

## **LOGISTICS FOR HARVESTING SHORT ROTATION FORESTRY WITH A SPECIAL EQUIPPED FORAGE HARVESTER**

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**Abstract:** *The working time requirement and the costs per ton dry matter significantly depend on the plot size and the mass flow through the forage harvester for harvesting short rotation forestry. Because of the limited operation speed of the forage harvester, the yield often significantly influences the mass flow. The mass flow through the forage harvester, the loading space and driving speed of the transport vehicles, the bulk density of the wood chips, the expenditure of time for unloading and transshipping of the wood chips, the haul distance and the idle times influence the working time requirement as well as the costs for the logistics of the wood chips. Tractors with trailers are the most cost-effective possibility to transport wood chips when the distance between field and storage is shorter than 9 to 13 km. A transport chain basing on containers is more effective for larger distances.*

### **1. Introduction**

Short rotation forestry is an agricultural area for planting fast growing tree species (e.g. willows and poplars) and is used for approximately 25 years. Below working time requirement and logistics for harvesting by means of forage harvester equipped with a special short rotation forestry header are analysed.

### **2. Material and methods**

Especially willows and poplars at a planting design according to the Austrian custom with an aimed harvest cycle of 2 to 4 years were analysed. Willows were planted in double rows with a distance of 75 cm between both rows and a distance of 150 cm between double rows. For poplars, the distance between rows was 300 cm. Within the row, the distance varied between 50 and 57 cm.

Harvest was done with a forage harvester (Claas Jaguar 890 - 370 kW) equipped with a special header (Biomasse Europa). The theoretical cutting length was adjusted to 34 mm. The header cut down one row at poplars and one double row at willows and fed them to the chopping unit. The header was able to manipulate trunks with a diameter up to 13 cm. The harvester blew the wood chips into accompanying tractor-pulled trailers, which transported them to the storage or interim storage.

For the transport of the wood chips four logistics chains were analysed:

- Chain 1: Tractor-pulled trailers directly transported the wood chips from the field to the storage.
- Chain 2: Tractor-pulled tippers transported the wood chips from the field to an interim storage near the field. Articulated lorries or road trains carried out the transport from the interim storage to the storage. A wheel loader or teleloader loaded the lorries.

- Chain 3: Tractor-pulled adapted field transfer trailers transported the wood chips from the field to the articulated lorries or road trains. By means of an auger, the field transfer trailers directly loaded the wood chips on the lorries.
- Chain 4: Tractor-pulled hook lift trailers with a container transported the wood chips from the field to an interim storage for the containers near the field. At the interim storage, two loaded containers were picked up by a road train equipped with a hook lift and were then transported to the storage.

For data collection all operations (e. g. cutting down and chopping the trees by the forage harvester, transport of the wood chips from the field to the interim storage, loading the lorries, transport of the wood chips from the interim storage to the storage) were divided into parts of an operation and work elements (Handler and Blumauer 2010). For collecting labour input data of the individual work elements, the digital time measurement system Ortim a3 was used.

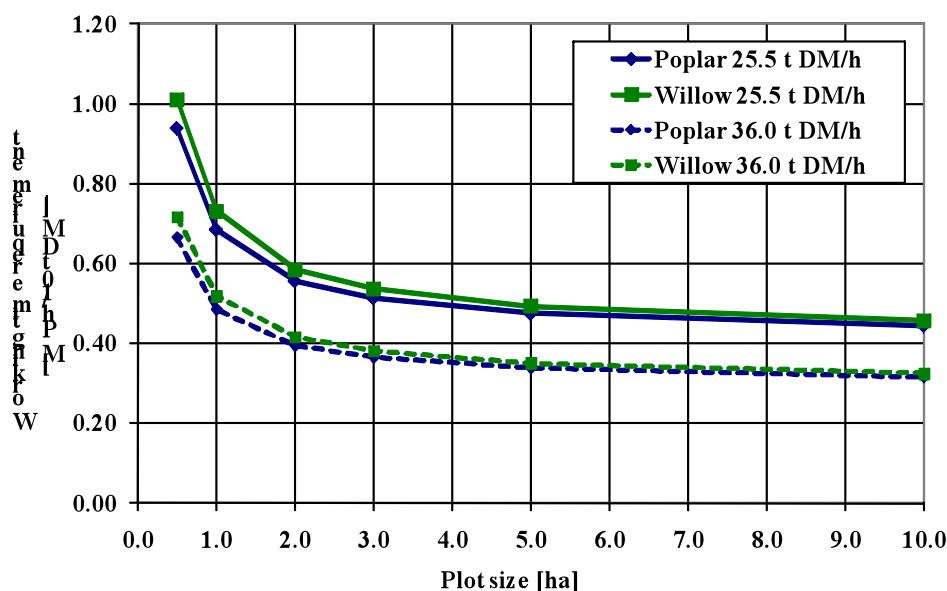
Distances were measured by means of GPS. The mass of harvested wood chips was determined by a weigh-bridge. The moisture content of the wood chips was determined in accordance to CEN/TS 14774-2:2004 (European Committee for Standardization, 2004). The bulk density of the wood chips was measured in accordance to CEN/TS 15103:2005 (European Committee for Standardization, 2005).

