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Logistics of the silage storage at high mass flows

The material properties of the raw material and the process parameters during harvesting and filling of the bunker silo have a great influence over the quality and the losses of the silage material. The mass flow from the field has to be filled in the silo, compressed and covered in such a way that the gas exchange will be very low. The harvest technology developed during recent years does not allow to process high mass flow and to compress the material sufficiently. From a physical point of view a required density of the ensiled material can only be rea-lised by wheel tractors for an adequate compression time. Therefore, a high number of tractors would be necessary depending on the mass flow. In addition, the silo must have an appropriate width.

Keywords
Logistic, silage storage, silage silos

Abstract
Landtechnik 64 (2009), no. 3, pp. 168 - 171,
2 figures, 1 table, 12 references

The quality of the silage is an important prerequisite for the performance and health of the life stock. Moreover, high quality silages are consequently the best guarantee for healthy food production. Losses of dry mass due to incorrect processing of the raw material certainly have an economic impact. Besides using silages for feeding life stock, they have been gaining significance as a raw material in bio-gas generation, and for the future they will probably be important for fuel production. The quality of the silage is influenced by the quality of the raw material as well as by diverse processing parameters. Important for silage quality are harvesting methods, storage and compression, ensiling processes, the coverage, and removal. Mass flows at harvest, storage, and removal play a particularly significant role in the entire process. Therefore, they must be coordinated within the logistics chain in such way that optimal silage quality can be achieved.

Basics of Logistics

The processes of harvest, transport, storage, and compression have to be coordinated thoroughly to achieve high quality silages. Harvesting and picking the raw material is carried out with forage harvesters and loading wagons. Loading wagons require lower investments and are particularly suitable at shorter distances between field and silo. Currently, wagons with loading capacities >40 m³ are available on the market. Due to the high number of cutters, chop lengths of up to 34 mm can be achieved theoretically. This is sufficient for compression in the recommended dry mass range, thus the silage qualities achieved are not inferior to those made from crop of forage choppers [1]. Forage harvesters can theoretically achieve chop lengths of minimum 4 mm. Due to engine outputs exceeding 500 kW it is possible to achieve throughputs of >70 t/h of wilted grass and >200 t/h of maize. Thus, there are high requirements on the logistics management of the entire process chain.

Loading volumes and driving speed have also increased in the means for crop transport from the field [2]. Several manufacturers have developed special self-loading wagons for crop transport with loading volumes of >43 m³ or high volume silage wagons with 80 m³ loading volume. Transport speeds have increased to a range of 60 km/h to 80 km/h.

The number of required transport units in the logistic chain results from the transport distance and the mass flow from the forage harvesters (**figure 1**). For example, 10 to 30 transport units with a loading volume of 40 m³ each are required at a transport distance of 10 km depending on varying harvester outputs.

In farming praxis the current challenge lays in storing and appropriately compacting the high mass flows coming from the forage harvesters into the bunker silos. Here it is of the essence to provide the sufficient number of compacting units and appropriate silo widths respectively (**Table 1**).

Storage and Compaction in Horizontal Silos

Upon storage, the density of the silage raw material has significant impact on successful ensiling. In experimental trials [3, 4] the gas exchange was examined, and the exponent of the gas exchange speed α as well as the exponent of gas generation in the silage α bio dependent on the storage density of the original substance (OS) was determined. Imperative criterion for storage density is that the storage density of the original substance must not be higher than the gas generation in the silage, i.e. $\alpha < \alpha_{bio}$. Thus, for wilted silage material with exposed silage surface without plastic covering a density of >750 kg OS/m³ should be achieved. Since this cannot be achieved in praxis, the silage material is covered with silage plastic to seal it of from air. Using silage plastic and applying weight load equally on its surface reduces the required storage density to 400 – 500 kg OS/m³.

The storage densities are mostly dependent on the applied static pressures as well as on the physical properties of the silage material, i.e. the dry mass content [TM], the flexural stiffness of leaves and stalks [EI], and the chop length [lH], as well as the time of weight load [t] – i.e. the storage time. As for static loads, the storage density can be defined by a compression function [5].

Principles of compression with tractors were examined by Herold [6]. From retardation tests with freshly cut field grass with a chop length l_H = 40 mm and dry mass content TM = 16% we see in lasting deformation ε_{bl} dependent on the vertical pressure p_v and the force load time t_H of vertical pressure a connection in which the amount of the vertical pressure has the strongest impact on the lasting compression.

Based on consideration of extensive research [7; 8] and latest research at ATB [9], the compression effort in tractor minutes per ton original substance [Tr.-min/t/OS] can now be specified for practical application.

According to this, all types of material and dry masses require ca. >1.0 to 1.5 Tr.-min./t OS. Thus, for example, upon harvest output of 100 t OS/h more than 2 compression tractors are needed. This in turn requires appropriate silo width (**table 1**). In dry masses exceeding 50 % the required surface densities cannot be achieved anymore.

