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Online-determination of silage density by radiometry

In order to store wilted grass or chopped maize in bunker silos the ensiled material must be compacted. High losses can occur if the compaction is too low. The aim of the project was to develop a measuring device to determine the density of the ensiled material during the compaction drives. The measuring method is based on the radiometric density determination by backscattered gamma-photons. For use in practice the developed measuring device is mounted in a measuring wheel behind the compaction vehicle. In conjunction with data from a Differential Global Positioning System (DGPS), the density values can be related to certain positions in the silo.

Keywords
Silage, compression, radiometry, bunker silos

Abstract
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When storing wilted grass or chopped maize in bunker silos the ensiled material has to be sufficiently compacted by driving over it, in order to avoid losses. At present, in order to measure the density of silage, samples are taken out from the silo using special drills or silage blocks are cut out with a silo block cutter. The density is calculated from the volume withdrawn and the associated mass. However, both these methods can only be applied after the storage period when the silage is removed. Hitherto, the farmer does not have a possibility to measure the density of the ensiled material during the compaction drive. The aim of ongoing research activities is to measure the volume increase during storage intake of the silage material in horizontal silos using a laser theodolite [1]. Knowing the stored mass the average density of the ensiled material can be calculated.

Own research had the objective to develop a device for online measurement of the material density during storage intake. After previous investigations [2; 3; 4] the radiometric method using gamma rays was selected as measuring principle.

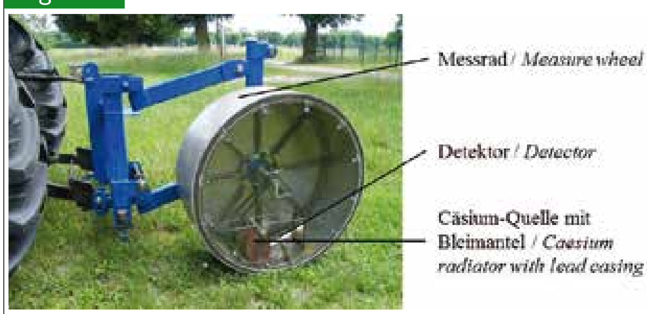
Material and methods

The core of the measuring device consists of a caesium radiator Cs-137 (662 KeV) with an activity of 37 MBq and a sodium iodide scintillation detector. The method is based on the back scattering principle. In this case, gamma photons are injected into the ensiled material. Once the injected photons bounce against electrons of the atoms they change thereby the direction of their motion. A part of the photons is scattered back in such a way that they are reflected and hit the detector. The detector counts the impinging photons and release their number as impulse rate (1/s).

In preliminary experiments on lab scale, the optimal geometric arrangement of source and detector and the penetration depth of the gamma rays into the examined material are determined [5]. Based on these examinations a wheel-like measuring device with optimized arrangement of source and detector was developed (**Figure 1**) and tested while driving over the silo. The measuring wheel is connected with the tractor by the three point linkage at the rear. The design is suitable for road transportation as well. The measuring wheel has a diameter of 1 m and a design width of 0.4 m. The lateral area of the measuring wheel is made of 5 mm aluminium sheet, so that as few gamma photons as possible are absorbed when the radiation passes through it.

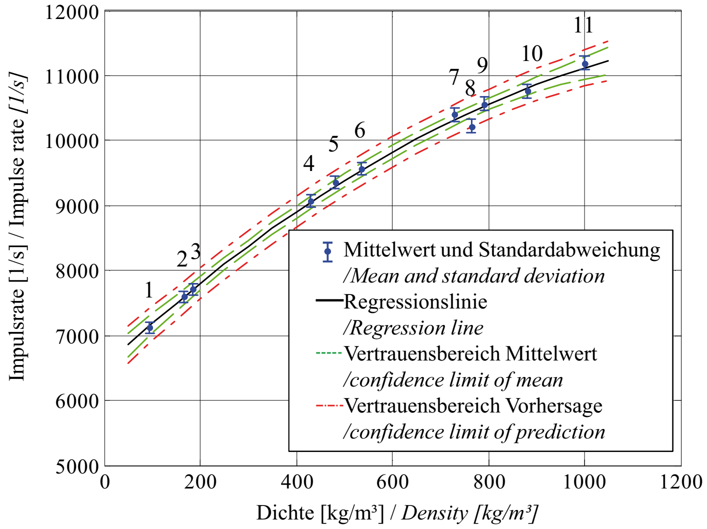
The radiometric measuring device was mounted on the compaction vehicle. The calibration was carried out using natural raw materials of known densities. This method is

Fig. 1



Measuring wheel with Caesium source and detector
(Foto: Geyer, ATB)

Fig. 2



Calibration curve with confidence areas for the radiometric density measuring device: 1 balsa, low density, 2 hemp shives, 3 balsa, high density, 4 spruce, natural, 5 oats, loosely poured, 6 oats, firmly tapped, 7 rye, loosely poured, 8 oak, 9 rye, firmly tapped, 10 spruce, compressed, 11 water

suitable, because organic materials are similar in their stochiometric composition and thus also display similar mass absorption coefficients [6; 7]. The materials used were hemp shives, balsa, spruce and oak, as well as oats and rye grains. For each material 100 single values were determined. Each single value consists of the impulse rate of the back scattered photons.

