Harvest methods, capacities, and costs

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2014 REPORT

Harvesting methods of grain, rape, beets, maize, and grass, including average capacities and costs per hectare for large machinery under Danish conditions. Alternative harvesting methods are described if any relevant methods are found.

Baling and collection of straw from grain, rape, and maize are also described.

Capacities and costs are mainly obtained from “Farmtal Online” (farmtalonline.dk) as approximately average values delivered from investment calculus on farm equipment.

Requirements for dry matter content are obtained from LandbrugsInfo (landbrugsinfo.dk). Some numbers are estimates based on experience.

2015 REPORT:

The following topics have been added:

The results from the 2015 SEGES FarmTest “Selecting cutting length in clover grass – fuel consumption, capacity and density” are described.

Transport costs in relation to distance are calculated. Furthermore the necessary numbers of wagons using tractor propelled transport and transport by lorry are calculated.

Combined harvest of catch crops and straw from grain has been evaluated. If using this method, there will be a considerable loss of straw and catch crop since part of the biomass is lost due to decompression by the tires of the harvest machinery and loading wagons. The amount of biomass being lost is calculated.

All preconditions are based on a combination of the SEGES database FarmtalOnline.dk, SEGES reports and FarmTests combined with experience from users and suppliers. Data based on experience has been assessed conservatively by SEGES. All capacities match what can be expected under Danish field conditions.

HARVESTING EQUIPMENT

Existing harvesting methods and equipment for various crops are described below. Variations in equipment and harvesting methods are also described.

GRAIN

Harvesting methods today

Harvesting of dry grain (15-25%) is done with a combine. If grain is harvested for roughage, the same harvesting method as grass for roughage is used. In this case, the crop is harvested approximately 5 weeks earlier than the harvesting of dry grain.

Picture 1. Harvesting of grain – in this case wheat. Photo: CNH

The combine can be equipped with different kinds of headers, depending on the crop. For dry grain harvesting, a standard header or a draper header is typically used. The difference is how the crop is transported to the centre of the header. The standard header uses an auger whereas the draper uses belt conveyors. The draper is more expensive but has a 5-15% higher grain capacity and 20-40% higher seed grass capacity. When harvesting rape, however, the capacity is similar or lower.

Picture 2. Standard header with an auger.
Photo: Henning Sjørslev Lyngvig

Picture 3. Draper header with belt conveyors.
Photo: Henning Sjørslev Lyngvig

Topics for optimisation

Harvesting of grain is already highly optimised. When collecting straw for biomass the optimisation should be focused on straw collection. When collecting straw the weather is the opponent. The straw must be dried to less than 15% to make it storable in dry condition. Alternatively, it may be stored wet in an airtight environment under plastic. This method, however, is not fully developed.

Large combines in Europe use very wide headers of 35-45 feet (10.7-13.7 m). When focus is on harvesting capacity the larger, the better. If focus was on getting the straw dried and collected, however it would be better to use more narrow headers. By using narrow headers, the swaths of straw are less compact and will dry faster.

Rotor combines tends to crush the straw and consequently increase straw mass loss, compared to use of combines with straw walkers. In new rotor combines, this problem has been reduced. When it comes to large combines, there is no choice, because the threshing systems used for larger combines all use some type of rotor technology.

Capacity and costs per hectare

Capacity varies with yield and shape of the fields. The largest combines harvest 4-6 hectares per hour in average under normal Danish conditions, – 6-8 hectares per hour under exceptional conditions.

The costs are 800-900 DKK per hectare (100-120 Euros per hectare) in Danish conditions. For combines bought for very large areas the costs may be reduced significantly. On Large fields the capacity is much larger. Lower labour cost also influence price in other regions than Denmark where wages are cheaper.

RAPE

Harvesting method today

Direct harvesting of rape is done in practically the same way as grain harvesting. The main difference is the requirements for the header. Side knives are recommended to avoid loss of rape when the header drives through the crop.

Because rape is a taller crop, the headers must be longer and higher. If they are to short or low, the rape will not fall into the main auger, allowing it to skate over the rear edge of the header. To avoid this, the pilot must reduce the speed of the combine with consequential loss of capacity. There are two solutions to this problem:

1) A unit may be mounted in front of the header to elongate it. This is shown in Picture 4.
2) On new types of headers the length can be varied hydraulically. Thus the length may be varied to the present condition of the crop. Furthermore, most new headers are constructed with a tall rear edge.

Side knives may be mounted separately depending on the type of header.

Picture 4. Unit for making the header longer with side knives included. Photo: Mosegaarden

Picture 5. Header with adjustable length – the bottom can slide forwards. Photo: Henning Sjørslev Lyngvig

Rape may also be harvested after windrowing. In rape with uneven ripening of the crop this can be an advantage. The period between windrowing and harvest is approximately 21 days. In this period of time the crop will air dry, so the crop is more even when harvested. Harvest of windrowed rape is performed with a similar header as for direct rape harvesting.

Topics for optimization

When harvesting windrowed rape a pick-up header may be used. Contractors who have bought pick-up headers conclude that this results in increased harvesting capacity. Furthermore, the crop may be harvested when dryer.

Picture 6. Harvesting rape with a pick-up header. Photo: Shelbourne Reynolds

The method is widely used for organic farming because of the large amount of weeds in the field. In the period between windrowing and harvest, the weeds wither making harvesting easier and faster.

Capacity and costs per hectare
Capacity varies with yield and shape of the fields. The largest combines harvest 3-5 hectares per hour in average in Danish conditions.

The costs are 800-900 DKK per hectare (100-120 Euros per hectare) in Danish conditions. For combines bought for very large areas, the costs may be reduced significantly. Labour cost also influences the price in other regions than Denmark.

The costs of windrowing are 500 DKK per hectare (65 Euros per hectare).

BEETS

Harvesting method today

Beet harvesting, called beet lifting, is mainly used for sugar beets, as beets for roughage is not common in Denmark. Normally the beet top is not used, though the beet top is excellent cattle fodder. Three decades ago the beet top was collected before beet lifting, but this is not profitable today. Storage of the beet tops would also present a challenge, because of a low dry matter content of an estimated 10%.

Picture 7. Large self-propelled beet lifter with beet topper in front. Photo: Søren Ugilt Larsen

When sugar beets are lifted, the beet top is usually chopped with a unit integrated in the front. The top is often deposited on the ground where the beets are lifted, but it may also be chopped and deposited between the rows.

Picture 8-1 and 8-2. Tractor-propelled beet lifter with topper. Photo: Thyregod

The type shown in Picture 8 is often used for beets for fodder, sometime without the beet topper unit.

Topics for optimisation

For years the focus has been on optimising harvesting capacity. Thus the machines have become increasingly larger. This has increased axle load of the machine critically, and especially the axle load of beet harvesters have reached a point where some farmers consider returning to tractor-propelled beet harvesters to minimise soil compaction.

If beets are grown for biomass purposes collecting the beet top may be considered. It is relatively simple to reconstruct the topper so the top is deposited to a wagon driving alongside the beet harvester.

Capacity and costs per hectare

Capacity varies according to yield and shape of the fields. A self-propelled six-row beet harvester can harvest 1.4 hectares per hour in average under Danish conditions. For a tractor-propelled three-row the capacity is 0.7 hectare per hour. The capacity is linearly with the number of rows.

The costs are 1.700 DKK per hectare (220-230 Euros per hectare) in average under Danish conditions. For beet lifters used on very large areas costs may be reduced significantly. Labour cost will also influence the price in other regions than Denmark.

MAIZE

Current harvesting method

There are three methods for harvesting of maize. The use of the maize subsequently decides what method to use:

1) Harvesting of silage maize for roughage where the complete plant is chopped and stored.
2) Harvesting of earlage for roughage where only the cop is chopped and stored. The rest of the plant is chopped and left on the field.
3) Harvesting of grain maize where only the grain is used. In Denmark grain maize seldom dries below 35-45% water content due to climate conditions. In southern Europe it can be harvested dry, or nearly dry. The rest of the plant is chopped and left on the field.

1) Harvesting of silage maize is performed using a forage harvester with a whole plant header. The header cuts the maize about 30 cm from the ground and transports it further to the chopper. The chop length of the silage maize must be 6-20 mm depending on ripeness. The recommended chop length is 9-10 mm at 31-34% dry matter which is the recommended dry matter content for the crop. At low dry matter content the chop length must be longer to minimise the risk of effluents.

There is usually a very small amount of stem left on the field after harvesting of silage maize.

