg FM m-3) of Bale 4 was the highest. These results show that bales packed by variable chamber machine can attain higher bulk density.

Data analysis in single-dimensional space. Although the obtained statistical results are meaningful to assess the packing quality of the bales, they are incapable of perceiving site-specific variations inside bales. To represent the measured data in a single-dimensional space, **figure 1** exhibits four curves relating penetration resistance to depth, from which two significant observations can be made. Firstly, Bale 4 had a hard core, because the peak value of penetration resistance was found around a depth of 60 cm, whereas the other bales had soft cores, as can be observed by the concave appearance of the respective curves. Thus, it can be determined whether the bales were packed by fixed chamber or variable chamber machines by using single-dimensional analysis. Secondly, each bale, regardless of hard or soft core, has a symmetrical structure in accordance with the central axis. Despite these advantages of the use of a single-dimensional space over the statistical analysis, it still remains uncertain whether it detects site-specific discrepancies of bulk density/ porosity.

Data analysis in a two–dimensional space. The two-dimen-

Fig. 3



Two-dimensional results: pressure distribution maps of bales 1-3: fixed chamber baler, bale 4: variable chamber baler sional graphics in **figure 2** show the allocation of penetration resistance over bale width and height. As anticipated, a hard core in Bale 4 is confirmed. Unlike Bale 4, other bales had soft cores. Moreover, a laminated structure can be observed in these bales packed by fixed chamber baler. In particular the core of Bale 1 seemed notably softer, whereas the middle part between the core and surface appeared extremely dense. The qualitative differences show a similar picture as a radiometric scan of bales from different types of balers.

Conclusion

Although the penetrometer is regarded as an effective tool to detect silage density, both the statistical analysis and the single-dimensional analysis are insufficient to characterize the site-specific variations within bales in detail. By incorporating the map-based method into the conventional penetrometer technique, additional information for the visual assessment of compression quality can be provided without additional costs.

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