Statistical evaluations of the work-studies were done by means of ORTIMzeit Professional and SPSS 17.0.

Model calculations were done based on determined standard times, which are published in Handler and Blumauer (2010).

### 3. Results and discussion

Working time requirement per ton of dry matter for harvesting depends essentially on the plot size and the mass flow through the forage harvester (see Figure 1). With increasing plot size the parts of working time for turning on the headland and changing the field decrease and lead to a reduction of working time



**Figure 1.** Working time requirement for chopping poplar and willow by a forage harvester equipped with a special header<sup>1</sup>

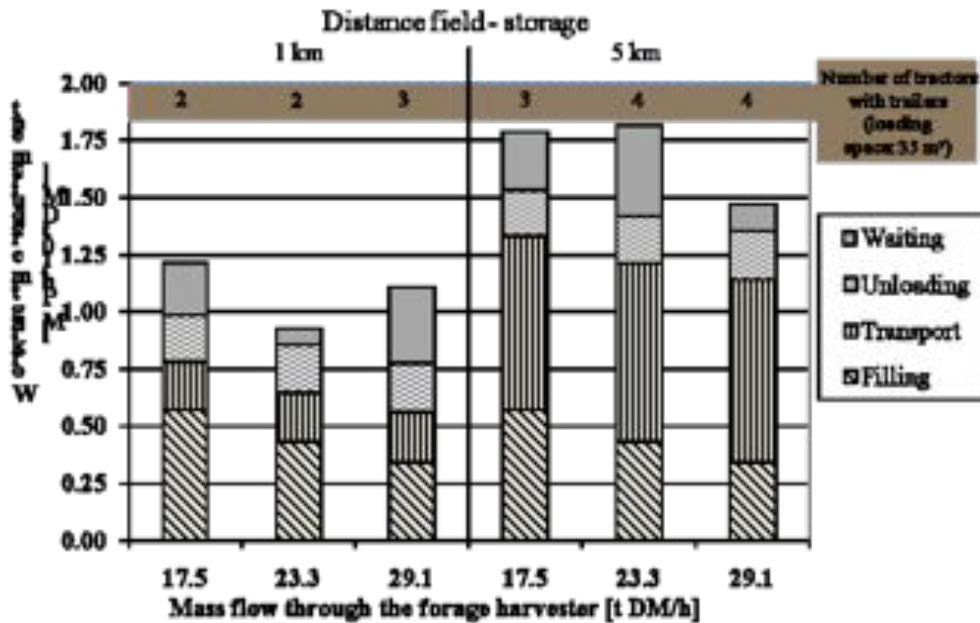
<sup>1</sup> DM ... dry matter, MPH ... man power hour, t ... tons, h ... hour, ha ... hectares, mass flow related to effective time for chopping, ratio of plot length to plot width: 2:1

requirement. The operating speed of the harvester is limited to 5 to 7 km/h to avoid destruction of stools. Therefore, a low yield leads to a significant decrease of the mass flow through the harvester and to an increase of working time requirement per ton of wood chips. Due to the smaller distance of willow double rows compared to poplar single rows the number of turnings on the headland is higher for chopping willow. This effects a higher working time requirement for chopping willow at the same mass flow<sup>2</sup> through the harvester.

The costs of the harvester including the operator amount to approx. 320 €/h. Depending on mass flow and plot size the costs of the harvester vary between 9 and 32 €/t DM. The results of Eckel et al. (2008) and Spinelli et al. (2009) range within the same scope.

