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New principle of a mower-chipper for short rotation coppices

Currently commercial available mower-chipper for short rotation coppices (SRC) based on forage harvesters are very expensive in machine mass and investment costs. Tractor-based devices are limited due to technological applicability. Contributing to an extension of economical harvest technique, a novel principle of a tractor-based mower-chipper was developed. It is characterized by a simple construction and wide range of applicability.

Keywords
Short rotation coppices, mower-chipper, research version

Abstract
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Due to limited fossil energy resources, green house effect, and safety issues in nuclear power stations, the use of plant biomass as material as well as energy source is increasingly on the focus of public interest. Energy wood from farmland is a promising option for the sustainable production of biofuels in agriculture, and it may help to secure the income of farmers. Under European conditions fast growing wood types like poplar, willow, and robinia from short rotation coppice (SRC) offer substantial potential for the production of plant biomass. Hence, short rotation coppices have been planted on approx. 40,000 ha in Europe, of which approx. 4,700 ha [1] are in Germany. Research has established that an extension of farmland for wood production still encounters some problems. It was determined that, dependent on the biomass yields and the production technology, 35–60 % of the total costs are related to harvest [2; 3; 4]. In order to facilitate machine harvest of short rotation coppices several technological approaches were introduced in the past 30 years. Many of these, however, have not survived the prototype stage.

Currently available technology

An analysis of the current state of the harvesting technology for short rotation coppices shows that there are basically four groups of technological lines:

- the log line
- the bundle line
- the chip line
- the bale line

For evaluation of the single lines, numerous publications were made in the past, which besides analyses of benefits and drawbacks also compared process costs and achieved harvest yields [5; 6; 7; 8; 9; 10; 11]. Summarizing this it can be concluded that high investment costs for harvesting technology, low flexibility in adapting to harvesting conditions, as well as high machine weights on the soft soil of the plantation are the main problems. With respect to few process steps and low harvesting costs, the chip line with mower chippers is considered to be beneficial. In this process, the mowing, chipping, and discharge of the chips to a transport vehicle are facilitated with one machine without stop driving. If machines of this type can meet the specific requirements with regard to chipping quality there are no further process steps necessary for preparation to energy utilization. Due to these benefits, this paper focuses on the analysis of the development status of mower-chippers.

The mower-chippers for harvesting short rotation coppices can be specified in three groups:

- mower-chippers on adapted base machine
- mower-chipper based on forage harvesters
- mower-chippers as tractor with auxiliary devices

Mower-chippers on adapted base machines feature specific mowing and chipping tools mounted on existing self-propelled machines or their units. They have existed mainly as research models and prototypes and shall, therefore, not be considered more closely in this paper.

Mower-chippers based on forage harvesters are mainly used for harvesting SRC areas, thus they have the highest relevance at present. These machines consist of a special mowing unit and the base machine of a high performance forage harvester. Renowned manufacturers like Claas, John Deere, Krone, or New Holland offer such solutions to expand the application range and the annual runtime of their forage harvesters. Although this harvesting technology facilitates high area capacity; average investment costs are with approx. 420,000 € fairly expensive and machine weights of approx. 15 t are fairly high. An annual harvesting area of at least 300 ha is required for economic utilization [12].

Mower-chippers as tractor-driven units are a cost-efficient alternative compared to forage harvesters based solutions (**Table 1**). These units feature machine weights of 0.9 to 3.5 t and

Table 1

Table 1: Commercial available mower-chippers for tractors for harvest in SRCs

Maschinenbezeichnung ***Name of machine***	**Masse/*Mass*** **[kg]**	**Preis/*Price*** **[€]**	**Reihenanordnung/max. Stammdurchmesser** ***Arrangement of rows/max. diameter of trunks***
Jenz/Schmidt GMHT 140	3,500	85,000	Für Einzel- und Doppelreihen *For single and double rows* 140 mm
NYVRAA JF 192	900	21,000	Einzelreihen/*Single rows* 50-60 mm
NYVRAA JF Z20	1,500	28,000	Doppelreihen/*Double rows* 30-40 mm
EBF Dresden	3,500	>100,000	Doppelreihen/*Double rows* 170 mm
Erforderliche Standardtraktoren *Needed standard tractors* 75-200 kW	6,000–8,000	75,000–150,000	

can be operated with medium to high performance range standard tractors. Tractor weights range from 6 to 8 t, sometimes in excess of that. Altogether, these tractor based machines range at approx. 50 % of the investment costs and machine weights compared to forage harvester based solutions.