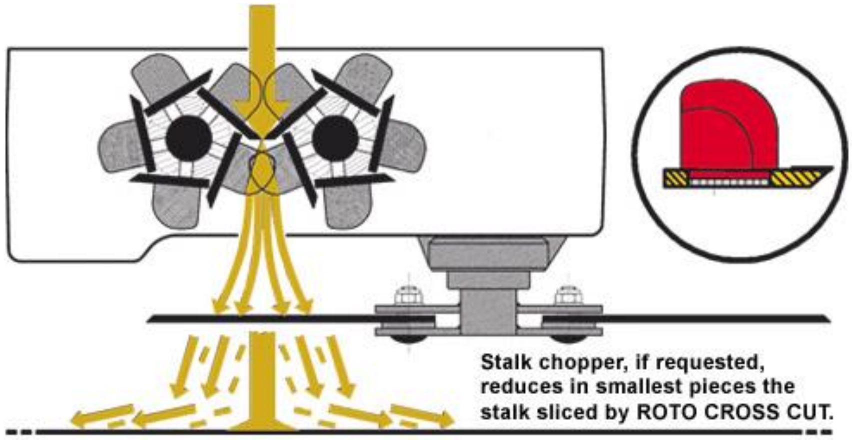
Picture 9. Harvesting of silage maize. Photo: Claas

2) Harvesting of earlage for roughage is performed using a similar forage harvester as for silage maize. But a different header is used, called a maize picker.

Picture 10. Harvesting of earlage. Photo: Claas

The maize is cut as close to the ground as possible. Two rough rollers drag the stem downwards until the cob meets a steel plate. The steel plate rips the cob off the stem and the cobs are transported further to the chopper, chopped and delivered to a wagon. Because the stems are omitted the product is fodder with a high energy concentration.

The stems are chopped under the rollers. A lot of crop mass is left on the ground.



Picture 11. How a maize picker works. Two rough rollers drag the stem downwards. The stems are chopped and left on the field. Photo: Bulldog Agri

3) When harvesting grain maize the same header is used as for earlage harvesting. The only difference is that a combine is used instead of a forage harvester. When the cobs have been separated from the stems, they are transported to the threshing system and the grain is separated from the cobs.

Picture 12. Harvesting grain maize.
Photo: Henning Sjørslev Lyngvig

Picture 13. Maize picker.
Photo: Champion

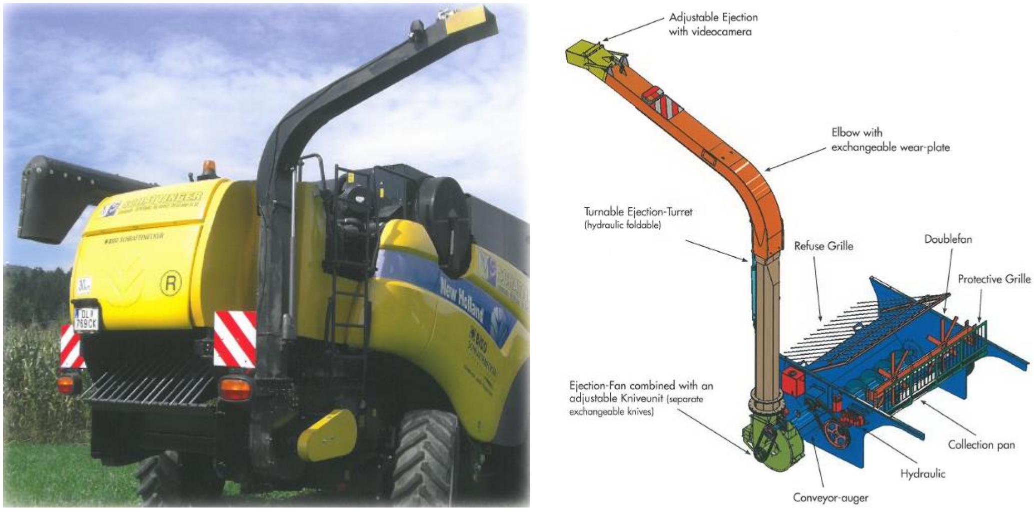
As after earlage, a lot of crop mass is left on the field. In addition to the chopped stems, the threshed cobs are also left.

Topics for optimisation

If maize is harvested as grain maize the straw can be collected cleaner and with less loss of mass if the straw is placed in swaths under the combine. This can be accomplished by collecting the straw with a belt conveyor, instead of chopping it under the maize picker and collecting it subsequently. Equipment for this operation is invented and is known as the Cornrower.

Picture 14-1 and 14-2. The stems are blown to a belt conveyor (under the yellow cover behind the header), and placed between the wheels of the combine. Photo: Cornrower / Henning Sjørslev Lyngvig

In theory the Cornrower can be mounted on a forage harvester, but it needs to be modified. On a chopper there is no space for the belt conveyor, so the intake has to be extended. If so the header will be too heavy for the chopper. This might be solved by attaching wheels on the header to relieve the front axle of the forage harvester.



Picture 15. The threshed cobs are blown to a wagon driving beside or after the combine. Photo: BISO

If needed cobs can be collected separately during harvest. A CornCobCollector produced by BISO will perform this task.

Capacity and costs per hectare

Capacity varies according to yield and shape of the fields. The largest forage harvester can harvest 2-4 hectares maize per hour. The largest combines can harvest 3-4 hectares maize per hour.

Silage maize: The cost is approximately 675 DKK per hectare (~90 Euros per hectare) under Danish conditions.

Earlage: The cost is approximately 450 DKK per hectare (~60 Euros per hectare) under Danish conditions.

Grain maize: The cost is approximately 1.000 DKK per hectare (~130 Euros per hectare) under Danish conditions.

For forage harvesters and combines bought for very large areas the costs can be reduced significantly. The labour cost will also influence the price in other regions than Denmark.

GRASS FOR ROUGHAGE

Harvesting method today

Grass for roughage is harvested in 3-4 processes. The goal is to dry the grass on the field, before it is stored as silage. When grass is windrowed when dry matter is 17-20%. It needs to be 30-34% to make it storable as silage.

Safe ensiling of grass depends on being able to compress material in the silo. And it is much easier to compress material if it is finely chopped. When filling the silo grass must be distributed in thin layers (maximum 10 cm, preferable 5 cm). Every layer must be compressed thoroughly with a payloader or a tractor before placing the next layer.

Normally silage grass can be cut 4-5 times per year. Grass for biomass is normally only harvested 3 times per year. The reason is that when producing grass for biomass the focus is on mass. For roughage the focus is on quality.

1) First the grass is mowed – typically with a disc mower. The disc mower can be equipped with belt conveyers, so the grass can be collected in swaths, if required. After field drying, the grass is chopped with a forage harvester and transported for storage. Disc mowers are up to 12 m wide and are usually equipped with a crimper. A crimper damages the grass surface, so it dries faster.

In Denmark the weather conditions for field drying is good. In other regions field drying is not possible due to higher humidity.

Picture 16. Cutting grass with a disc mower. Belt conveyers can be lowered to collect in swaths, if required. Photo: Krone

2) Some choose to use a disc mower not equipped with a crimper. In this case the grass is dispersed using a tedder. The tedder aerates and distributes the grass evenly on top of the grass stubbles allowing the grass to dry quicker. This process is usually omitted if the grass is crimped.

Picture 17. Grass dries faster if dispersed by a tedder. Photo: Pöttinger

3) Optimally, dry matter content must be 32% before ensiling. If the grass is raked into swaths when the dry matter content is 30, it will be approximately 32 when ensiling.

Picture 18. Swathing grass before ensiling. Photo: Claas

To ensure a high harvest capacity, it is crucial that the swats contain a sufficient amount of grass. The size of the swaths must be adapted to the size of the forage harvester. Therefore rakes up to 18-19 m width are used.

4) There are mainly 2 different solutions for chopping and collecting the grass from the field – harvesting with a forage harvester or with a loader wagon. The loader wagon also chops the grass, but the product is not as finely chopped as when using a forage harvester.

Picture 19. Forage harvester.
Photo: Henning Sjørslev Lyngvig

Picture 20. Loading wagon.
Photo: Henning Sjørslev Lyngvig

For obtaining the best fodder quality and largest harvest capacity, the forage harvester is the optimal solution. The loading wagon cannot obtain the optimal cutting length at 10-15 mm. It is mainly “on farm solution” and cannot be recommended. Some use it because of the possibility for collecting the grass with their own machinery.

Topics for optimisation

When growing and harvesting grass conventionally, traffic is spread all over the fields. Especially clover grass is very intolerant to traffic. Even one pass with a tractor can reduce yield. One solution is CTF (Controlled Traffic Farming). By using high precision GPS (RTK-GNSS), every track is permanently positioned, and no traffic is allowed outside these fixated tracks. During grass production fixated tracks every 12 m can be used, but in crop rotation with maize only 9 m is possible, since the current harvest equipment for silage maize is not made with a width of 12 m. In a few years a 12 m maize header will probably be on the market.

