Evolution of the quality of sugar beet harvesting over the last decades

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Abstract: The publication comprises a description of a test method for sugar beet harvesting devices and presents the field test results from 1984 to 2012. Quality parameters examined for harvesters were beet mass losses (both surface and sub-surface), root breakage, soil tare, and topping quality (accuracy and crown retention). The tests were held at Seligenstadt Estate near Würzburg/Germany on a test plot with loess soil. The introduction together with the chapter methods focuses on the test method which is constituted as an international standard of the International Institute of Sugar Beet Research (IIRB) dedicated to unifying the assessment of the working quality of harvest machines. The results from the last test held in 2012 are introduced in more detail outlining the working quality of the participating harvesters representing the state of technique. As a review targeted to reveal the trend of the last decades the test results from the beginning in 1984 are presented with a preceding paragraph on the progress and changes in the design and functions of the harvest machines in this time range.The test results outline a shift in the topping quality tending to a slighter topping of the beets to avoid mass losses due to excessive overtopping. The share of beets that are over-topped decreased in the last tests. Major mass losses over the entire time span originate from breakage of the root tips accounting for 2.7%, on the surface, and underground mass losses amount to 0.9%. Soil tare strongly depends on soil conditions (soil water content and soil type) having an average of 9.8% over test years.

Keywords: root crop harvest, test standards, topping, soil tare, root losses, tanker, field test

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1 Introduction

Sugar beet is a biannual crop that is harvested in the autumn of the first year of vegetation when the tap root contains the maximum sugar. In the EU, sugar beets are grown on around 102 500 farms with 1.385 mill ha and processed by 89 factories producing around 16.200 mill t of sugar (WVZ, 2024).

Harvesting beets requires (I) defoliation of the leaves, (II) lifting the tap roots from the soil, (III) cleaning the beets, and (IV) transport of beets to the headland. The entire harvesting process aims at clean beets with minor injuries and low mass losses (Brinkmann, 1982, 1986; IIRB, 2015).

The test events were held ten times (1984-2012) on the Seligenstadt Estate near Würzburg/ Germany. The farm owns two appropriate fields with an area of 15.4 ha facilitating the test with similar soil conditions which are typical for sugar beet cultivation in Europe. The test was is an assessment of the work quality of the harvest machines related to the functions (I-IV) as defined in the previous paragraph. The test results are dedicated to documenting the state of the art and to inform users e.g. farmers about the quality of operation not including durability and strength or live time of machine components.

Similar tests were conducted in 1994 in Berny-en-Santerre/France (Institute Technique de la Betterave

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[ITB], 1994), in 2005 in Peterborough/United Kingdom (Schmittmann and Schulze Lammers, 2006), in 2006 in Lelystad, the Netherlands, (Tijink, 2010), and in 2011 in Polland. From the institute for sugar beet research in Göttingen/Germany tests were performed to evaluate the harvesting system in terms of post-harvest storage losses (Hoffmann et al., 2018).

The Institute Technique de la Betterave (ITB, 1994) organized in the region of Hauts-de-France a test with 12 6-row machines, out of which 6 were tanker type, 6 1-stage harvesters with parallel loading on transport vehicles and 4 6-row 2-stage harvesters using combined topping and lifting implements completed by self-loading tanker vehicles. The test criteria comprised topping quality in 3 categories and mass losses. In 1995 and 1996, Ružbarský et al. (1998) (Slovak and Czech University of Agriculture at Nitra and Prag) performed a test with 7 6-row tankers. A test in Peterborough/UK 2005 (Schmittmann and Schulze Lammers, 2006) was attended by 16 harvest machines out of which were 5 trailed 3- and 4-row harvesters and 11 self-propelled 6- to 12-row tanker machines. To evaluate the mechanical impact on beets causing superficial damage an electronic beet was employed. The test in 2010 was organized by Dutch Instituut voor Rationele Suikerproduktie (IRS, 2010) on an experimental farm of the Wageningen University near Lelystad growing beets on polder soils. 10 harvesters were tested out of which 9 were 6-row self-propelled bunker machines and 1 trailed 6-row machine loading on a parallel walking trailer (Tijink, 2010). Apart from the test criteria following the IIRB standard the harvest machines were weighed with full and empty bunkers. The heaviest machine (three axles) weighed 57.5 t and had a bunker capacity of 24.8 t. 2011 the Institute of Biosystems Engineering at Poznan university, Poland performed a test with 2 6-row harvesters and 2 sets of 2-stage harvesters on different sites in Poland (Przybył et al., 2013). A comprehensive field test of sugar beet harvest technology out of Europe was conducted by Morad et al. (2007) in Egypt recording lifted and un-lifted beets, bruised beets, damaged and un-damaged beets. In contrast to the IIRB method, they studied the impact of travel speed, soil water content, and the method of sowing (manual and mechanical planting) on the quality of harvested beets. Beets were harvested manually, by a chisel plow, or by a 1-row harvester with disc shares.

1.1 Mechanization of harvest

Following the manual harvesting procedures of sugar beet in the last century characterized by ca. 200 h of labor demand with drudgery, various technical devices were developed and designed from the beginning 1950th. As outlined in Figure 1, operations comprise the full mechanical harvest. Topping is the elimination of the leaves which do not contain sugar and would worsen the sugar extraction from the liquid resolution in the refinery process. Hence the leaves are required to be eliminated which adversely leads to a loss of beet mass when the beet crown is cut off. Topping is subdivided into defoliation which is chopping the leaves by flails and subsequently feeling of the beet crown as well as cutting off the beet crown with basal petioles.

The Second item in the scheme addresses the digging off from the soil which is separating the beets from the soil. The remaining soil adhering to the beets and loose soil picked up by digging tools need to be separated which is denoted as cleaning. The adhering soil to the tap root after lifting is evaluated in terms of operation quality by assessing soil tare. The last two functions – collecting the beets on the machine and discharging at headland- are not a matter of evaluating the process quality, these items are more important for an efficient mission of the machines in the field as well as for labor management.

1.2 Harvest machines

In the time span regarded diverse techniques of harvesting existed itemized as trailed machines, self-propelled, bunker or continuously discharging, number of rows harvested and operations performed independently time wise (1- to 3-stage).