Four different types of transport chains are analysed for the transport of the wood chips from the field to the storage (see chapter Material and methods). The transport chain 1 completes the transport from the field to the storage in one go.

The columns in Figure 2 show the composition of working time requirement for transporting the wood chips by tractor-pulled trailers from field to storage. All this was depending on the mass flow through the forage harvester as well as the haul distance between field and storage. In this case, the increasing mass flow reduces the working time requirement for filling up the trailers by the harvester. The working time requirement for transport<sup>3</sup> and unloading the trailer are not influenced by the mass flow. Because of the high costs, idle time of the forage harvester is avoided in the model calculations. However, idle time of transport vehicles occurred. The increase of the mass flow from 17.5 t DM/h to 23.3 t DM/h at a distance of 1 km between field and storage causes a better degree of capacity utilization of the logistics chain,



**Figure 2.** Working time requirement for transport of wood chips by tractor-pulled trailers from field to storage depending on mass flow through the forage harvester and haul distance between field and storage<sup>4</sup>

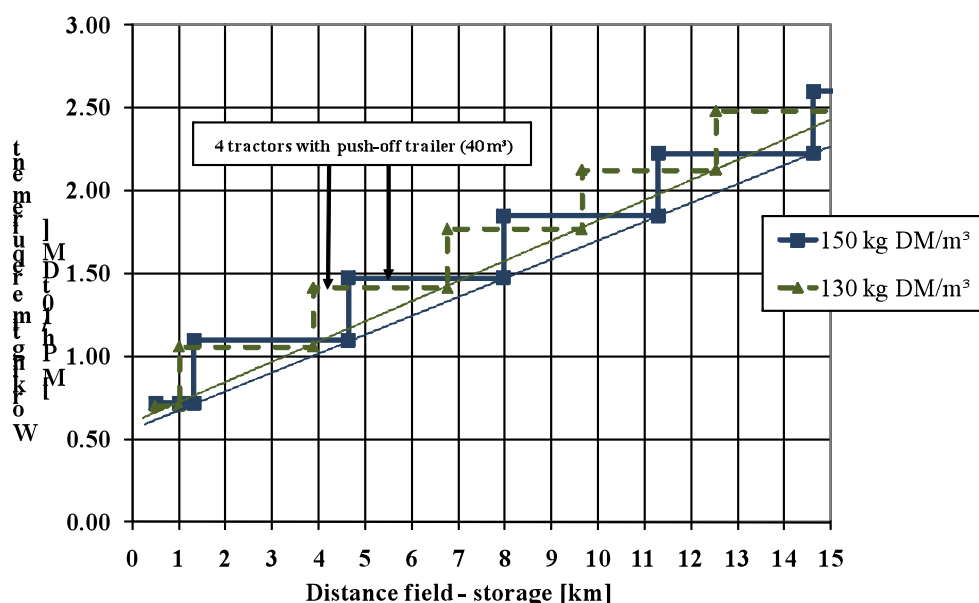
<sup>2</sup> Related to effective time for chopping

<sup>3</sup> Time for driving from the field to the storage and from the storage to the field

<sup>4</sup> Plot size 3 ha, ratio of plot length to plot width 2:1, mass flow related to time including auxiliary process time, bulk density of the wood chips 130 kg DM/m<sup>3</sup>, dry matter content 45 %, loading space of the used push-off trailers 35 m<sup>3</sup>, average driving speed of the tractors 32.5 km/h

which consists of tractors with trailers. A further increase of the mass flow requires an additional transport vehicle otherwise idle time of the harvester arises. However, the third transport vehicle reduces the degree of capacity utilization; therefore idle time of the transport vehicles increases. At a distance of 5 km between field and storage, the increase of the mass flow from 17.5 t DM/h to 23.3 t DM/h requires an additional transport vehicle. A further increase of the mass flow improves the degree of capacity utilisation and reduces the idle time of the logistics chain.