Picture 21. Forage harvester with wagon attached – both driving in the fixated tracks. There is no traffic between the fixated tracks. Usually the track width is 9 or 12 m. Photo: Mogens Kjeldal, DM&E

If the grass is not used for roughage, but for biomass, optimisation is dependent on requirements for dry matter. If a lower dry matter content can be tolerated, harvest can in theory be done in 2 steps instead of 3. But in reality, we will always use 3 steps to be able to obtain a good capacity on the forage harvester. If swaths are not raked together, there will not be sufficient mass to fulfill chopper capacity. Fulfilling chopper capacity is often a problem in grass. Therefore very wide rakes are often used.

Capacity and costs per hectare

Capacity and price varies according to yield and shape of the fields.

12.5 m disc mower: A 12.5 m disc mower has a capacity of 9-12 ha per hour. The cost is approximately 250 DKK per hectare (~33 Euros per hectare) under Danish conditions.

18 m tedder: A large tedder has a capacity of 12-15 ha per hour. The cost is approximately 150 DKK per hectare (~20 Euros per hectare) under Danish conditions.

18 m rake: A large rake has a capacity of 12-15 ha per hour. The cost is approximately 150 DKK per hectare (~20 Euros per hectare) under Danish conditions.

Forage harvester: Early in the year the grass yield is highest. Here the largest forage harvester can harvest 10 hectares grass per hour. Late in the year the grass yield is much lower. Here the largest forage harvesters can harvest 15 hectares per hour.

The cost is approximately 675 DKK per hectare (~90 Euros per hectare) under Danish conditions.

CUTTING LENGTH IN CLOVER GRASS

In a SEGES FarmTest from 2015 “Selecting cutting length in clover grass – fuel consumption, capacity and density”, chopping-capacity, fuel consumption and density of clover grass chopped with a forage harvester to 22, 16 and 8 mm theoretically cutting length were measured. The goal was to determine the overall costs when reducing cutting length in clover grass for silage.

The FarmTest was conducted at 1st cut late May and at 3rd cut early August 2015 in Southern Jutland, Denmark.

At 1st cut the capacity (ha per hour) of the forage harvester is decreased with reduced cutting length (fig. 1).

- If the cutting length is reduced from 22 to 16 mm, the capacity is decreased by 4%
- If cutting length is reduced from 22 to 8 mm, the capacity is decreased by 23%.

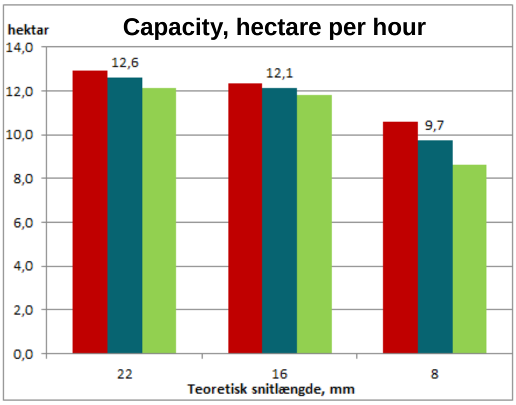


Figure 1. Time consumption relative to cutting length during 1st cut. Red: Field 1, green: Field 2, blue: Average.

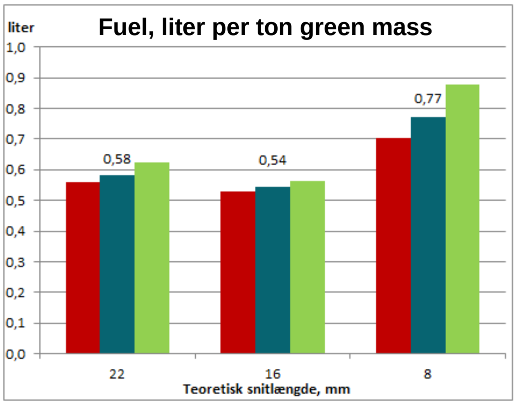


Figure 2. Fuel consumption relative to cutting length during 1st cut. Red: Field 1, green: Field 2, blue: Average.

At 1st cut, fuel consumption for chopping the grass in 16 mm cutting length decreases or equals the 22 mm cutting length, while the fuel consumption increases if the cutting length is further reduced to 8 mm (fig. 2). The lack of increase in fuel consumption for the 16 mm cut length is due to a more uneven flow in the silage harvester caused by the longer straw size. Using 8 mm cut length result in higher fuel consumption

- When cutting length is reduced from 22 to 16 mm, fuel consumption decreases 7%
- When cutting length is reduced from 22 to 8 mm, fuel consumption increases 33%
- When cutting length is reduced from 16 to 8 mm, fuel consumption increases 43%

Reduction of cutting length from 22 to 16 mm only causes limited additional costs. Reduction of cutting length to 8 mm causes large additional costs. Therefore, 8 mm cutting length can only be recommended if the profit is well-documented.

At 3rd cut there is a small increase in fuel consumption from 22 to 8 mm cutting length. But when fuel consumption per ton green mass is calculated, the difference is too small to show for any certain difference.

Harvest capacity does not change, when cutting length is reduced. There is not enough green mass to reduce capacity of the silage harvester. The engine simply never has to perform to its maximum.

Density of the crop for each cutting length is calculated by weighing wagons with a known capacity. Measurements show that from both 22 to 16 mm and 16 to 8 mm cutting length, the weight increases 11-12%. In average, the weight increases 5 kg per m^3, each time the cutting length is reduced 1 mm.

Table 1. Density related to cutting length.

Cutting length, mm	Weight, kg per load	Increased weight, %	Density, kg per m^3
22	11,800	reference	295
16	13,100	+11.0	328
8	14,550	+23.3	364

Below the definition swath capacity is used. It means the all measurements of capacities are made in the swats. In reality a lot of capacity and time is lost in the front land where there is no grass, because the head land is chopped at first.

Calculations of the cost show large variations related to how much time is redrawn from the measured capacities. In the table beneath 25% is redrawn. This number can be both smaller and larger according to size and shape of the harvested fields under varying conditions.

Table 2. Capacity and cost (forage harvester, two wagons and payloader). 25% is redrawn from swath capacity.

Cutting length, mm	Swath capacity, hectare per hour	Swath capacity –25 %, hectare per hour	Cost, € per hectare	Cost, € cent per feed unit
22	12.6	10.1	53.8	1.65
16	12.1	9.7	54.9	1.72
8	9.7	7.8	68.4	2.13

One feed unit resembles 1.17 kg dry matter. DM is 32.5%. Yield is 11.5 ton green mass per ha (wet weight). All calculations are made from the time measurements in this FarmTest and from 3.200 feed units per hectare, which is the average clover grass yield in Denmark at 1st cut.

The report concludes that harvest capacity and fuel consumption for 22 and 16 mm cutting length are nearly the same. If the cutting length is reduced to 8 mm, there cost increases considerably. Therefore, 8 mm cutting length can only be recommended if there is a well-documented profit.

HARVEST CAPACITIES AND COSTS

For comparison capacity and costs are listed below.

Table 3. Capacity and costs for harvesting of different crops using large machinery.

	Capacity, hectares per hour	Calculated approx. costs, DKK (Euro) per hectare
Grain	4-6	800-900 (100-120)
Rape	3-5	800-900 (100-120)
Beet	1.4	1.700 (220-230)
Maize, silage	2-4	675 (90)
Maize, earlage	2-4	450 (60)
Maize, grain	3-4	1.000 (130)
Grass, disc mower	9-12	250 (33)
Grass, tedder	12-15	150 (20)
Grass, rake	12-15	150 (20)
Grass, forage harvester (early season with high yield)	10-12	675 (90) in average
Grass, forage harvester (late season with low yield)	15-18	

STRAW COLLECTING EQUIPMENT

STRAW FROM GRAIN AND RAPE

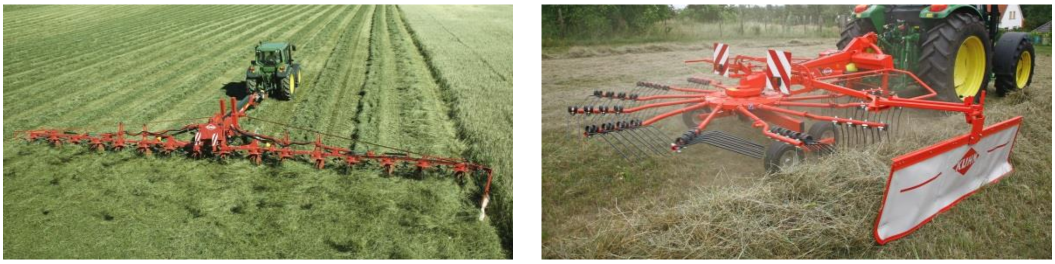
Straw from grain and rape are collected using identical machinery. Under normal conditions, straw is harvested when the dry matter contents constitute 80-90%. In order to be storable, the dry matter must be no more than 14%. If the straw is too wet when balled, this may cause dry matter loss and growth of fungi. Under normal conditions the straw is balled with a water contents at 89-91%.

The straw is usually left to dry in the field for 1-2 days after harvest before baling it. Under the right weather conditions this will allow the straw to obtain the required water contents.