The measuring wheel was tested on bunker silos with chopped maize and wilted grass altogether eight times in 2011 and 2012. The measuring passes were always conducted together with the compaction vehicles of the respective farms.

Special software was developed in order to record and evaluate the measured values. Data from a Differential Global Positioning System (DGPS) were added in order to be able to allocate the density values to concrete positions in the silo.

Results

The calibration by various organic materials and water shows a quadratic connection between the given material density and the impulse rate (Eq. 1, **Figure 2**).

$$I = -0.002677 \cdot \rho^2 + 6.7956 \cdot \rho + 6193.1465 \qquad \text{(Eq. 1)}$$

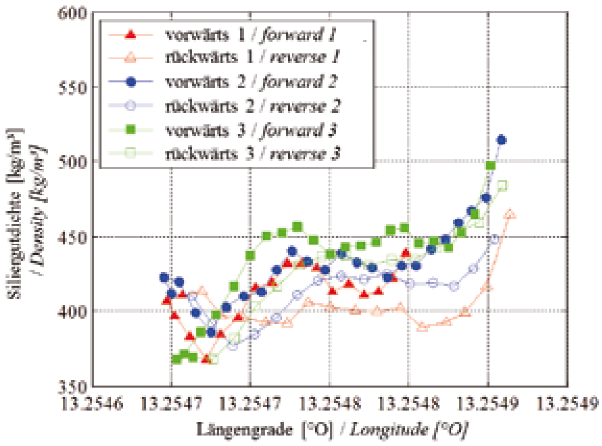
$$r^2 = 0.99$$

with I impuls rate (s^{-1})
ρ density ($kg\ m^{-3}$)
r^2 coefficient of determination (-)

The calibration curve shows a higher impulse rate with increased density. This refers to an increasing number of backscattered gamma photons (**Figure 2**). This is due to an overlapping of scattering and absorption processes in the material depending on the material density [3]. In the present case the back scattering process based on the Compton-scattering is predominant. The number of atoms and therefore also the number of electrons rises inside the material with increasing material density. Consequently, more gamma photons are scattered back.

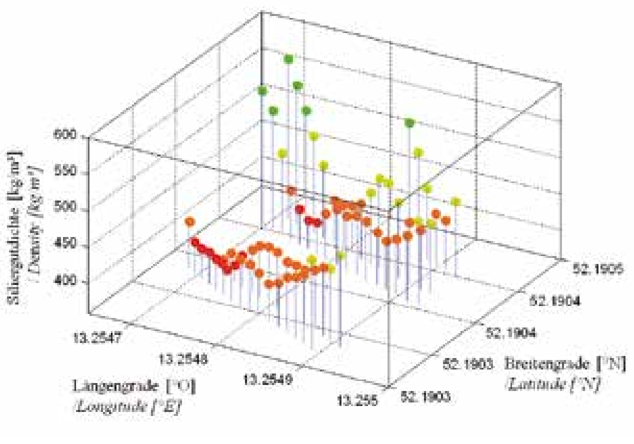
In consecutive compaction passes in the track, an increase in density becomes evident (**Figure 3**). The measuring system is thus in a position to determine the compaction effect of repeated roller passes in a track or rut. A lower density is measured during reverse drive than in forward drive due to the elastic recovery of the ensiled material.

Fig. 3



Density curve for three consecutive forward and reverse trips in one track for wilted grass

Fig. 4



Measured silage density as a function of longitudes and latitudes on a bunker silo with wilted grass

By means of own preliminary tests regarding the penetration depth of the gamma rays it is known, that density differences inside the material at 760 kg/m³ (dry mass) can be observed up to a depth of 10 cm [5]. This implies for the compaction drives that the density value determined is representative for the upper material layer, which is just compacted.

Using the longitude and latitude, the compaction trips can be shown three-dimensionally (**Figure 4**). For better clarity, only the respective last trip is shown. The densities achieved are evaluated via colour grading of the measuring points, from red (for insufficient density) to green (for sufficiently compacted silage). In general, the density values vary widely in accordance with their position.

Conclusions

By arranging source and detector in a trailed measuring wheel, the silage density can be measured online during travel. In conjunction with data from a Differential Global Positioning System (DGPS), the density values can be allocated to certain positions in the silo. Consequently, the prerequisites for density mapping of the silo surface exist.

In general, the driver of the compaction vehicle gets assistance in planning any further compaction tracks with density mapping and appropriate software.

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