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Multiphase transportation methods in silage maize harvesting

A continuing growth of silage maize production with increasing field to farm distances challenges contractors to carry out the harvesting and logistics process efficiently. A multiphase harvest process chain separates field and road transport. In the joint KTBL/ART project "biomass logistics" a work analysis of different methods was carried out. Results show under model conditions a higher process performance compared to the common parallel method.

Keywords
multiphase transportation methods, silage maize harvesting, working-time requirement, model calculation

Abstract
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Transport-linked working procedures in agriculture are undergoing a trend towards the separation of the transport process [1]. Bulky harvested material is transferred at a collection point close to the field for road transportation on trucks. A higher payload and a higher average driving speed on the road are used to increase haulage capacity, for example in beet and cereal harvesting [2]. With the growing use of silage maize as an energy resource for biogas plants, multiphase transportation has also become a practical part of silage maize harvesting.

Multiphase silage maize harvesting methods differ primarily with regard to the technology used for loading the road transport vehicle (truck). Self-propelled or towed transfer vehicles, which in the parallel method are filled by the forage harvester, transport the chopped material to the transfer point and unload it from a height of more than 4 m straight into the waiting truck. At least two transfer vehicles per forage harvester are needed so that the harvester can work without interruption. In combination with the usual field transport units (tipper, forage wagon), transfer conveyors or even transfer stations are used to convey the harvested material onto the truck in multiphase methods. An alternative here are hopper forage harvesters, which take on both the chopping as well as transportation to the transfer point and the transfer. This saves having to use a field transport unit, although the chopping process has to be interrupted for the transfer.

The aim of the present study is to provide key labour planning figures for harvesting maize silage by the multiphase method. This involves analysis of loading in the field, loaded and unloaded trips, transfer from field vehicle to road vehicle, and of setting-up times. The results are presented for three multiphase mechanisation variants M1 (**Figure 1**), M2 (**Figure 2**) and M3 (**Figure 3**) and by comparison for the parallel method M4 (**Figure 4**). The mechanisation variants are shown in **Table 1**.

Fig. 1

Transfer conveyor (photo: ART)

Fig. 2

Transport vehicle (shuttle) (photo: ART)

Fig. 3

Hopper forage harvester (photo: ART)

Fig. 4

Parallel method (photo: ART)

Material and methods

Labour organisation studies of multiphase maize harvesting methods were conducted using job observations on commercial farms in Germany. To this end, working processes were split into task elements, their smallest components. Associated standard times were calculated in order to quantify the working-time requirement under defined conditions at model level [3]. To carry out the time studies a workflow model containing all the task elements connected with the working method was created first, and measuring points for the relevant workflow segments and elements were defined. Associated influencing variables were also recorded (distances, mass, volumes, etc.). Recording was carried out by means of Pocket PC (Dell Axim) and special time recording software (Ortim b3), measurements were taken in centiminutes (cmin = 1/100 min). Each time segment could be assigned to the associated task element. For cyclic measurement segments, the arithmetic mean, the epsilon accuracy and the standard deviation were already given continuously during the surveys as a quality criterion of the sample.

Mean value, variance and standard deviation were calculated from the repeat measurements for the individual methods. Evaluation was followed by entry into a standard time database. The PROOF model calculation system, a modular system based on table calculation software, was used to model the working-time requirement [4].

Model operation influencing variables

Silage maize harvesting and logistics are determined by numerous influencing variables, for example plot size and transportation distance, which are entered in the model calculation sys-

Table 1

Mechanisation of the silage harvesting methods investigated

Verfahren ***Method***	**M 1** **Überladeband** ***Transfer conveyor***	**M 2** **Transportfahrzeug (Shuttle)** ***Transport vehicle (shuttle)***	**M 3** **Bunkerhäcksler** ***Hopper forage harvester***	**M 4** **Parallelverfahren** ***Parallel method***
Häckseln AB, Maisvorsatz Ladekapazität *Chopping* *Working width, maize header,* *Loading capacity*	SF-Häcksler 6 m, 8-reihig - *SP forage harvester* *6 m, 8-row* -	SF-Häcksler 6 m, 8-reihig - *SP forage harvester* *6 m, 8-row* -	Bunkerhäcksler 6m, 8-reihig 35 m³ *Hopper forage harvester* *6 m, 8-row* *35 m³*	SF-Häcksler 6 m, 8-reihig - *SP forage harvester* *6 m, 8-row* -
Feldtransport Ladekapazität *Field transport* *Loading capacity*	Traktor + Häckselwagen 40 m³ *Tractor + transport trailer* *40 m³*	Traktor + Shuttle 30 m³ *Tractor + shuttle* *30 m³*	(siehe Häckseln) *(see chopping)*	Traktor + Häckselwagen 40 m³ *Tractor + transport trailer* *40 m³*
Überlademaschine Techn. Leistung *Transfermachine* *Techn. performance*	1 Traktor + Überladeband 685 t/h *1 tractor + transfer conveyor* *685 t/h*	-	-	-
Straßentransport Ladekapazität *Road transport* *Loading capacity*	Lkw 60 m³ *Truck 60 m³*	Lkw 60 m³ *Truck 60 m³*	Lkw 60 m³ *Truck 60 m³*	(siehe Feldtransport) *(see field transport)*

tem as variables with upper and lower limits. A predetermined value corresponding to the data collected on commercial farms is specified for all the variables in order to compare different methods under uniform model conditions. The following assumptions were made when modelling and calculating working-time requirement:

- 5 hectare plot size
- Rectangular shape
- Transport distance 10 km
- Yield 50 t_{FM}/ha, dry matter content 35 %
- Forage harvester throughput of 120 t_{FM}/h

The system begins when the vehicles and machinery arrive in the field and ends when the road transport vehicles discharge to the silo. This model does not include compaction of the harvested material in the silo. The forage harvester, the most expensive machine in the chain, chopped without any waiting time. The transfer point was located right by the field edge midway down the width of the plot. A constant mass flow was assumed, i. e. the number of units available was equal to the number of transport units required. Due to the greater loading capacity of the road vehicles than that of the field transport units, the trucks experienced waiting times between two transfer procedures. Waiting time was taken into account when calculating the time requirement.