Picture 22. Baling straw from grain. This type of bales is approximately 80 x 120 x 220 cm. Photo: CNH

If it rains between harvest and baling, the same wilting procedure as described for grass will have to be applied.

- The straw must be dispersed by a tedder
- It must field dry until the required water content is reached
- It must be collected with a rake before baling in the chosen size



Picture 23-1 & 23-2. Dispersing and collecting straw. Photo: Kuhn

The straw may still be green even when the seed is harvested dry, particularly in the early season. Therefore it is often necessary to field dry the straw for several days (up to one week) before collecting and baling it.

Size of bales

It is recommended to choose the bale size as appropriate for subsequently transport. In Denmark the standard bale size for straw used for heating purposes has been 120 x 120 x 235 cm (width/height/length) for years. Depending on water contents this size corresponds to a weight of 450-600 kg per bale.

Because of investment made in the handling equipment, heating plants tend to adhere to this standard even though new types of balers can bale straw with a much higher density. As the limiting factor in road transportation is size (not weight), a high density –and thus higher per-bale weight –allows cheaper per-bale transportation.

Report no. 130 from “Videncentret for halm og flisfyring” states that density for 120 x 120 cm bales is 114-153 kg/m^3 or 139 kg/m^3 in average. The new type of bales mentioned above has the same width (120 cm), but the height is 80-90 cm compared to 120 cm. The length of the bale can be adjusted between 60 and 300 cm. Density in the new bales is 20-50 higher than the traditional 120 x 120 cm standard. The reduced height makes it possible to increase compression of the straw.

Yield

Beneath straw-yield from the most common grain and rape are listed. Some variation must be expected according to type of soil, crop growth and the varying conditions each year.

Table 4. Average straw yield from grain and rape.

Crop	Straw-yield, kg per hectare
Spring-barley	3.000 - 3.500
Winter-barley	3.300 - 4.000
Spring-wheat	2.700 - 3.500
Winter-wheat	4.000 - 4.800
Winter-rye	4.500 - 6.000
Spring-rape	2.000 - 3.000
Winter-rape	3.000 - 4.000

STRAW FROM MAIZE FOR BIO-MASS

Straw from maize is normally not collected in Denmark. It is possible but would be challenging because of very high water content. When harvested, the water content will seldom be below 35-45%. Because maize is harvested late in the year, frequent rain makes it impossible to field dry maize straw. Thus, it will have to be stored wet or dried mechanically.

Mechanically drying of maize straw to a water contend of 10-14% is possible, but exceedingly expensive. The only viable alternative, therefore, is to store the maize straw in an air tight environment to avoid loss of dry matter and development of fungi.

In 2011/12 collecting and storage of maize straw for bio-ethanol purposes was examined by the Knowledge Centre for Agriculture (today SEGES). Three methods were examined:

1) Harvest of earlage followed by harvest of straw from root.
   Airtight storage of maize straw in square bales wrapped in plastic.
2) Harvest of earlage followed by harvest of straw from swath (some field drying).
   Airtight storage of maize straw as silage.
3) Harvest of grain maize followed by baling from swaths (only the driest top layer was raked). Non-airtight storage of maize straw in round bales under plastic.

The results were as follows:

1) Storage in square bales wrapped in plastic was a good but very expensive solution. It can only be recommended for small quantities of maize straw.

Picture 24-1 & 24-2. Baling and wrapping maize straw in plastic. The job is done in two steps.

2) Harvest and storage as silage was the optimal solution, when price and harvest capacity is considered.

Picture 25-1 & 25-2. Harvest with a forage harvester and storage as silage was the optimal solution for maize straw concerning price and capacity. Photos: Henning Sjørslev Lyngvig

3) Storage of maize in round bales under plastic was not recommendable. Because of the water content fungal growth was massive after approximately 4 weeks and an extensive dry matter loss was observed.

Picture 26-1 & 26-2. Storage in a not airtight environment resulted in extensive growth of fungi and a high dry matter loss. Photos: Henning Sjørslev Lyngvig

Yield according to harvest method

In table 2, kg dry matter for each method can be seen. Dry matter content for method 3 is high. It is properly because only the driest straw was swathed before baling.

	Method 1	Method 2	Method 3
Kg straw per hectare	2.500	8.755	2.632
Dry matter content, %	31-33	37-39	65-69
Kg dry matter per hectare	800	3.327	1.763

Table 5. Yield according to harvest method for storage.

Straw yield is highest in method 2 because it was the only method where the main part of straw could be collected. In method 1 a large amount of straw could not be picked up by the silage harvester. In method 3 the straw loss was caused by the fact that the rake could only collect the upper layer of the straw.

BALING CAPACITIES AND COSTS

For comparison capacity and costs are listed below.

	Capacity, hectares per hour	Costs, DKK (Euro)
Dispersing straw with a tedder, cost per hectare	12-15	160 (21)
Collecting straw with a rake, cost per hectare	12-15	160 (21)
Baling into large square bales, cost per bale	4	80 (11)
Baling into round bales, cost per bale	3	50 (7)
Baling into medium bales wrapped in plastic, cost per bale	2	115 (15)

Table 6. Capacity and costs for collecting and baling of grain and rape.

Collecting and baling of maize straw is estimated to be 25-50% more costly than the numbers in table 3.

TRANSPORT EQUIPMENT FOR GRAIN AND RAPE

Agricultural wagons for grain and rape are the most common wagons on the farms. They are made from approximately 8 ton (10 m³) to approximately 30 t (40 m³). Normally they can carry more mass/weight than can be transported on the road legally. The wagons are made for use, both in the fields and on the roads.


Picture 27-1 and 27-2. Two examples of off-road wagons for grain and rape. Photos: Baastrup and MI.

Large farms use a special auger-wagon for unloading combines. The auger-wagon subsequently transport the grain further to a lorry or an on-road tractor propelled wagon (see picture 28-1) parked on the road beside the field.


Picture 28-1 and 28-2. Auger-wagon delivering grain to a lorry or a tractor with an on-road wagon. Photos: Henning Sjørslev Lyngvig

On large farms and for long-distance transport of grain and rape use of an auger-wagon is preferred. The auger wagon can support 3-4 combines. The necessary number of on-road wagons is thereby determined by the distance from the field to the storage facilities.

TRANSPORT EQUIPMENT FOR ROUGHAGE

Agricultural wagons for roughage are made from approximately 16 ton (40-45 m³) to approximately 24 t (60-65 m³). Often they can contain more mass/weight than can be transported on the road legally. The wagons can be used off- and on-road.

Picture 29-1 and 29-2. Two examples of roughage wagons. Photos: Henning Sjørslev Lyngvig

Special roughage wagons are needed for lorry transport. These wagons can be lifted, so a 4 m trailer can be filled (see picture 30). They can be used both off- and on-road, but due to higher cost for this type of wagon they are most suitable when having the need to unload in a lorry.

Picture 30. Roughage wagon with the ability to unload in trailer, four meter high. Photo: Stroco-Agro.

When transporting roughage with lorries, a higher cost for ensiling must be expected. The reason is that a tractor pulled roughage wagon can be unloaded in the silage stack. Lorries cannot drive into the stack. Therefor an additional payloader is needed to push the silage up in the stack. The extra payloader will result in an additional cost of approximately 67 euro per hour.

TRANSPORT EQUIPMENT FOR STRAW

Due to the low density of the bales, the limiting factor is size, not weight. It is not possible to obtain the maximum weight limit for lorries, because of the low density. This fact increases transport costs. It is essential that the highest possible weight is obtained when transporting straw. The allowed width (2.55 m), height (4.00 m) and length (18.75 m) for road transport set the limits.

By using bales that are 80-90 cm high it is possible to transport three bales on top of each other instead of two. And because of the higher density, a larger load (in terms of mass) can be transported at a time.

Picture 31-1 & 31-2. Bale size and density decides how many tonnes per load are transported. Photos: Mosegaarden

Time consumption for collecting and loading one load of straw is approximately:

Table 7. Number of bales, time consumption for loading and possible weight per load.

Type of bales	Bales per load, legal for road transportation	Time for collection and loading	Approximated total weight
Big bales **(131 x 121 x 240 cm)**	20 pcs.	approx. 30 min.	approx. 11 ton
Mini big bales **(88 x 82 x 220 cm)**	36 pcs.	approx. 45 min.	approx. 10 ton

TRANSPORTATION COSTS FOR GRAIN, STRAW AND ROUGHAGE

All preconditions in this chapter are based on a combination of the SEGES database FarmtalOnline.dk, SEGES reports and FarmTests combined with experience from users and suppliers. Data based on experience has been assessed conservatively by SEGES. All capacities match what can be expected under Danish field conditions. The used capacities and yields are used as precondition for all calculations.

CROP-DENSITY

There is a huge variation in size of the wagons used for transport of crops. In table 8 the typical density of the most common crops are listed. Density determinates how much weight the wagon can carry according to the volume of the wagon.