Over the years the number of manufacturers and by that the spectrum of machines have been reduced remarkably to only about seven companies in

Western Europe. This trend affected the test by reducing the number of test candidates from 31 machines in 1984 to 9 in 2012.

In the current century, the predominant harvest machines in Germany and with an increasing share in the EU were 6-row self-propelled tankers with a harvesting capacity of 0.8 to 1.1 ha h^{-1} (Buhre et al., 2014).

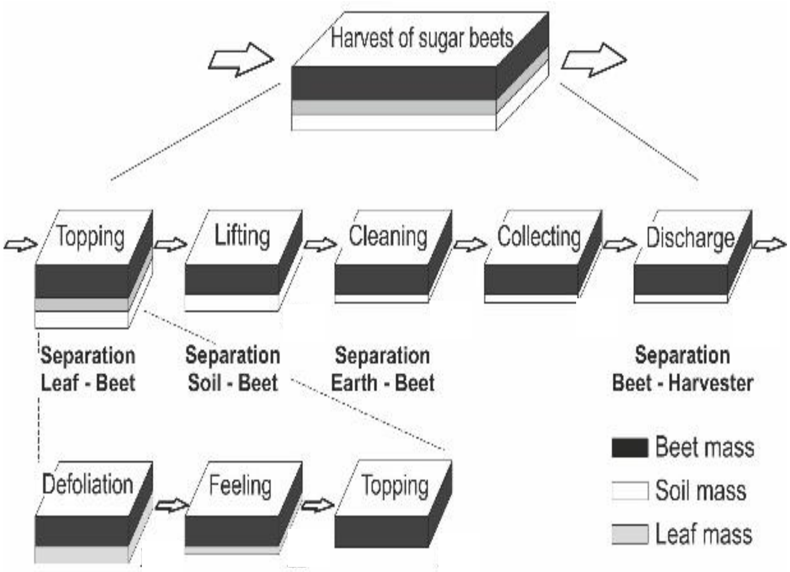

Figure 1 Process phases and separation processes of sugar beet harvest (Kromer et al., 1990, modified by authors)

1.3 Test standard

Since 1975 members of the International Institute of Beet Research (IIRB) organized tests of harvesters under field conditions. IIRB established a task force (Agricultural Engineering Study Group) in 1980 to constitute a test method for uniform field test conditions. An international standard for testing sugar beet harvesters emerged from a group of experts from national research institutes and beet grower associations in Europe. The standard (IIRB Test Procedures for Measuring the Quality in Sugar Beet Production -Seed Drillability, Precision Seeders, Harvesters, Cleaner Loaders) was published in a booklet as a 1st edition 1997 and comprises the following test criteria:

- Lifting, cleaning and conveying losses
- Root tip breakage
- Topping quality
- Soil tare
- Superficial damage

Amendments to the standard were made in 2004 and 2015. In the autumn 1984 the first test with the standardized method was performed in Seligenstadt/ Germany.

The subsequent chapter names the specifications, definitions, and test methods as documented in the IIRB standard.

2 Method as defined by the IIRB-standard

2.1 Field conditions

Beet mass and maximum diameter as well as the yield are an information on test conditions and should be uniform for all machines under test. These data are determined by manual measurements digging out 500 beets from different places in the test field one week in advance of the test. Additionally, soil water content is taken by samples from the test area of each machine during the test run and determined by oven drying for 24 h. Soil type and texture should be given as background information on the operational conditions of the harvesters.

2.2 Harvesting losses

Beets are mechanically lifted from the soil and conveyed in the machines as well as cleaned by mechanical measures. The handling of the beets leads to mass losses which are determined by collecting the left roots and beet pieces from an area of a minimum of 100 m^2(four times by 6 rows on a length of 10 m). To catch beet fractions left in the soil the test plots are tilled twice with a spring tine cultivator. Parts smaller than 4.5 cm are left in the field as they are considered under root breakage.

2.3 Root breakage

Breakage of the tap roots can be traced back to the mechanical treatment in the harvesters. Fracture peaks smaller than 2 cm are considered unavoidable losses. The diameter at the, point of breakage is measured from 500 beets which are collected when the tank is unloaded after the test run. The samples are caught in big bags and the diameters are taken manually by a rule. From the breakage diameter the mass of the lost root tip is concluded using a master beet. This master beet is determined by 100 beets from the plant stand. 5 categories are taken (diameter: 0-2, 2-4, 4-6, 6-8, and > 8 cm) in order to establish the relationship between the fracture diameter and the mass of the lost part.

The results of mass losses are given as relative values in relation to the calculated yield (obtained by manual harvest).

2.4 Topping quality

Separating the leaves from the beets is associated with the removal of the leaf modalities. The optimum topping is when all leaves are eliminated from the beet crown without the remaining green parts. This is in the IIRB-standard defined as the category “correctly topped”. Other categories reveal “under topped” and “over topped” etc. as outlined in Figure 2. Over topped beets are not desirable as mass loss of the beet crown appears. Under topped beets lead to inefficient sugar extraction in the refineries. Similar categories are defined for defoliated beets as displayed in Figure 2 (lower line). The assessment is performed manually for 500 beets and the results are given as a relative number of beets taken for one test candidate.