Results

The total working-time requirement for the three multiphase silage maize harvesting methods (M1, M2 and M3) and harvesting by the parallel method (M4) comprised chopping, field transport, transfer to the truck and road transport, including discharge of the harvested material at the silo (**Figure 5**). A comparison shows that the total working-time requirement differed significantly between the various methods. Whereas under the given basic conditions the transfer conveyor and shuttle methods had a similar working-time requirement at 3.4 and 3.2 MPh/ha, 2.8 MPh/ha was required for the hopper forage harvester method and 4.7 MPh/ha for the parallel method. The time requirement for chopping was the same for variants M1, M2 and M4, as the same mechanisation was used. The hopper forage harvester should be considered separately, as in this method chopping and intermediate transportation are carried out by the same machine. The time requirement of 0.38 MPh/ha for conveyor transfer (M1) differed only slightly from the time requirement of 0.36 MPh/ha for shuttle transfer (M2), although in variant M1 an additional manpower unit was used to operate the conveyor. This is due to the difference in transfer time, only 5.7 MPcmin/m^3 for the conveyor compared with 8.1 MPcmin/m^3 for shuttle transfer.

As expected, the time requirement for road transport in the parallel method was the highest at 3.6 MPh/ha, because the silage was delivered to the silo by the field transport units and hence with lower transportation volume and speeds.

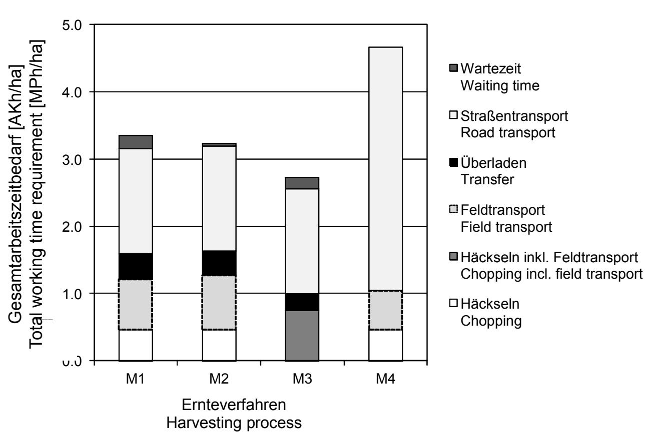
The waiting times experienced by the trucks between the unloading procedures of the field transport vehicles differed as well. At 11.7 MPmin the waiting time in method M2 was considerably less than the 60 MPmin in method M1. This high figure is due to the fact that after a transfer operation the transfer conveyor operator waited at the conveyor in addition to the truck driver until the next wagonload was discharged.

Conclusions

Using the PROOF model calculation system various transportation methods could be reduced to a common denominator and thus compared. At the same time the model can be used to plan and optimise working practices.

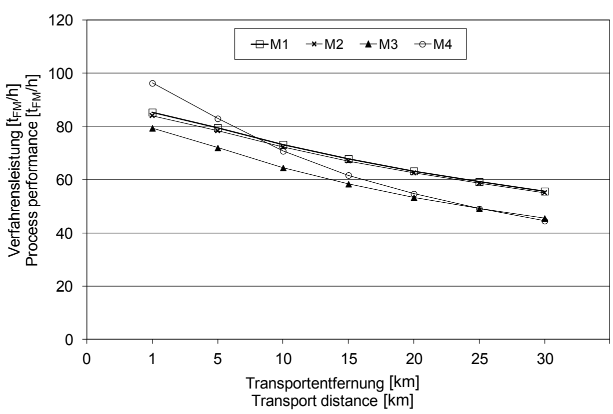
Under the basic conditions defined in the model it is shown that the total working-time requirement of multiphase methods is up to 1.9 MPh/ha less by comparison with the classic par-

Fig. 5



Total working time requirement for multiphase methods and parallel method of silage maize harvesting (plot size 5 ha, rectangular, transport distance 10 km, yield 50 t_{FM}/ha, throughput forage harvester 120 t_{FM}/h)

Fig. 6



Comparison of the process performance of multiphase methods and parallel method in silage maize harvesting (plot size: 5 ha, yield: 50 t_{FM}/ha) allel method. Using multiphase methods process performance for a transportation distance of 10 km can be increased by up to 3.4 % compared with the parallel method, by up to 15.8 % for a transportation distance of 20 km.

The number of transport units required increases with distance, posing a further challenge to coordination within the harvesting chain. Poor coordination in the process chain leads to delays, not only at the loading point but at the transfer point as well. In commercial farming the interim storage of chopped maize material is being discussed as a solution, but this results in avoidable aerobic losses. At larger transport distances, the coordination of harvesting logistics increasingly requires the use of electronic systems to manage the growing demands of efficient fleet management.

Literature

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