Table 8, Density of grain, roughage and straw measured on the wagon.

Crop	Density, kg per m^3
Grain and rape (approx. 85 pct. DM)	
Barley	680
Wheat	760
Rye	690
Rape	740
Maize, grain	710
Roughage	
Beet (approx. 20 pct. DM)	275
Clover Grass, roughage (approx. 32 pct. DM)	295
Maize, silage (approx. 32 pct. DM)	370
Maize, earlage (approx. 50 pct. DM)	300
Straw	
Maize straw (approx. 30-38 pct. DM)	390
Straw, grain and rape (approx. 90 pct. DM)	130

***DM = dry matter content**

LEGISLATION CONCERNING ROAD-TRANSPORT

In Denmark a tractor with one or two wagons may carry up to a total mass of 44 ton. A lorry with a wagon or trailer with 6 axles may carry a total mass of 50 ton, whereas with 7 axles, 56 ton.

To calculate the permitted load for different vehicles in Denmark, some preconditions have to be determined. In Table 9, average values for the unladen masses are shown "Unladen mass" refer to the weight of the vehicle with no load.

Table 9. Approximately unladen masses for agricultural vehicles and lorries.

Vehicle	Unladen mass, ton	Unladen mass, average ton
Agricultural vehicles		
Tractor	10-11	10.5
Wagon for grain and rape	5.5-7.5	6.5
Wagon for roughage, 2 axles – 40 m³	7-8	7.5
Wagon for roughage, 3 axles – 60 m³	10-12	11.0
Wagon, trailer with dolly	8-9	8.5
Lorries*		
Lorry, 3 axles	9	9.0
Tipper-trailer, 3 axles – 45-50 m³	8	8.0
Tipper-trailer, 4 axles – 55-60 m³	9	9.0
Walking floor trailer – 95-100 m³	10	10.0

***Data are obtained by contact to dealers in Denmark.**

To determine average calculation values, the following estimates are made:

Table 10. Maximum permitted load – for road transport – for different combinations of vehicles.

Vehicle combination	Max. permissible wagon load, ton
Tractor + grain/rape wagon (for both off- and on-road transport)	approx. 27 ton
Tractor + roughage wagon (for both off- and on-road transport)	approx. 23 ton
Tractor + tipper-trailer with dolly (only for on-road transport)	approx. 25 ton
Lorry + tipper-trailer with 4 axles (only for on-road transport)	approx. 38 ton
Lorry + walking floor trailer with 4 axles (only for on-road transport)	approx. 37 ton

As shown in Table 10, a lorry with trailer can transport approximately 12 t more per load than a tractor with wagon. Furthermore, a lorry drives with approximately twice the speed as a tractor. On smaller roads a tractor drives approximately 25 km per hour in average and a lorry approximately 50 km per hour in average. Lorries can probably drive 60 km per hour in average, over longer distances, on good roads and highways.

When transporting crops with low density such as straw, total load is limited by volume rather than weight.

TIME CONSUMPTION AND AMOUNT OF WAGONS NEEDED RELATED TO DISTANCE

To establish time consumption for transport of different crops, some preconditions have to be established. The harvest capacities in Table 11 are used for all calculations in this chapter. The harvest capacities equal some of the largest harvest machinery on the marked. Thus they can be used as a guideline for the realistic maximum harvest capacity per machine.

Preconditions

There are special circumstances regarding clover grass. Yield from 1st cut are approximately twice as high as yields from 2nd to 4th cut, using a 4 cut strategy. In reality a large variation is seen influenced by weather, rainfall etcetera. Here only two yield levels are used. Measurements have shown that harvest capacity in 2nd, 3rd and 4th cut is approximately half of capacity in 1st cut.

In harvest capacity and internal tank capacity of the harvest machines are shown, according with the maximum load which can be transported legally in Denmark by tractor.

Table 11. Harvest capacity, internal tank size and maximum wagon load for road transportation.

	Harvest capacity, hectare per hour	Internal tank capacity, ton	*Max. permitted wagon load, ton
Combine, grain	5.0	10	27
Beet	1.4	10	27
Maize, silage	3.0	0	23
Clover grass, 1st cut	9.0	0	23
Clover grass, 2nd – 4th cut	18.0	0	23

***Permitted wagon loads due to Danish legislation. From Table 10.**

Average yield of different crop and time consumption for harvesting one wagon load are described in Table 12.

Table 12. Yield per hectare and per hour and time consumption for harvest of one wagon load.

	Yield, ton per hectare	Ton crop per hour	Wagon loads per hour	Time for harvesting one wagon load	
				Hour	Minutes
Combine, grain	8.9	44.5	1.65	0.61	37
Beet	85.0	119.0	4.41	0.23	14
Maize, silage	40.0	120.0	5.22	0.19	11
Clover grass, (1st cut)	12.0	108.0	4.70	0.21	13
Clover grass, (2nd – 4th cut)	6.0	108.0	4.70	0.21	13

In

Table 13, time consumption for loading and unloading different crops are described along with transport time using tractor (average road speed 25 km/h, distance 5 km).

Table 13. Time consumption per load, off-field and on-field (5 km transport distance).

	Time for road transport	Time for emptying one wagon	Off-field time per load	[3)]On-field time per load
Combine, grain	24 min.	8 min.	32 min.	[1)]44 min.
Beet				[1)]22 min.
Maize, silage				[2)]20 min.
Clover grass				[2)]21 min.

1) Combines and beet harvesters can store crop while harvesting. The internal storage tank is emptied onto a transport wagon driving beside the harvesters while still harvesting. When the transport wagons arrive to the field the harvester will unload the first time. Hereafter the unloading wagon has to wait for unloading almost two more times, before it is full, because the wagon can hold 27 t compared to 10 t in the internal storage tank (see table 10).

2) When harvesting roughage, a transport wagon drives beside the harvester all the time, because there is no internal storage tank.

3) Time for filling one wagon + 8 minutes for driving to and from the harvester.

If lorries are used for larger transport distances, it is usually sufficient with one on-field wagon to fill the lorries beside the field. However there must always be two when chopping roughage, because the harvester has no internal tank.

In Table 14, the maximum time span between two transport wagons is determined

Table 14. Maximum time between wagons to insure full capacity on harvester (5 km transport distance).

	Off-field time, min.	On-field time, min.	Total time, min. per load	Max. time between wagons, min.
Combine, grain	32.0	44	76	14
Beet		22	54	5
Maize, silage		20	52	0
Clover grass		21	53	0

Combine: Time consumption off-field and on-field ads up to 76 minutes. Because off-field time is 32 min. two wagons seems insufficient. But because maximum time between two wagons is 14 min. two wagons are sufficient anyway.

Beet harvester: Beets are normally stored on the harvested field. If so, the time span between two wagons decides how many wagons is needed. Here 8 min (see

Table 13). A wagon is filled in 5 min (see Table 14). Consequently there must be two wagons. If the beets are stored 5 km away, 3 wagons are needed.

Forage harvester, maize: A forage harvester have no internal storage tank for the harvested mass. Therefore a new wagon must be ready, when the full wagon leaves the forage harvester. Off-field time is 32 min. but on-field time is only 20. Consequently three wagons are needed. Some waiting time must be accepted for the wagons.

Forage harvester, clover grass: A forage harvester have no internal storage tank. Therefore a new wagon must be present, when the full wagon leaves the forage harvester. Off-field time is 32 min. On-field time is only 21 min. Consequently, three wagons are needed. Some waiting time must be accepted for the wagons.

Transport time relative to distance

Using the same method as above the necessary number of wagons can be calculated related to distances. As an example the necessary number of wagons is calculated for 1-5 km transport distance.

In Table 15 time consumption off (off-field time) and on the field (off-field time) are listed.

Table 15. Time consumption on and off the field in relation to distances between one and five km.

	Time consumption off the field, minutes per load					Time consumption on the field, minutes per load
Distance, km	1	2	3	4	5	
Combine, grain	13	18	22	27	32	[3]44
Beet	13	18	22	27	32	22
Maize, silage	13	18	22	27	32	20
Clover grass	13	18	22	27	32	21

1) Off-field time includes 8 minutes for emptying the wagons.

2) On-field time includes 8 minutes for driving to and from the harvester, when coming to the field.

3) When using more than 1 wagon the internal storage tank on the combine will be full when a wagon arrives. In this situation time consumption on the field will be less - approximately 31 minutes.

From the table above the necessary number and wagons can be calculated. When calculating, the 8 minutes that are included in the off-field time must be subtracted and added to the on-field time, because the wagon is away from the harvester in this period of time.

The necessary number of wagons can be calculated from the numbers in Table 15. The 8 minutes that is included in on-field time must be deducted and added to the off-field time.

Necessary number of wagons = (Off-field time + 8) / (on-field time - 8).