The bulk density according to CEN/TS 15103 varies in a wide range depending on clone, moisture content and grit sizes (Handler and Blumauer 2010). Fig. 3 illustrates the effect of the bulk density on the working time requirement for transport from field to storage. Depending on the haul distance between field and storage, each step of the graphs represents a specified number of transport vehicles, which is necessary to avoid idle time of the forage harvester. For example, four transport vehicles can handle the transport of the wood chips up to a distance of 8.0 km at a bulk density of 150 kg DM/m<sup>3</sup>. In case of increasing the distance to 8.1 km, an additional transport vehicle is necessary and the working time requirement jumps up. Up to 11.3 km, the working requirement remains constant because the additional working requirement for driving from field to storage is compensated by a decrease of idle time of the transport vehicles. The dotted line at the basis of the steps illustrates the sum of the working time requirement for filling of the trailers by the harvester, for transport<sup>5</sup> and unloading the trailer. This sum at a bulk density of 150 kg DM/m<sup>3</sup> is always lower than that at the bulk density of 130 kg DM/m<sup>3</sup>. The maximum idle time (height of the steps) relates to the working time requirement for filling one trailer. At the same capacity of the harvester and loading space of the trailer, a higher bulk density of the wood chips causes a higher working time requirement for filling one trailer. Therefore, at several haul distances, the stepwise increase of the idle time of the transport vehicles leads to a higher total working time requirement when the bulk density is higher. However, the higher bulk density allows higher haul distances at the same number of transport vehicles. In the example shown in Figure 3, the working time requirement is always lower at the bulk density of 150 kg DM/m<sup>3</sup> for haul distances longer than 18.3 km.



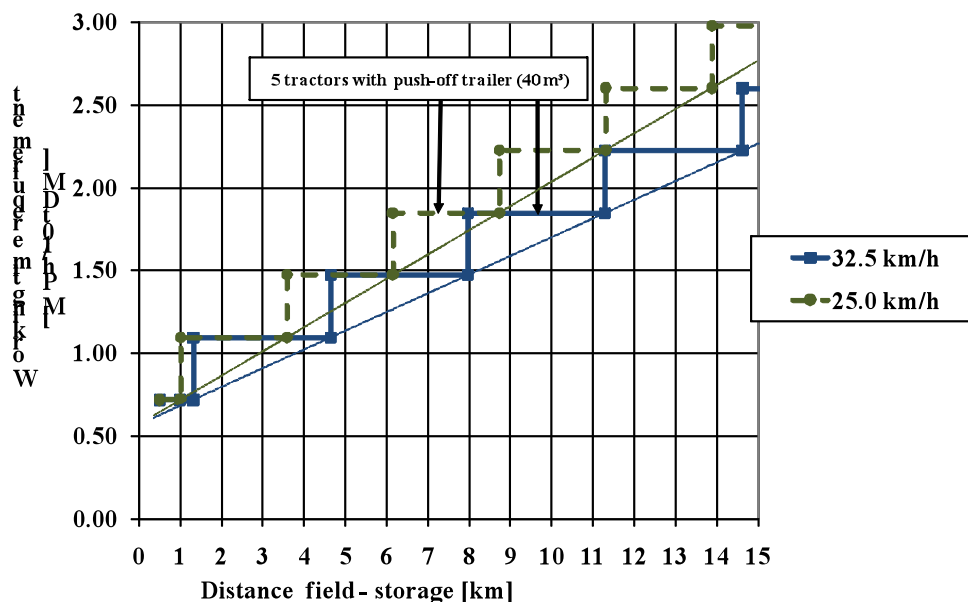
**Figure 3.** Working time requirement<sup>6</sup> for transport of wood chips by tractor-pulled trailers from field to storage depending on bulk density and haul distance between field and storage<sup>7</sup>

<sup>5</sup> Time for driving from the field to the storage and from the storage to the field

<sup>6</sup> Including filling up the trailer, transport, unloading and waiting

<sup>7</sup> Plot size 3 ha, ratio of plot length to plot width 2:1, mass flow related to time including auxiliary process time 29.1 t DM/h, dry matter content 45 %, loading space of the used push-off trailers 40 m<sup>3</sup>, average driving speed of the tractors 32.5 km/h

Figure 4 illustrates the working time requirement for the transport of wood chips by tractor-pulled trailers from field to storage depending on driving speed of the transport vehicle and the haul distance between field and storage. For both average driving speeds, the height of the steps of the graphs is the same because the capacity of the harvester and the loading capacity of the trailers are the same. However, the higher average driving speed causes a longer additional haul distance (depth of the steps) for an additional transport vehicle.