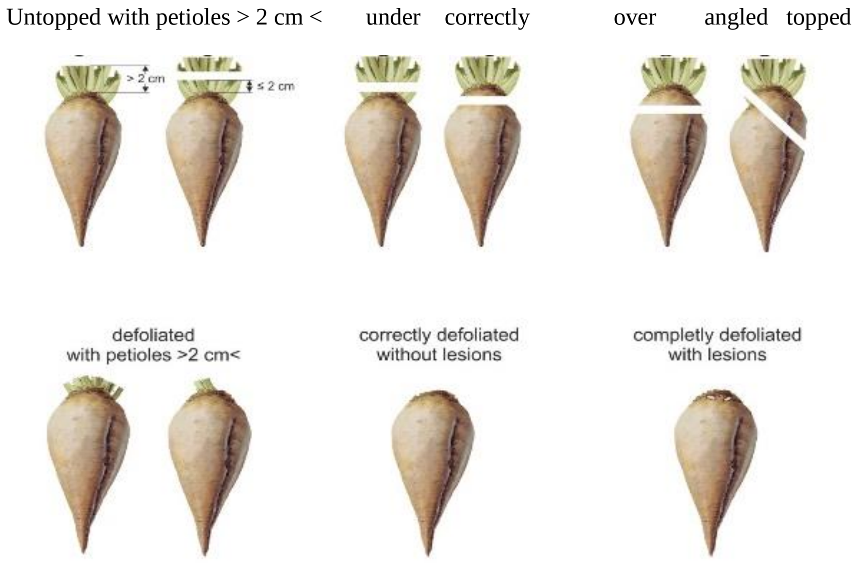

Figure 2 Categories of topping and defoliation as defined in the IIRB-standard

2.5 Soil tare

During harvest, the beets are taken from the soil and conveyed in the harvesting machines to be collected in the tank. Both operations serve for minimizing soil adhering to the beets and get rid of the loose soil in the beet flow. Additionally, cleaning devices are provided to separate or clean the beets from the soil. The most effective measure is to apply shear stress which separates the soil from the tap root near the surface. Other effects of cleaning are friction between the beet roots (turbines rotation), brushes and even cleaning by liquids (water) is conceivable but is not applied so far in existing harvest machines.

Clean beets are a basic requirement for an effective transport and processing of sugar beets. Soil tare as the relative fraction of beet mass is determined by washing and weighing 500 beets. Drum washers with a run time of ca 3 min are used for cleaning beet samples. Results are presented as relative values of gross beet weight.

2.6 Superficial damage

Damage to the tap root skin occurs due to mechanical impacts in the harvest process. Already lifting the beets out of the soil can cause injuries to the skin when the shares are not correctly adjusted or by the miss-steering of the harvesting vehicle. The transport in the harvesters and predominantly cleaning is an operation of transducing mechanical impacts to the sugar beet with the aim to resolute adhering soil from the surface of the beets. As a consequence, beets are injured on the surface to different extend depending on soil tare, soil water content, soil type und the applied technical measures. Injuries to the beet surface cause deterioration by microbial activity and higher respiration during storage.

So far, no other method has been successfully introduced to assess the magnitude of injuries by taking the dimensions of the area on the beet surface being injured. The injured area is determined following the IIRB-standard from the largest length and rectangular distance to it. This area is considered as an approximation for superficial damage indicated by cm ²per 100 beets.

3 Results from 2012 - last test conducted

3.1 Field data

The IIRB-standard recommends a plant density between 50,000 and 120,000 plants per hectare with a regular distribution. Table 1 outlines the essential agronomic information on the crop stand, the crop morphology, and yield. The soil type in the test plot is para-brown soil (ca. 48% clay, 45% silt, 7% sand) on loess with 180 mm usable field capacity (Scheffer and Schachtschabel, 1991).

Table 1 Crop parameters of the test plot, 2012 Seligenstadt

Plant population	Row width	Seed target spacing	Beet hight*	Topping hight*	Max beet diameter*	Single beet mass*	Yield calculated	Sugar content**
Plants ha^{-1}	cm	cm	cm	cm	cm	g	t ha^{-1}	%
100 800	50	17.9	5.2	3.3	10.4	904	91.2	20.3

Note: *mean of 250 beets **polarization as described in ICUMSA (1994)

Table 2 Specification of harvest machines under test, 2012

	Engine - Power	Net weight	Tank volume	Share type	Pickup device	Cleaning device
Machine 1 Agrifac Big Six	440 kW 660 PS	30.7 t	40 m ³ 28 t	Polder	turbine	Turbine
Machine 2 Grimme Maxtron 620	360 kW 490 PS	32.6 t	33 m ³ 22 t	wheel driven	roller	Roller
Machine 3 Grimme REXOR 620	360 kW 490 PS	27.4 t	33 m ³ 22 t	polder	roller	turbine
Machine 4 Holmer Terra Dos T3 Eco	383 kW 520 PS	30.7 t	28 m ³ 20 t	polder	roller	turbine
Machine 5 Kleine Beetliner Large	360 kW 490 PS	28.2 t	30 m ³ 21 t	polder	roller	turbine
Machine 6 Kleine Beetliner Max	375 kW 510 PS	32.8 t	40 m ³ 26 t	polder	roller	turbine
Machine 7 Ropa euro-Tiger V8-4b	440 kW 598 PS	32.4 t	40 m ³ 26 t	polder	roller	turbine
Machine 8 (9 rows) Ropa euro-Tiger, V8-4b	440 kW 598 PS	35.3 t	40 m ³ 26 t	polder	roller	turbine
Machine 9 Vervaet BEET EATER 625	362 kW 492 PS	33.0 t	36 m ³ 25 t	polder	turbine	turbine

Note: six rows, width 3 to 3.38 m; height 3.80 to 4 m, length 10, 40 to 14,95 m

3.2 Specification of machines under test

In the test 2012 9 pieces were tested, all of them were 6-row tanker harvesters, one machine (machine 4) was equipped with a crawler belt chassis, wheel shares, roller cleaning device, and a flail defoliator. All others had tire chassis, used Polder shares and defoliators associated with topping knives as well as turbines for cleaning the beets (Table 2).

3.3 Results on quality of harvest

The working speed was set at > 6 km h^{-1} and was undercut in the test despite the clear and previously agreed target. The travel speed of machine 8 (nine-row Ropa) was the lowest at 5.5 km h^{-1} and machine 4 (Holmer) drove with the highest speed of 6.6 km h^{-1} (Table 3). The throughput of the machines is derived from the working width, the travel speed, and the yield (real yield after delivery to the sugar factory) resulting in 135 t h^{-1} to 150 t h^{-1} for the six-row harvesters. The nine-row Ropa euro-Tiger had a throughput of 186 t h^{-1} at a working speed < 6 km h^{-1}, which indicates that the harvester run under full capacity.