The result must be accessed according to maximum time between two wagons (Table 16).

Table 16. Necessary number of wagons related to distance.

	Max. time between two wagons, min.	[1]Necessary number of wagons related to distance, pcs.				
Distance, km		1	2	3	4	5
Combine, grain	14	[2]1 (2)	2	2	2	2

Beet	5	2	2	3	3	3
Maize, silage	0	2	3	3	3	4
Clover grass	0	2	2	3	3	4

1) It is a precondition for the calculations, that wagons are fully loaded according to the capacity determined by the maximum load according to Danish legislation. If maximum time between wagons is higher than off-field time, additional wagons are required. When distances exceed 5 km, transport by lorry is often more cost effective.

2) When calculated then necessary numbers of wagons are 2, but the difference between 1 or 2 wagons is approximately 4 minutes. In real world 1 wagon would be used and the short waiting time accepted. The calculated numbers cannot stand alone. It must always be accessed, if waiting time is acceptable.

Wagons with a lower loading capacity than permitted are often used. If so the numbers in the table above needs to be adjusted according to the actual capacity.

NECESSARY NUMBER OF WAGONS - USING COMMON SIZE WAGONS

Generally the largest allowed wagons are used in all calculation. In this chapter common size wagons are used to calculate the necessary number of wagons in relation to distance. All other preconditions are from the previous chapters.

Figure 3. Combine harvester with 10 ton internal storage tank. Transport with 20 ton wagons.

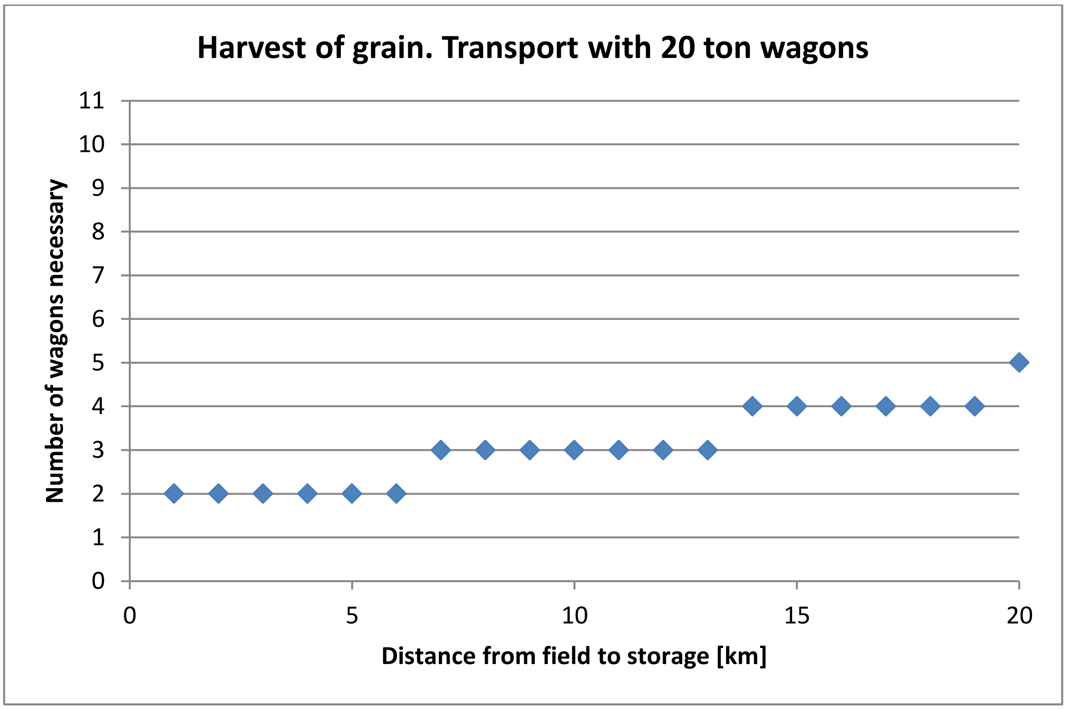


Figure 4. Beet harvester with 10 ton internal storage tank. Transport with 27 ton wagon load.

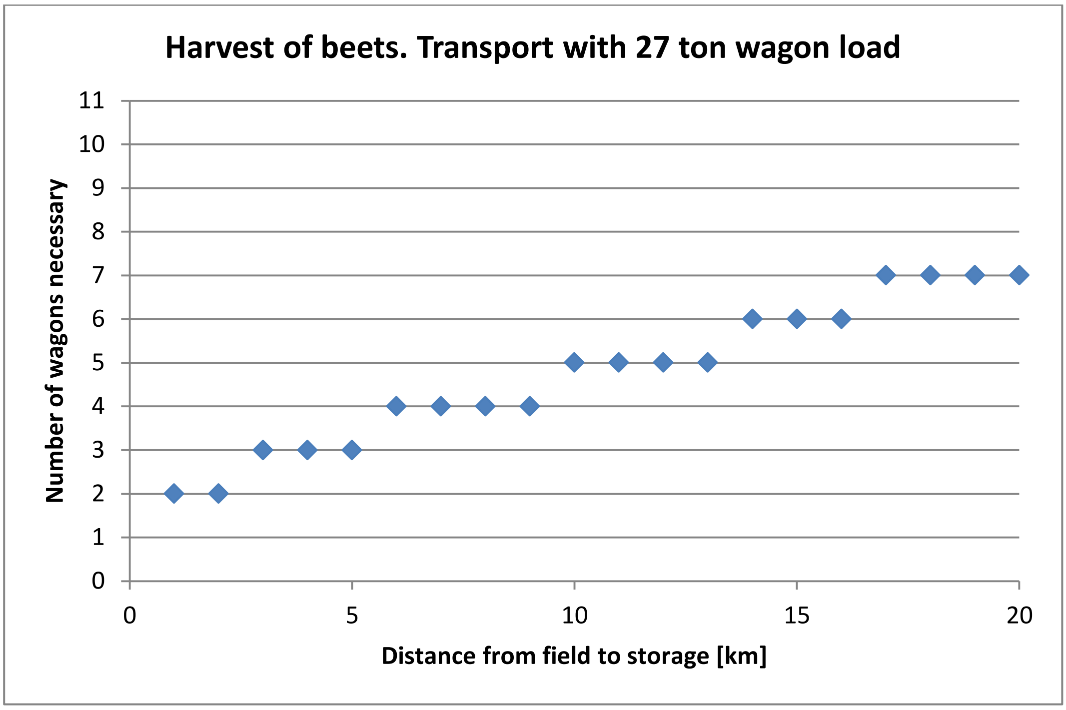


Figure 5. Forage harvester – in silage maize - no internal storage tank. Transport with 23 ton wagons.