**Figure 4.** Working time requirement for transport of wood chips by tractor-pulled trailers from field to storage depending on driving speed of the transport vehicle and the haul distance between field and storage<sup>8</sup>

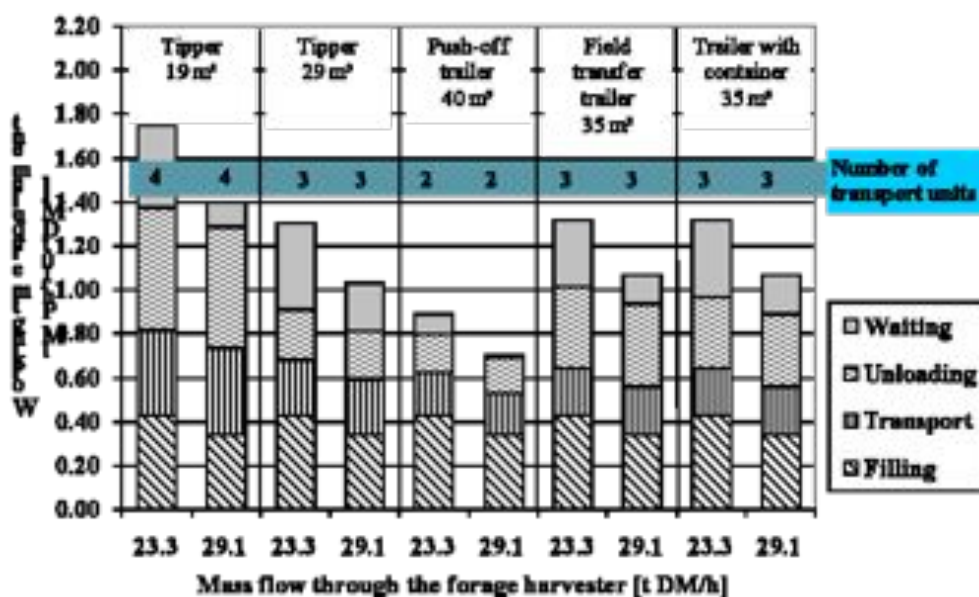
Chain 2, 3 and 4 consist of two steps. The first step comprises the transport from the field to the interim storage. The second step covers the transport from the interim storage to the storage. Figure 5 shows the working time requirement for the first step of the chains 2, 3 and 4. The categories “Tipper 19 m<sup>3</sup>”, “Tipper 29 m<sup>3</sup>” and “Push-off trailer 40 m<sup>3</sup>” could be first steps of chain 2. The field transfer trailer is the first step of chain 3 and the hook lift trailer with container is the first step of chain 4. The names of the categories contain numbers, which indicate the loading space of the trailers. The distance between field and interim storage amounts to 1 km.

In Figure 5, the section filling corresponds to the working time requirement of the harvester. A lower working time requirement of the harvester causes a lower working time requirement for the transport of wood chips due to faster filling of the trailers. The working time requirement for transport<sup>9</sup> corresponds to the loading space of the trailers. With increasing haul distance working time requirement also increases. If idle time of the harvester should be avoided, the number of required transport units should also increase. The working time requirement for unloading the trailer depends on the type of the trailer and its loading space. Because of the high costs, idle time of the harvester should be avoided. This requirement causes idle time of the transport vehicles. The different idle times of the transport vehicles depend on the mass flow through the harvester and the degree of capacity utilization basing on the haul distance of the transport vehicles. For example in Fig. 5, the idle time of the push-off trailer declines to zero when the mass flow increases from 23.3 to 29.1 t DM/h. A further increase of the mass flow would require an

<sup>8</sup> Plot size 3 ha, ratio of plot length to plot width 2:1, mass flow through the harvester related to time including auxiliary process time 29.1 t DM/h, bulk density of the wood chips 130 kg DM/m<sup>3</sup>, dry matter content 45 %, loading space of the used push-off trailers 40 m<sup>3</sup>

<sup>9</sup> Time for driving from the field to the storage and from the storage to the field

additional transport vehicle for avoiding idle time of the harvester. Caused by the additional transport vehicle degree of capacity, utilization reduces and their idle time increases.