Table 3 Machine operational data

	Speed km h^{-1}	Throughput t h^{-1*}
Machine 1 (Agrifac Big Six)	5.9	135.4
Machine 2 (Grimme Maxtron 620)	6.5	147.9
Machine 3 (Grimme REXOR 620)	6.5	147.9
Machine 4 (Holmer Terra Dos T3 Eco)	6.6	149.5
Machine 5 (Kleine Beetliner Large)	6.1	139.6
Machine 6 (Kleine Beetliner Max)	6.4	145.5
Machine 7 (Ropa euro-Tiger V8-4b)	5.8	131.5
Machine 8 (Ropa euro-Tiger, V8-4b XL, 9-rows)	5.5	186.5
Machine 9 Vervaet BEET EATER 625	6.2	140.3

Note: *Clean beets equivalent to: without soil tare

Topping is essentially determined by the travel speed (one reason to specify this as a test condition), the plant density, and the uniformity of the beet height. These factors limit the vertical adaptation of the topping device. As a trend from the test in 2012 it can be recorded that, for the first time in the Seligenstadt tests, a considerable proportion of the beets were assessed as “not topped”, between 7.2% and 37.8% (Figure 3). The trend is therefore towards a significantly flatter head cut, which also results in a considerable proportion of beets with a short leaf brush and no visible head cut.

Machine 2 (Grimme Maxtron) was equipped with a defoliation head and is classified in the same categories here. In this context "not topped" means beets with green leaves and petioles (7%). A share of 17.4% beets were over topped which means that they have been completely defoliated but damaged by the flails due to a too low or aggressive setting.

For the machines with regular topping attachment, the highest portion in the categories was under topped in a range between 48.6% and 69%. Correctly topped was in the range of 10.5% and 38.4%. The category of beets that have been over topped is almost non-existent.

Soil tare, consisting of adherent and loose soil, was between 4.8% and 24.8%, with the maximum value being attributable to incorrect machine setting (Figure 4). A check of this result on the following day yielded a lower value of 6.8%. On the one hand, the soil separation depends on the soil type and its water content, which had a mean of 29.7% on the test day, and on the other hand on the setting of the cleaning organs of the harvesters, as well as on the mass flow. The aggressive setting of the cleaning organs in machine 1 (Agrifac) led to the lowest earth attachment, but also to the highest root tip losses (Figure 5). Machine 8 (eight-row Ropa) had a soil tare of 10.4% with a lower root tip loss value, which indicates that the maximum soil separation capacity had been achieved.