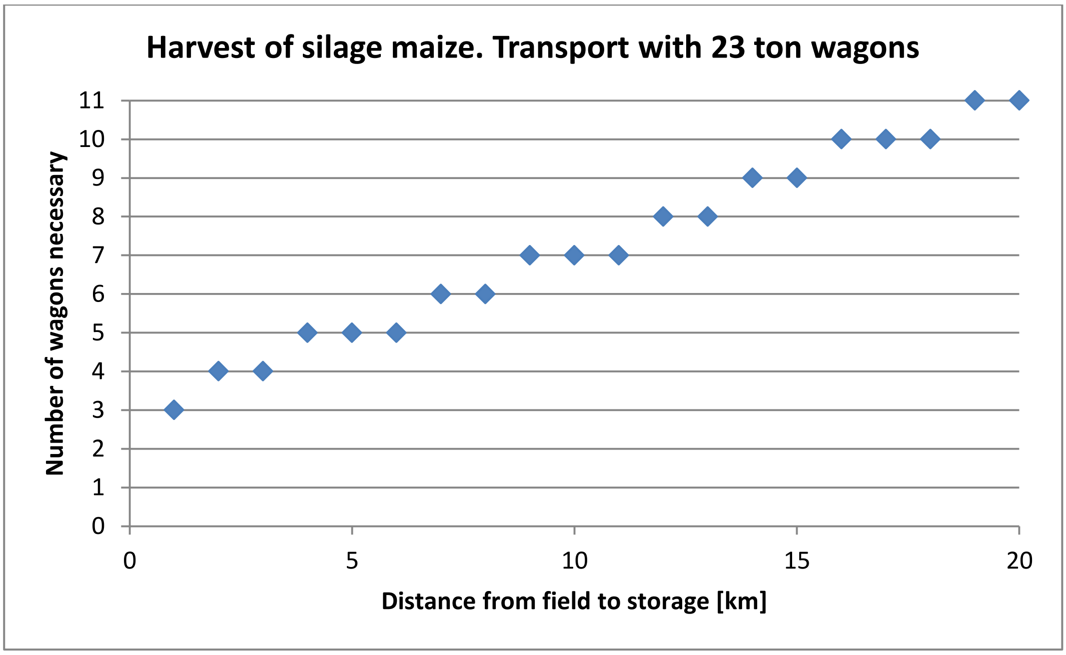
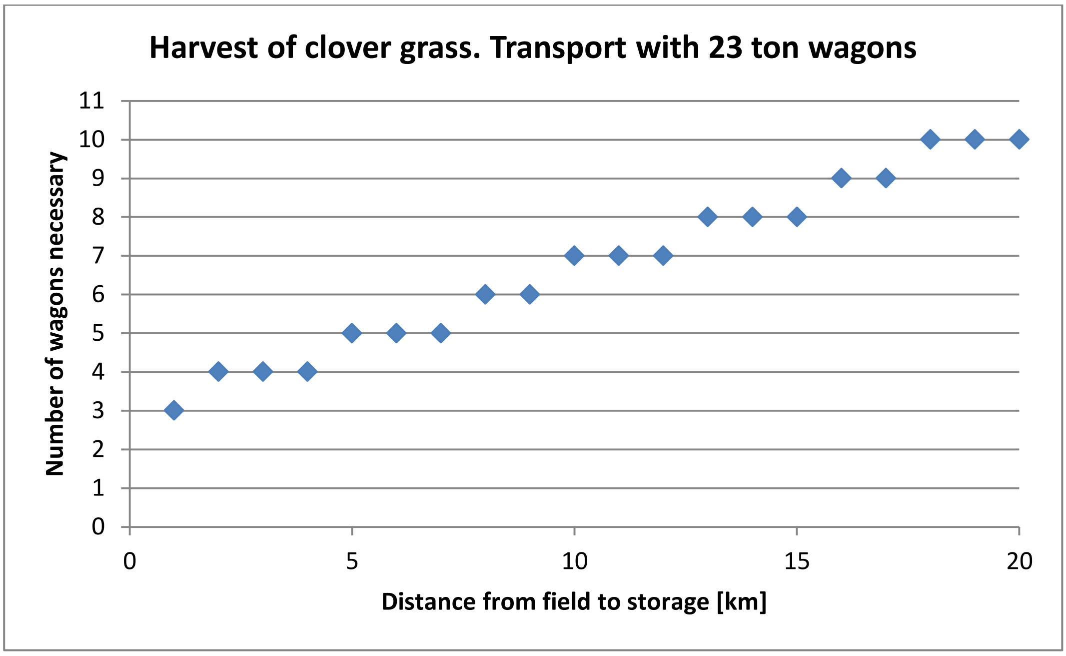


Figure 6. Forage harvester – in clover grass - no internal storage tank. Transport with 23 ton wagons.


Harvest of clover grass. Transport with 23 ton wagons
Number of wagons necessary
Distance from field to storage [km]
0
1
2
3
4
5
6
7
8
9
10
11
0
5
10
15
20

TRANSPORTATION COSTS, FIVE KM DISTANCE

Below approximated costs for transport of different crops and straw are listed. One wag-on with tractor cost 625 DKK (83 Euro) per hour.

Table 17. Transport costs for different crops, five km transport distance.

Transport costs	Necessary number of wagons, 5 km	Cost, DKK (Euro) per hour	Cost, DKK (Euro) per ton crop
Grain	2	1,250 (167)	28 (3.75)
Beet	3	1,875 (250)	15 (2.10)
Maize, silage	4	2,500 (333)	21 (2.78)
Grass, silage	4	2,500 (333)	23 (3.09)

TRANSPORTATION OF ROUGHAGE WITH LORRY OR TRACTOR

As example of transportation cost for maize silage, transport costs for 5, 10 and 15 km are calculated for both tractor propelled transport and for transport with lorry. Following preconditions are used:

- Working load with tractor propelled transport: 23 ton
  (The same weight is used for on-field transport to lorries)
- Working load with lorry and trailer, 7 axles: 38 ton
- Yield per hour: 120 ton
- Time to fill one on-field wagon: 12 minutes
- Time consumption for on-field driving to and from the silage harvester: 8 minutes
- Time consumption for unloading on the storage facility: 8 minutes
- Price per hour for a tractor and wagon: 625 DKK (83 euro)
- Price per hour for a lorry and trailer: 750 DKK (100 euro)
- Price per hour for a payloader: 500 DKK (67 euro)

As a precondition average on-road tractor speed is set to 25 km/h and average lorry speed is set to 50 km/h bearing in mind that most transport will be on smaller roads. For longer transport distances partly on main roads average speed might be 60 km/h.

Table 18.Necessarry equipment using tractor propelled transportation.

	Off-field time, min.	**On-field time, min.**	**Total time, min. per load**	**Necessary wagons**
Tractor, 5 km transport	32	20	52	5
Tractor, 10 km transport	56	20	76	7
Tractor, 15 km transport	80	20	100	9

From the number of wagons in Table 18 and the chosen preconditions, total transport cost per hour for tractor propelled transport is calculated:

- 3,125 DKK (417 euro) per hour for 5 km
- 4,375 DKK (583 euro) per hour for 10 km.
- 5,625 DKK (750 euro) per hour for 15 km.

Table 19. Needed equipment for transportation with lorry.

	Off-field time, min.	On-field time, min.	Total time, min. per load	Vehicles needed
On-field unloading wagon[1)]	0	27[2)]	20	2
Lorry, 5 km transport	20	27[2)]	47	2
Lorry, 10 km transport	32	27[2)]	59	2
Lorry, 15 km transport	44	27[2)]	71	3
Extra payloader[3)]				1

1) Minimum two wagons for unloading are needed to ensure maximum capacity for the silage harvester.

2) One lorry (38 ton) has to wait for 1.65 loads from the unloading wagons (23 ton). On field time is = 1.65 x filling time for one wagon + 8 minutes for on-field transportation. If one of the unloading wagons can be ready for unloading as the lorry arrives, on-field time can be reduced to 19 minutes.

3) When lorries unload in front of the stack instead of in the stack, an extra payloader is required.

From the numbers in Table 19 and the chosen preconditions, total transportation cost per hour for transport with lorry is calculated:

- 3,250 dkr. (433 euro) per hour for 5 km
- 3,250 dkr. (433 euro) per hour for 10 km.
- 4,000 dkr. (533 euro) per hour for 15 km.

The calculations above show that because of the need of two unloading wagons in the field plus an extra payloader, the transport distance must exceed 5 km, before it is profitable to use transport with lorry, compared with tractor propelled transport.

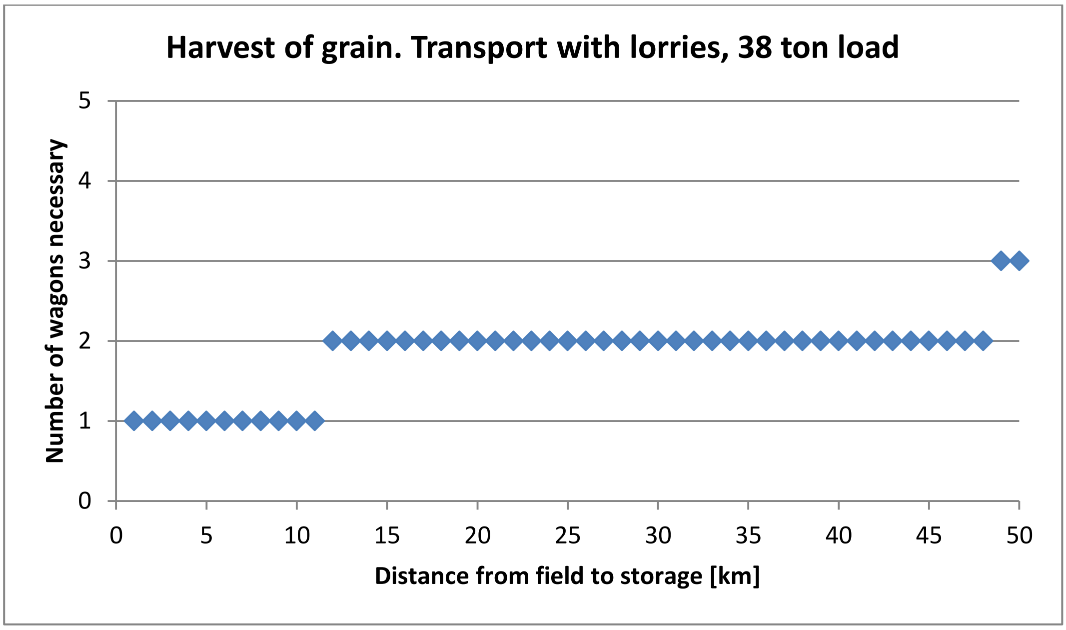
Table 20. Comparison of transport cost, using tractor and lorry.