**Figure 5.** Working time requirement for transport of wood chips by tractor-pulled trailers from field to interim storage<sup>10</sup>

Figure 6 shows the working time requirement for the transport of wood chips from the field to the storage. Chain 1 consists of tractor pulled push-off trailers with a loading space of 40 m<sup>3</sup>. The increasing distance between field and storage requires an increasing number of trailers. For example, a distance between field and storage of 5 km requires four trailers. Fewer trailers would cause idle time of the harvester. As already shown in Fig. 3, the stepwise run of the graph is caused by the fact that only the whole number of trailers is available.

Chain 2 consists of four tractor-pulled tippers with a loading space of 19 m<sup>3</sup>, which transport the wood chips from the field to the interim storage. At the interim storage, a wheel loader loads the wood chips on articulated lorries or road trains with a loading space of 90 m<sup>3</sup>, which afterwards transport the wood chips to the storage. The interim storage acts as a buffer store between the first and the second step of the logistics chain. This avoids idle times and uncouples the first from the second step concerning their capacity. In relation to chain 1, the additional working time requirement caused by transshipping the wood chips is compensated by the higher driving speed and the bigger loading space at haul distances larger than 24 km.

Chain 3 consists of three tractor-pulled field transfer trailers with a loading space of 35 m<sup>3</sup>, which transport and tranship the wood chips from the field to the articulated lorries or road trains with a loading space of 90 m<sup>3</sup>. They transport the wood chips to the storage. For avoiding idle time of the harvester and the field transfer trailers three lorries must be utilised up to a haul distance of 18.5 km. Longer haul distances require four or more lorries. Chain 3 has a lower working time requirement than chain 2 because of the higher loading space and the lower working time requirement for unloading of the field transfer trailer in relation to the tipper (see Figure 5). Additionally the wheel loader needs 0.57 MPH/10 t DM for loading the wood chips on the lorries. This is higher than the working time requirement for

<sup>10</sup> Plot size 3 ha, operation speed of the harvester 5.1 km/h, distance field - interim storage 1 km, bulk density of the wood chips 130 kg DM/m<sup>3</sup>, dry matter content 45 %, average driving speed of the tractors 32.5 km/h

unloading the field transfer trailer respectively transshipping the wood chips on the lorry. The stepwise run of the graph means that idle times of the lorries occur. However, an interim storage is not necessary.

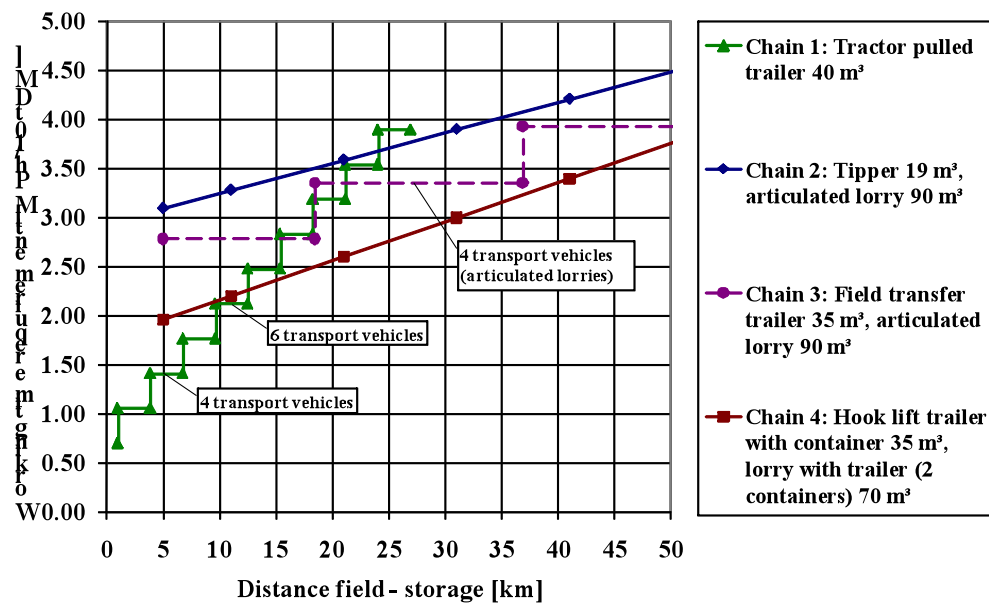


Figure 6. Working time requirement for transport of wood chips from field to storage<sup>11</sup>