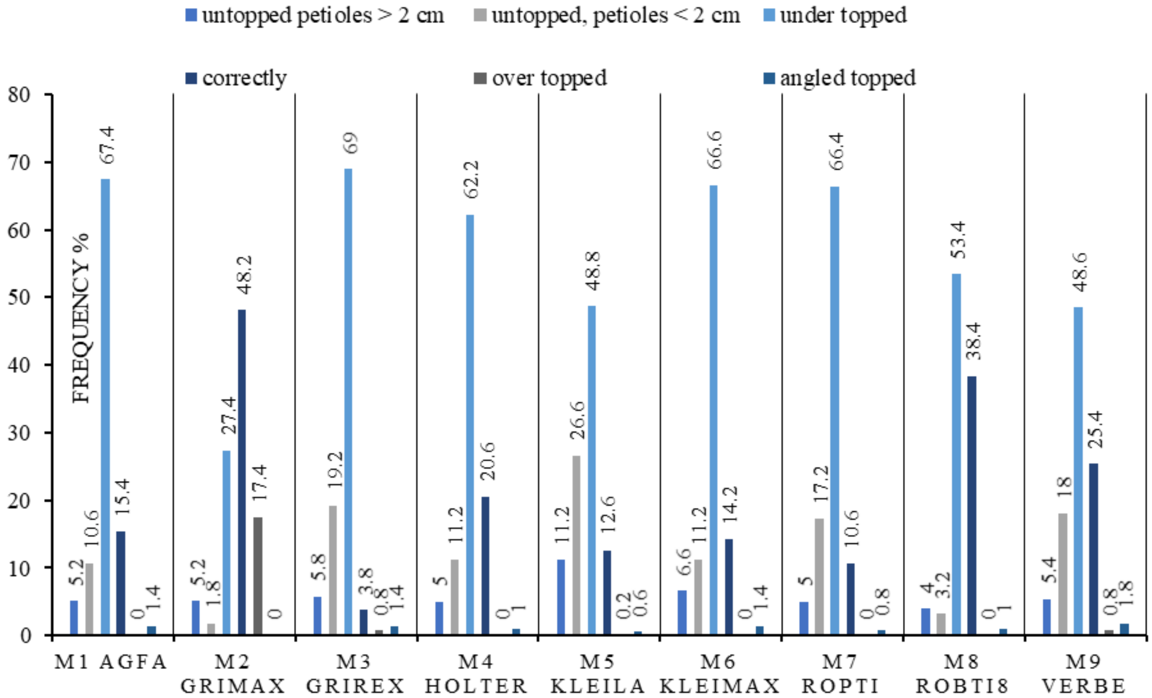

Figure 3 Topping quality of harvest machines, 2012

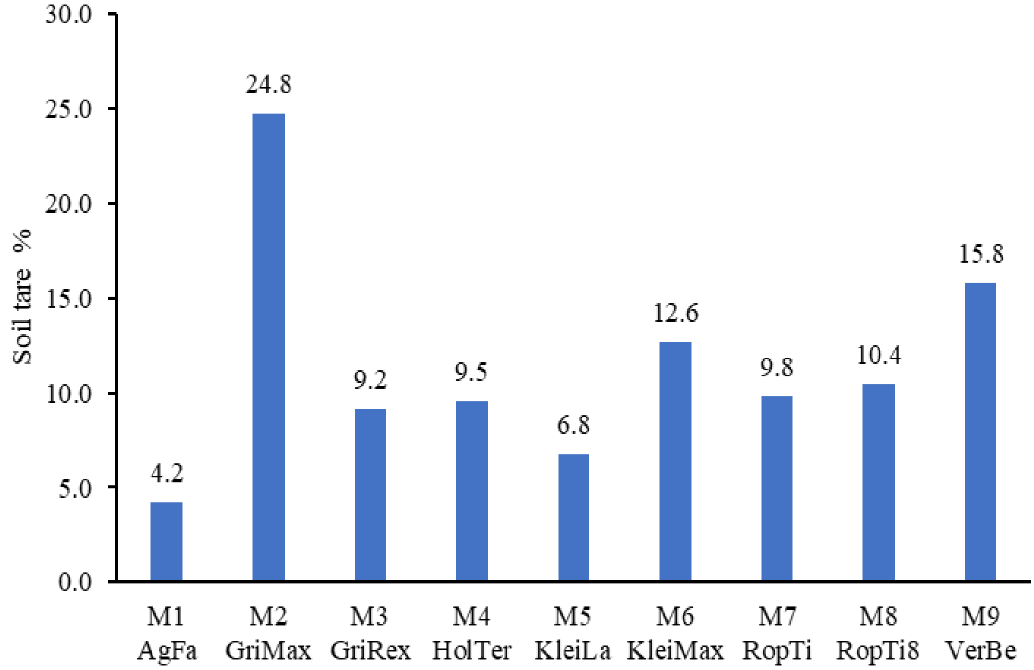

Figure 4 Soil tare of harvest machines, 2012

The mass losses originating from lifting, conveying, and cleaning the beets in the harvest machines are within a scattered range of 2.6% to 6.5% (Figure 5). The greater part resulted from broken root tips, which averaged 3.9%. Machine 9 (Agrifac), which worked with nine turbines, had a significantly higher value. The above-ground and in soil losses contributed with an average of 0.5% to 0.7% to a much lesser extent. As expected, machine 3 (Grimme Maxtron), which gently cleans the beets using cam and pinch rollers, achieved the most favorable value for mass losses. Machine 2 (six-row Ropa) shows that good results can also be achieved with turbine cleaning equipment.

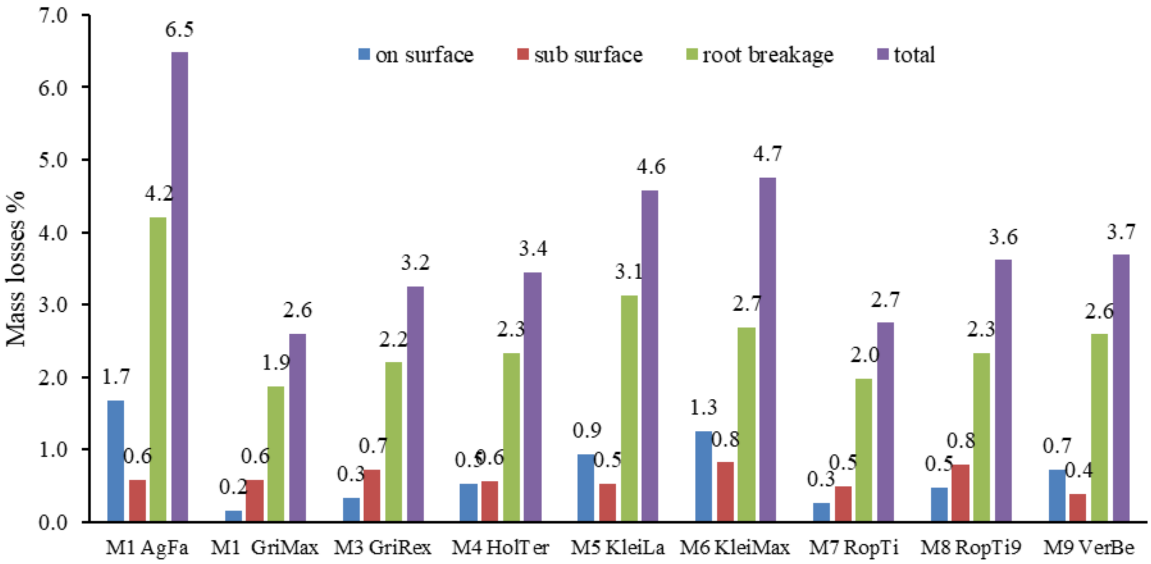

Figure 5 Mass losses of harvest machines, 2012

4 Survey of test results 1984 to 2012

The tests took place since 1984 on the same farm on fields with similar soil conditions. From 1994 to 2012 the same field was used. For the operation of the harvesters field and crop conditions are the most relevant test settings. Another impact comes from the perators` skills. Apart from relaying on the interest of the companies to employ experienced drivers, there is no measure to unify this condition. The same is for the weather conditions whereupon the soil water content as most affecting the harvest was documented in the tests and its data are displayed in Figure 8.

4.1 Evolution of crop data

The most significant change of crop data in the respected period time is in plant density and beet yield, while the beet mass remained in a range from 800 to 1000 g per beet. Figure 6 presents the evolution of these crop parameters for the Seligenstadt site. With respect to the evolution in the last decades (1984-2012) the field conditions underwent a significant increase in plant population by 47% and in beet yield by 40.3%. As a consequence, the average mass flow in a 6-row harvester increased by 46%.

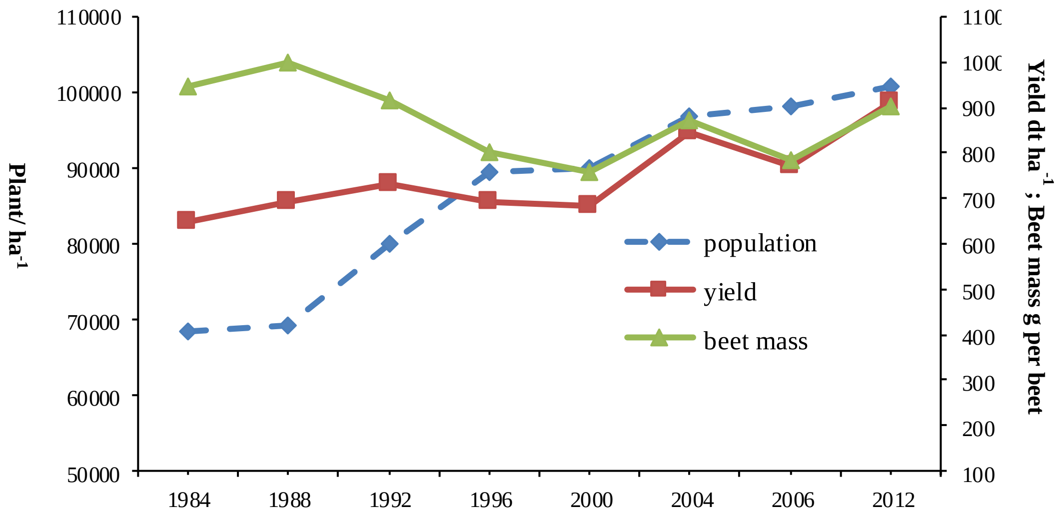

Figure 6 Yield (manual harvest), single beet mass, yield and plant population 1984 to 2012