Distance	Tractor		Lorry	
	Total cost per hour, DKK (euro)	Total cost per ton, DKK (euro)	Total cost per hour, DKK (euro)	Total cost per ton, DKK (euro)
5 km	3,125 (417)	26 (3.47)	3,250 (433)	27 (3.61)
10 km	4,375 (583)	36 (4.86)	3,250 (433)	27 (3.61)
15 km	5,625 (750)	47 (6.25)	4,000 (533)	33 (4.44)

NECESSARY NUMBER OF LORRIES IN RELATION TO DISTANCE

Below the necessary number of lorries can be seen in relation to distance and crop. All preconditions are from the previous chapters.

Figure 7. On-field transportation with 1 buffer wagon. Off-field transport with lorries, 38 ton load.



Reloading of beets from tractor propelled on-field wagons to lorries is not commonly used. Beets are normally stored on the field and reloaded with a payloader or a dedicated loading machine. Therefore no calculations are made for beets.

Figure 8. On-field transportation with 2 buffer wagons. Off-field transport with lorries, 38 ton load.

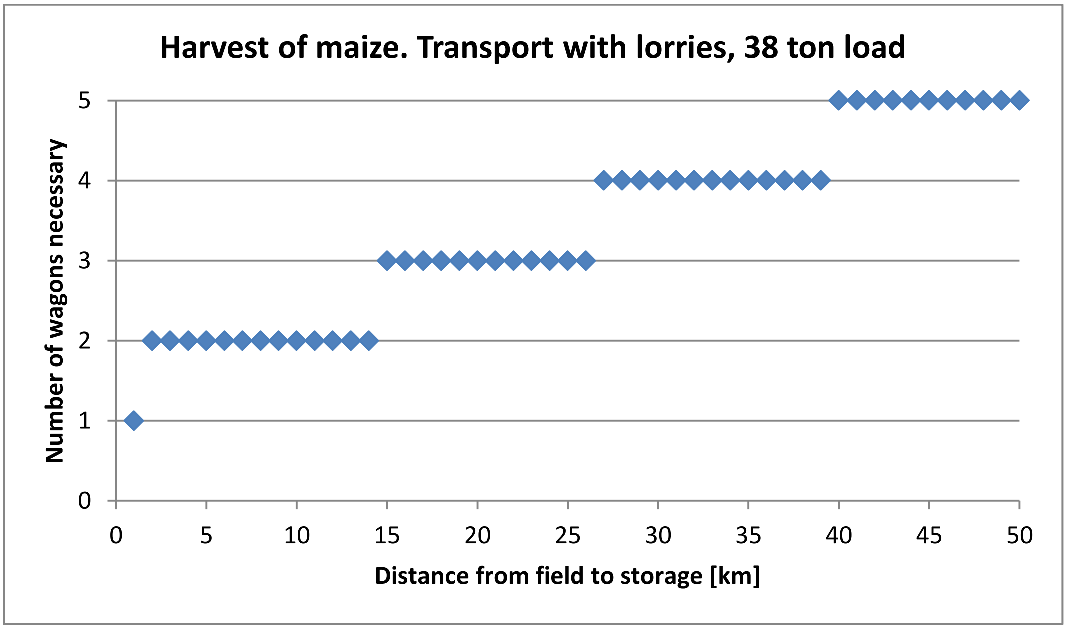
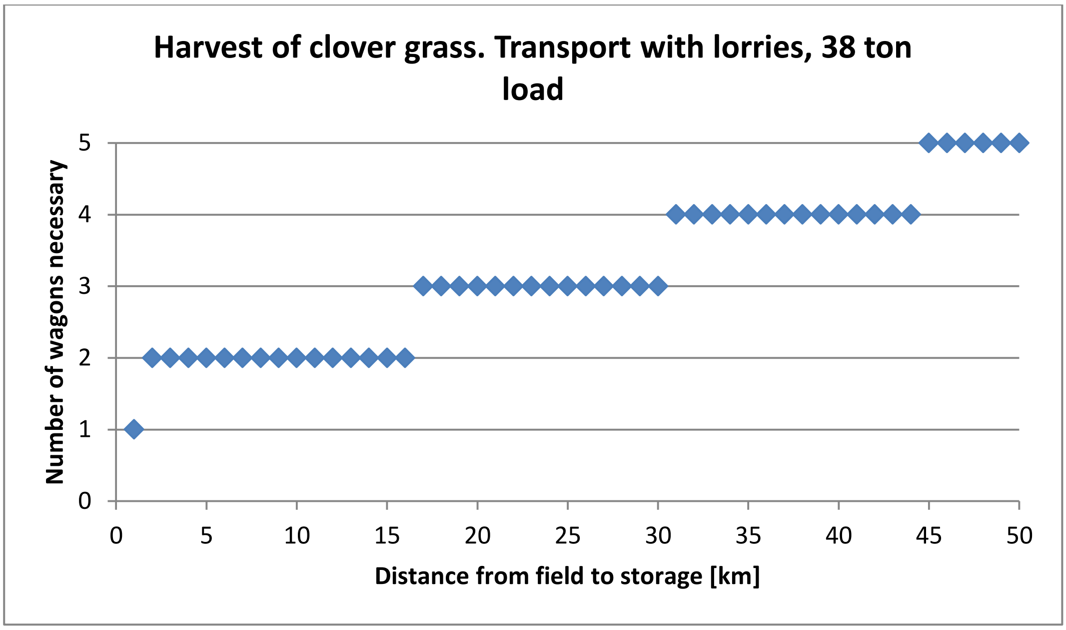


Figure 9. On-field transportation with 2 buffer wagons. Off-field transport with lorries, 38 ton load.



RIB HARVEST AND COLLECTION OF STRAW / CATCH CROPS FOR BIOMASS IN THE AUTUMN

Rib harvest, where straw from grain is harvested along with catch crops, has been suggested as a harvest technique to increase yield. The combined biomass can be stored as silage.

When harvesting grain conventionally, grain and straw are harvested at the same time. The straw remains at the field where it dries and will be collected when dry matter content is 85-95 %. The degradation of the straw is lowest at high dry matter and high dry matter is normally preferred for storage.

Picture 32. Using a stripper header the straw is left on the field. Photo: Shelbourne Reynolds

If the straw is left on the field using a stripper header, the straw will decompose on the field until it is collected in the autumn. In Denmark catch crops are used on a large scale, mainly because it is required by legislation. Thus it will be possible to chop both the straw and the catch crop in the autumn, using a silage harvester.

Picture 33. Design of a stripper header. The head is separated from the straw and threshed in the combine. Thereby the harvest capacity is increased. Photo: Shelbourne Reynolds.

By then, both the partly decomposed straw and the catch crop will have considerable lower dry matter, making it possible to store it as silage.

LOSS OF YIELD CAUSED BY THE METHOD

As the combine harvest the crop, the straw and catch crops hit by tires of the combine will be disposed flat on the ground and only a fraction of the biomass will rise again. As a percentage of the total field-area the loss of straw and catch crop is considerable. The calculation below shows how many percent of the field is run down by the combine:

Table 21. Percent run down straw and catch crop, caused by the combine and tractor with wagon.

	Tyre / track width, mm	[1]Crop loss in the regular field, %
Combine with 30' header (9,1 m)	750	16
Including trails from tractor and wagon[2] (without CTF[3])	650	24
Combine with 30' header (9,1 m)	900	20
Including trails from tractor and wagon[2] (without CTF[3])	650	27
Combine with 35' header (10,7 m)	900	17
Including trails from tractor and wagon[2] (without CTF[3])	650	23
Combine with 35' header (10,7 m)	1,050	20
Including trails from tractor and wagon[2] (without CTF[3])	650	26
Combine with 40' header (12,2 m), only with tracks	900	15
Including trails from tractor and wagon[2] (without CTF[3])	650	20
Combine with 45' header (13,7 m), only with tracks	900	13
Including trails from tractor and wagon[2] (without CTF[3])	650	18

1) Crop loss in the headland is considerable bigger due to turning machinery. This is not included.
2) In the calculation every second tractor trail is included for unloading of the combine.
3) CTF is controlled traffic farming, meaning that the same trails are used on the field year after year. In a CTF system the tractor and wagon that the grain is unloaded into, will use the same trails as the combine, reducing straw and catch crop loss considerable.

As shown above a loss of 13 to 27 percent is inevitable. Under normal conditions, not using Controlled Traffic Farming (CTF), and with a large header there will be a loss between 18 and 23 percent, if a tractor with wagon is loaded in every second trail, making their own trail. If CTF is used in combination with a large header, loss of straw and catch crop can be limited to 13 to 20 percent.

It is recommended to use CTF combined with as wide a header. To be able to use CTF the unloading auger on the combine must be extended to the same width as the header, to make it possible to unload grain to the next sprayer track.

The total loss will be some percent higher than the numbers in the table above, because turning machinery in the headland will increase the loss. Therefore it will not be possible to reduce loss to less than 15-20 percent in Danish conditions.

The numbers above is for grain. If straw from maize is collected with its catch crop, a FarmTest from 2015 proved that a loss of 30-50 percent must be expected.