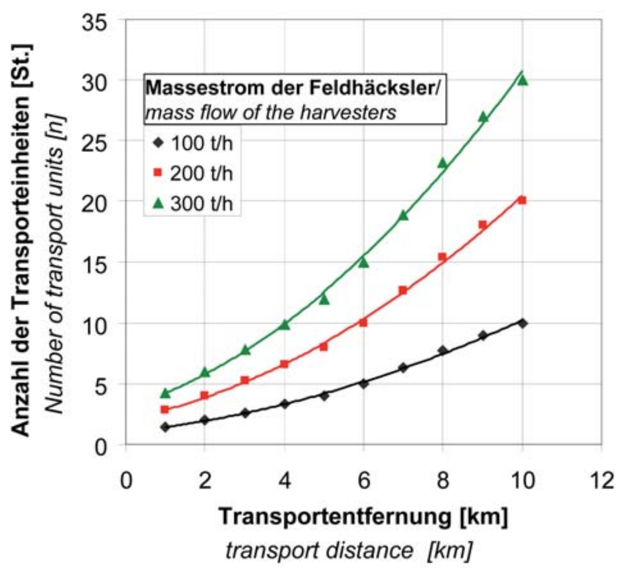
Determination of density is almost exclusively facilitated by weighing large volume elements upon removal or using drill core samples. Besides that, radioactive measuring methods and online measuring methods [10] have been developed. Those are suitable for density controlling during silage storing.

Tab. 1

Required compaction effort and necessary compaction units when storing silage material in horizontal silos

Trockenmasse [%] / *dry matter [%]*	20	25	30	35	40	45
Verdichtungsaufwand [Tr-min./t OS] / *compaction effort [Tr-min./t OS]*	1,0	1,0	1,5	1,5	1,5	1,5
Massestrom je Verdichtungseinheit [t/h] / *mass flow/compaction unit [t/h]*	60	60	40	40	40	40
Verdichtungseinheiten [St.] / *compaction units [n]*						
100 t/h	2	2	3	3	3	3
200 t/h	4	4	5	5	5	5
300 t/h	6	6	8	8	8	8

Fig. 1



Necessary number of transport units (40 m³) depending on the mass flow of the harvesters (DM = 35 %)

Removal from Horizontal Silos

The daily removal volume (feed rate) is determined by the number of cattle and feed ration. The cross section area of the silo must be designed to sufficiently provide for a daily minimum removal depth. Research results [7] suggest that the risk of perish of exposed silage at the discharge bay is mainly influenced by the silage density. Thus, required removal depths are 0.10 m/d to 0.25 m/d for grass silage and 0.20 m/d to 0.40 m/d for maize silage. Since the clear priority in the entire process of feed preservation lays in silage quality and avoidance of losses, the geometry of the silo must be designed according to the actual consumption, i.e. the daily removal. This determines the necessary silo width, which in turn has an impact on the number of compression tractors usable and the possible mass flow at filling/storage (**figure 2**).

Tube Ensiling

Tube ensiling has significantly increased in the past years. Main reasons are the small investment and the high flexibility. Pressing the forage in the plastic bag is facilitated by a press rotor taking the material from an input tray. The plastic bag is located between retainer and tractor, which are connected by wire. Thus, the compression pressure can be regulated by the brake of the tractor [11; 12]. At present, plastic bag diameters up to 3m are available. The throughputs are currently at 40-60 t/h for grass silage and 80-100 t/h for maize [12]. With reference to process costs there are no differences compared to bale ensiling, and no significant differences to ensiling in horizontal silo [11; 12]. It is of advantage that no additional tractors are required for compression, and time consumption is limited. Disadvantages, especially with large life stock, are the demand of space; and secondly the demand on plastic bag for environmental reasons. Removal technologies are not optimal either [11].

Bale Ensiling

Bale ensiling is mainly important for smaller consumption mass flows. Advantages lay in high flexibility and easy handling. Disadvantages are the high demand in plastic and the risk of damage to the plastic. Even minor damage may affect the silage quality. Upon ensiling, which is mainly carried out with press wrapper combinations, attention must be paid to the density required for silage. The bale density is more important for the silage quality than the hermitical sealing by wrapping with plastic or the dry mass content [5, 11]. The main standards require 6 layers of plastic [5]. In Switzerland, a machine based solution on a stationary operated press wrapper combination was developed, which allows ensiling maize crop in bales. The throughput is 20-30 t/h [11].

Conclusions

Besides some contained substances, the processing parameters for storage, compression, coverage, and removal have the most significant influence on silage quality and material losses. Utmost attention must be paid to sufficient compaction upon storage. Thus, in the planning of the entire logistics chain, capacities must be coordinated in such manner that allows for sufficient numbers of compression units to sufficiently compress the mass flow of produce from the field in the silo.

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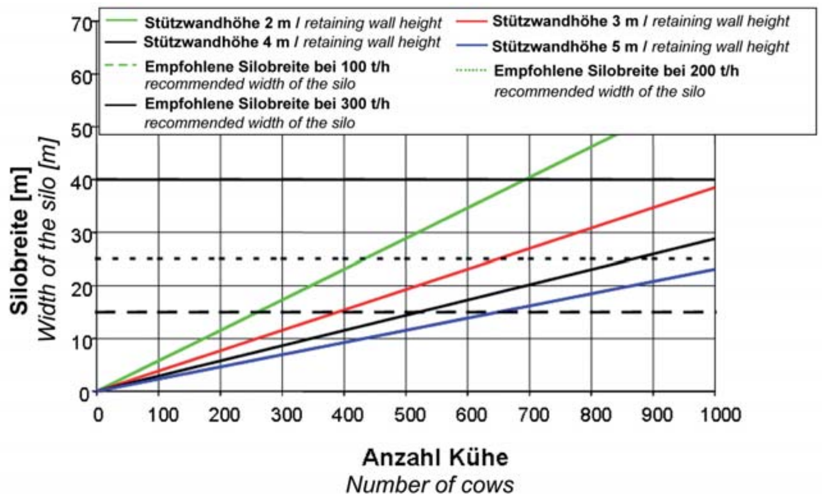
Fig. 2



Width and height of the silos as a function of the number of cows and mass flow of the harvesters (unilateral discharge, daily feed rate: 0.4 m)