4.2 Evolution and innovation of harvest machines

In the 1980ies there was a varying number of types taking part in the tests starting with 2-row trailed up to 6-row multi-stage machines and only one single-stage 6-row machine (Holmer/Paintner). At that time however, 60% of the beet crop (area-wise) in Germany was harvested by 1-row trailed single-stage machines (Rademacher, 1984; Kromer, 1987). The test in 2012 was performed with only 6-row single-stage machines. Buhre and Ladewig (2012) reported in 2010 that 87% of the beet crop area was harvested by this type of machine and 1-row trailed machines were employed only on less than 1% of the beet acreage. To cope with the increasing field size and field lengths the bunker volume went up from 2.8 to 4.3 m^3 per row in the 1980ies to 4.6 to 6.6 t per row for the tri-axle machines in 2012 to carry the beets to the headland. Tractors with increasing power helped to extend the capacity of the trailed machines from 0.24 of 1-row up to 0.8 ha per hour for 3-row harvesters (calculated on basis of speed and working width in tests 1984 and 2000). Self-propelled 6-rows tanker harvesters realize a capacity of up to 1.9 ha per h.

Another major progress in the harvesting process in the 1990ies was in reducing soil tare. Beets as delivered to the refineries had a soil share of 16.4% (Kromer, 1988). Thus, a major focus in advancing the harvest technology was on minimizing soil tare at that time. The effect of rollers and turbines was studied by Strätz and Brinkmann (1987) and for separating soil in the harvesters the length of the beet path through the machine and 2-stage cleaning was found as effective. Another effect of delivering more clean beets in the last decades was by interim storage of the beets on the headlands. Loading the beets from the piles requested an additional cleaning device which was combined with the loading process. The adherent soil to the beets dries out due to increasing temperature in the piles from microbial activity. Subsequently while loading the dry soil can easily be separated from the beets. As a consequence, the soil tare of beets as delivered to the refineries was reduced by ca. 50% (Kromer, 1988). Cleaner loaders appeared as part of the delivery process and more and more transport is hauled by trucks.

Rademacher and Buescher (1991) reported from the weighing of harvest machine along with the test in Seligenstadt 1988. The wheel load of 1-/2-row trailed machines amounted to a maximum of 3 t / 4.3 t. At that time the maximum wheel load for 6-row tankers was 9.3 t at the rear axle. In contrast, the inflation pressure of the wheels decreased from 22 kPa to less than 10 kPa.

None of the trailed harvesters used the axle load to generate propulsive forces. On the other hand, the self-propelled machines were already equipped with all-wheel drive, which gave them a significant advantage in wet soil conditions. The single and multi-row trailed harvesters had to clear up to 6 rows before the tractor could reach the fresh uncontacted area of the crop stand to use better soil conditions.

4.3 Topping

Decisive progress in topping quality appeared in the last decade (Micro-topping). Even an adjustment of the topping thickness was part of the kinematics of topping devices in earlier times in recent years the topping thickness increased with the size of the beet synonymic with the height of the beet which can be easily sensed by a mechanical feeler. Smaller beets are topped less and bigger beets need more topping to eliminate the petioles. Entirely less mass losses by topping are expected which is reflected by the field tests but can also be traced back to the higher adjustment of the toppers.

4.4 Lifting

Dominating lifting tools are the so-called Polder shares, characterized by self-aligning shared blades, low soil uptake, and applicable on a wide range of soils. Shakers moving the right and left wing of the polder share by an oscillating drive were introduced. This feature had become a regular kit of the lifting device except for wheel shares. Wheel shares became an innovation by suspension allowing lateral movement to adapt the share to the irregularities of the rows. Self-aligning wheel shares in addition need a positive slip to be free for lateral movement.

4.5 Chassis and engines

2004 a fully new harvester was presented by Grimme considering the high mass of the machine to be brought on the ground by rubber tracks with extended contact area as compared to wheel chassis.

Other manufacturers reacted to the challenge of higher mass of the machines and soil protection by different configurations of the chassis. Common to these solutions is to avoid multipathing by reverse tracking with crab steering. Even if all tires of the vehicles run in different lanes an overlapping of the tracks cannot be avoided. The limitation is given by the working width of maximum of 3 m (six rows) and tire width of 700 to 900 mm. For a two-axle vehicle with a tire width of 700 mm at the front axle tires and 900 mm at the rear axle tires the available width of harvested rows is exceeded by 6.7%, and for a three-axle harvester by 66%.

Characteristic of the wheel machines is all-wheel steering associated with an articulated central beam frame keeping the front of the vehicle in the direction of the rows.

Automated steering was introduced by row feelers mounted on the front end of the defoliation chopper, guiding the hydraulically served steering of the harvesters by adjusting the front and rear axle wheels. From the very beginning, the two- and three-axle harvesters were equipped with all-wheel-steering for better maneuverability.

Introducing electronics was a major driver of progress in the last decade for sugar beet harvesting machines. Apart from steering and engine control all setups of the machines are displayed on screens in the driver`s cab and offer a precise adjustment of the devices, e.g. angular speed of turbines, travel speed, topping height, etc. In recent years, management systems comprise data of harvesters, cleaner-loader, and logistics of beet haulage to optimize the entire process including just-in-time delivery of beets to the refinery. Apart from the management software telemetries are used to record machine data in operation and ease services to elicit defects and prepare the repair more efficiently from remote service stations.

For self-propelled machines using diesel engines are characterized by following the EU directives for clean exhaust gases. Coincidentally the engine power raised for 6-row harvesters from 195 kW in 1984 to 380 kW in 2012.

In the years the number of companies producing harvesters dropped from 15 in 1984 to 8 in 2012. The machines tested in these years decreases from 14 to 9.