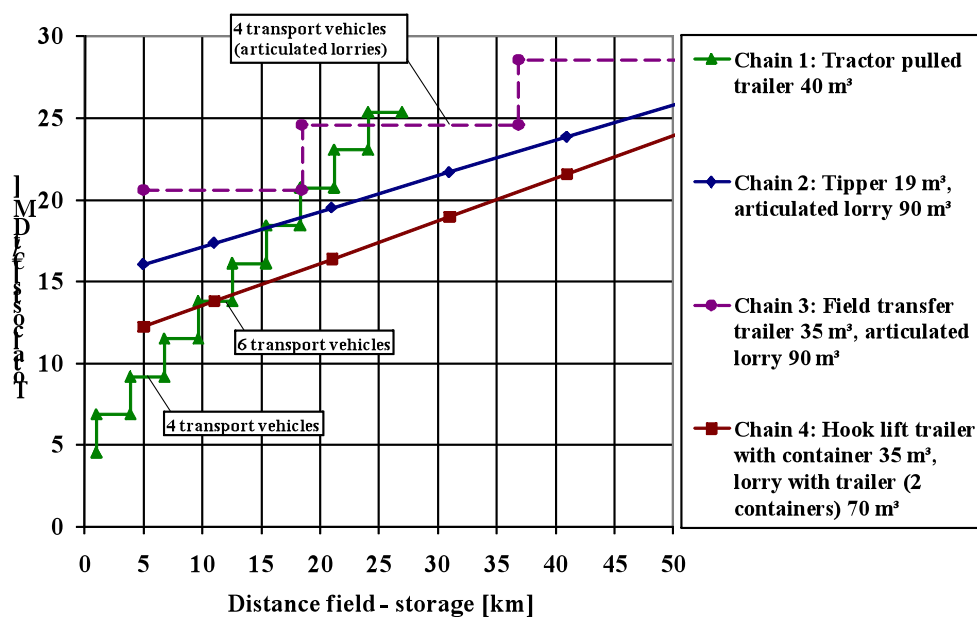


Figure 7. Costs for transport of wood chips from field to storage<sup>12</sup>

<sup>11</sup> Plot size 3 ha, mass flow through the harvester related to time including auxiliary process time 29.1 t DM/h, distance field - interim storage 1 km, bulk density of the wood chips 130 kg DM/m<sup>3</sup>, dry matter content 45 %, average driving speed of the tractors 32.5 km/h, average driving speed of the lorries 55 km/h

<sup>12</sup> Fundamentals for the calculations:

Chain 1: Tractor with push-off trailer (40 m<sup>3</sup>) 65 €/h,

Chain 2: Tractor with tipper (19 m<sup>3</sup>) 40 €/h, wheel loader 45 €/h, articulated lorry (90 m<sup>3</sup>) 70 €/h,

Chain 3: Tractor with field transfer trailer (35 m<sup>3</sup>) 80 €/h, articulated lorry (90 m<sup>3</sup>) 70 €/h,

Chain 4 uses containers with a loading space of 35 m<sup>3</sup>. For loading the containers with wood chips by the harvester and for the transport between field and interim storage, three tractor-pulled hook lift trailers carry the containers. At the interim storage, a lorry with trailer picks up two loaded containers, transports them to the storage and brings them back empty. The working time requirement for changing the containers is lower than the working time requirement for transshipping the wood chips from the field transfer trailer to the lorry in chain 3. This is the reason why the working time requirement of chain 4 is lower. When the haul distance increases, the rise of the working time requirement is higher than in chain 2 and 3. This is caused by the lower loading space of the containers. Additional containers act as a buffer store and avoid idle times.

Figure 7 bases upon the data from Figure 6. It shows the development of the costs for the transport of wood chips depending on the haul distance. Because of the high costs of the adapted field transfer trailers chain 4 features the highest costs. The costs of chain 4 and chain 1 are more or less equal for transport distances between 9 and 13 km. For running chain 1 six trailers are necessary at this distance. Chain 1 is competitive with chain 2 up to about 18 km. However, eight trailers are necessary for this distance. The advantage of chain 4 decreases at longer transport distances, because of the smaller loading space of the containers.

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Chain 4: Tractor with trailer for containers (35 m<sup>3</sup>) 60 €/h, special equipped lorry with trailer (70 m<sup>3</sup>) 65 €/h, including container's rental.

All mentioned costs per hour cover costs for machine and operator exclusive of VAT.