4 Results

The review begins with the test in 1984 as this was the first test performed under the IIRB test standard and the following test results are comparable as they are based on a uniform method. The last test was in 2012, for 2020 a new test was already organized but cancelled due to corona pandemic restrictions. So far there is no prospect of another test organized by IIRB Study Group Agricultural Engineering in the event series of Beet Europe.

The results of the test were published contemporary in Brinkmann (1984), Kromer (1992, 1996), Kromer et al. (2000), Schulze Lammers and Rose (2005), Schulze Lammers et al. (2006); Schulze Lammers et al. (2013).

The evolution of the topping quality reflects the interests of the sugar producer requesting beets with no petioles and the desideration of the beet growers aiming at delivering entire tap roots including the crown. What is else, the processing of sugar beet with leaf attachments has been constantly improved by more effective processing causing fewer sugar losses in the refining.

Figure 7 presents the major categories of topping quality comprising of under and over as well as correctly topped. The other categories are skipped as the figure would become unclear and they are of minor relevance due to low shares in most cases.

The category under topped was around 40% until the implementation of micro-topping devices causing a strong decrease followed by a strong increase in 2006 and 2012. The reason for this trend is seen in the adjustment of the topping tools with low strength. Under the current topping technique and prevailing adjustment, the category of correctly topped reacts adversely to under topped beets. The test in 2004, 2006 and 2012 reflects this phenomenon and is explained by progress in the technique of topping along with preferred adjustment with low topping strength. Adding both categories (green line) summarizes the trend of minimizing beet mass losses due to strong topping aiming to deliver the whole beet mass to the factory.

The portion of over topped beets is below 10% and declined slightly from 1984 to 2012.

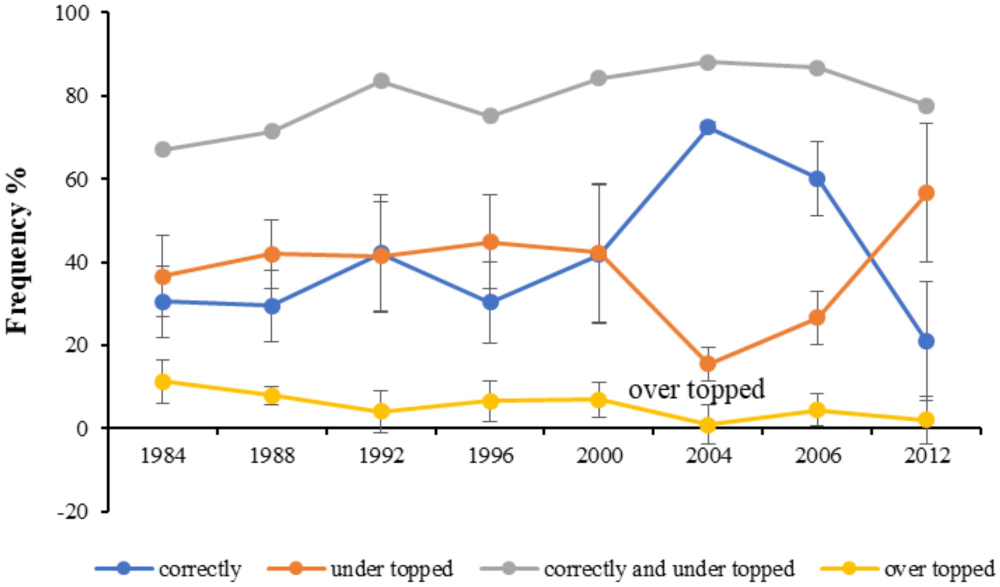

Figure 7 Topping quality with selected categories, Seligenstadt 1984 to 2012

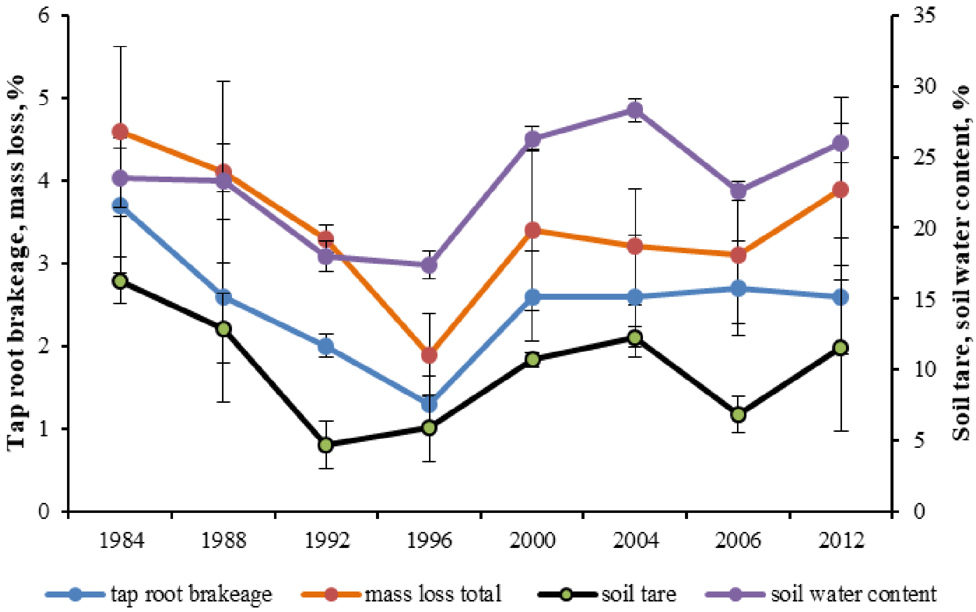

Figure 8 Soil tare, soil water content, mass losses, tap root brakeage, Seligenstadt 1984 to 2012

In summary, the main test items are displayed in Figure 8 compiling mass losses, tap root breakage, and soil tare associated with soil water content. In the diagram, the whiskers depict the minimum and maximum values of the tested machines. The graph outlines a decrease in mass losses (red line) until 1996 followed by higher losses since 2000 which can be explained by more intensive cleaning adjustment of the harvesters. Mass losses (between 1.9% and 4.6%) comprise not picked up beets or beet parts sub- and on-surface well as root breakage. The latter goes in parallel with mass losses as it is the dominant portion (between 1.3% and 3.7%) of mass losses in the harvest of sugar beet.

As the soil tare (between 4.7% and 16.3%) is dependent on soil water content, the test results vary accordingly. There was a positive trend for mass losses from 1984 to 1996, in the later tests the losses increased again which can be explained by more intensive cleaning adjustment of the harvesters. Over the period as a whole, the values decreased by ca. 30% which can be rated as a progress of the cleaning devices.

Superficial injuries have been recorded until 2000 and the assessment was terminated as the method is not adequate. Injuries of beets are still important as the wounded areas are inlet of macrobiotic deterioration. However, this area (1984: 1300 cm ²per 100 beets and 2000: 223 cm^2 per 100 beets) is small compared to the area induced by topping.

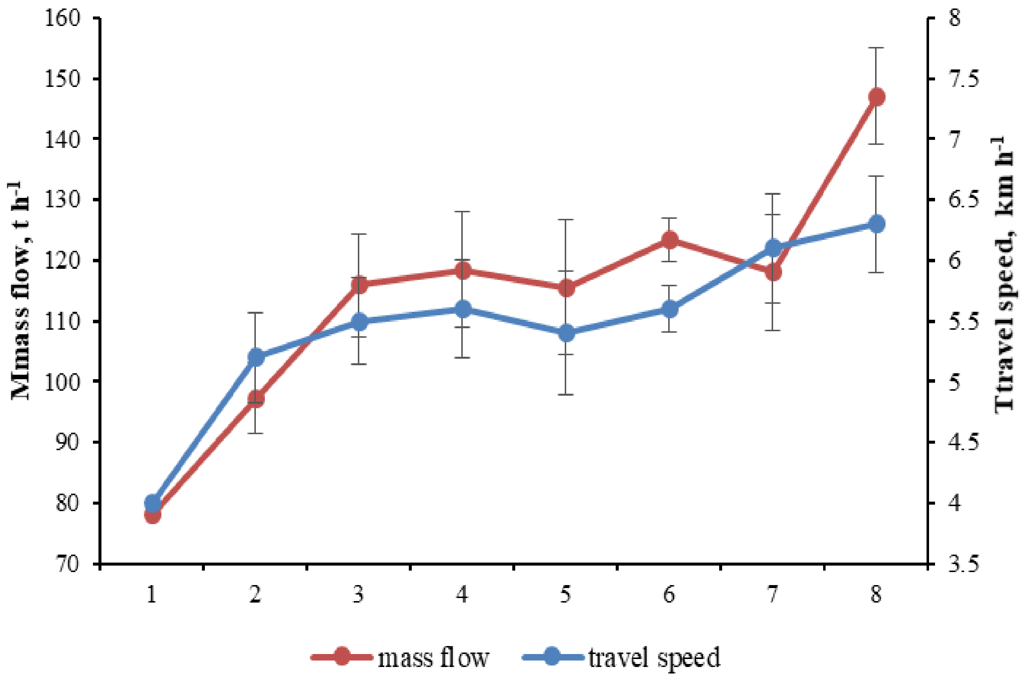

Figure 9 Working speed and mass flow, Seligenstadt 1984 to 2012

Both, the travel speed and mass flow of the six-row harvesters have been increased by 55% and 130% respectively. Considering the results in Figure 8 on quality of harvest, which do not exploit significant progress in mass losses, but in soil tare, the resume is that the harvest machines sustained the quality of harvested beet by a significant increase of mass flow which is an indicator of the machine`s capacity.

5 Discussion

In the test performed in 1994 by the Institute Technique de la Betterave up to 45% of under-topped beets for the French harvesters using uncomplex topping mechanisms appeared. It was reported that the soil transported from the field was on average 4.7 t ha^{-1}. The lowest mass losses originated from the 2-stage harvesting systems (2.9 t ha^{-1}). In a 2 years assessment of 5 6-row harvesters in 1995 and in 1996 in two locations in the Czech Republic and in Slovakia, the mass losses ranged from 2.1% to 8.1% as compared to Seligenstadt 1996 with 1.1% to 3.1%, and soil tare from 1.5% to 7.2% as compared to Seligenstadt 3.3% to 8.7% (Ružbarský et al., 1998). Šařec and Šařec (2000) compiling the results of harvester tests in 4 European countries stated no substantial difference in the mass losses of individual harvesters from different countries but two machines summed up to 11.2 t ha^{-1}. In Denmark in 2004 a comparative test of 2 6-row harvesters one with driven wheel shares and roller cleaning system (Grimme Maxtron) and a harvester with Polder shares and cleaning turbines (Kleine SF-10) was performed. As a result, superficial injuries were highlighted with 1.7% of bruised beets for the system with wheel shares and 3.4% with Polder shares (Bacher Pedersen, 2004). This result gives evidence for the termination of assessing superficial damage in the recent

Seligenstadt tests. In the test in Peterborough/UK (Schmittmann and Schulze Lammers, 2006) mass losses were determined by above-ground and root breakage losses totaling an average of 2.2 tha^{-1}. The Beet Europe 2010 test in Lelystadt (Tijing, 2010) showed soil tare from 8% to 22% with an average for the 6-row tankers of 13.3% which is in the range for the Seligenstadt test from 2004 under wet soil conditions with 12.3%.

6 Conclusions

The mass flow of beets in the machines has been increased due to higher yield of sugar beet induced by higher plant population and increased beet mass. Significant improvement was attained in cleaning of nearly 30% resulting in lower soil tare and reducing the mass losses by 18% whereas the highest portion originated from root tip breakage in the entire period. Topping underwent in the course of the years different regulations from the processing companies and due to higher precision of the topping devices the topping tends to become more accurate which means less than 3% over topped and nearly 80% correct or under topped beets resulting in less mass losses. The combination of the increase in mass flow as an indicator of the capacity of the harvesters together with improving the harvest quality highlights significant progress in the mechanization of sugar beet harvest since 1984.

Finally, it has to be stated that the test procedure is mainly a manual assessment requiring sufficient replications to generate reliable results but demands for huge manpower. Hence, new methods to assess the criteria are required e.g. by sensors or cameras with image processing and advanced testing equipment which even allows testing the harvest machines under changing conditions not only on one date and in one field condition.

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