Evaluating the available mower-chippers with respect to experience in use, it can be concluded that further research and development efforts are required to provide farmers and service providers with improved, cost-efficient harvesting technology for SRCs. For this reason, the principle of a simple and cost-efficient mower-chipper economically operable by medium to high performance range tractors was developed at the Leibniz Institute for Agricultural Engineering Potsdam-Bornim e.V. (ATB).

The following requirements were specified:

- Option of universal mounting on standard tractors (front, rear, and side mounting)
- Suitability for harvesting poplar, willow, and robinia in single-row plantations
- Harvest of SRCs up to a stem diameter of 15 cm
- Low specific energy input
- Variable chipping length up to 100 mm (coarse chips)
- Trees remain upright during mowing and chipping process
- Benchmark for machine weight of mower-chipper unit: 1,000 kg

Based on the analysis of existing literature and own experience with mower-chippers ATB pursued new, not yet introduced approaches. Generally envisioned was a simple and cost-efficient unit with applicability to existing base technology in agriculture and forestry companies, i.e. standard tractors.

Trend-setting was a mower-chipper developed by the University Goettingen [13; 14], which could be operated on standard tractors in front mounted configuration. While driving, the unit cut the vertically growing trees and shoots with a circular saw blade (diameter: 1,000 mm) and chipped them using a tapered auger. The circular saw as well as the auger was installed as a compact unit on a common, nearly vertically positioned rotation shaft. Due to the high rotation speed of approx. 1,000 min^{-1} and respectively arranged discharger elements the transport vehicles could be supplied via a discharge chute without deploying additional discharge boosters. One of these units was used, inter alia, for harvesting of an SRC with willow and poplar established at ATB in 1994. When operating this unit, it appeared that guiding and grabbing of the cut trees and shoots as well as the feeding into the auger caused problems. Moreover, frequent jamming occurred in the discharge chute and fairly varying chaff lengths added to the jamming tendencies. The power demand was increasing with progressing reduced sharpness of the cutting edge of the auger, while the quality of the chips was decreasing.

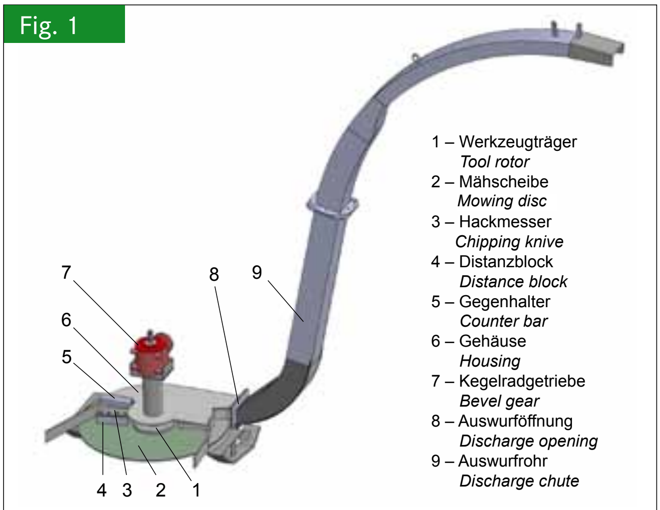
A new principle for a mower-chipper was developed step-by-step from 2009-2011 at ATB, applying own experience, understanding gained from machine presentations, and results collected with the auger chipper. This principle shall be introduced in the following.

The functional principle

The mowing-chipping unit

The mowing-chipping unit as a central unit consists of a tool rotor (1) in form of a rotor with nearly vertical rotation axis (**Figure 1**). In the lower section this tool rotor is designed to be mounted with a circular mowing disc (2), featuring saw teeth at its rim. On this disc, chipper knifes are arranged nearly radially (3) with distance blocks arranged below (4), limiting the length of the chips. By the sawing momentum of the disc and in correlation with forward movement the trees are cut just above surface level. Immediately after the mowing, the cut off tree is conveyed by the conveying momentum of the chipper knife with distance block in direction of the counter bar (5), and sheared there. The generated chips are now moved by the chipping knife with distance block - acting together like a throwing paddle wheel - due to centrifugal forces towards the housing edge (6) until, after a swivelling angle of approx. 90°, they are

Fig. 1



Principle of the mower-chipper-unit

Fig. 2

Technical solutions for supporting the material adoption

discharged through the discharge opening in the housing (8). Since the tool rotor is operated with a nominal rotation speed of 1,000 min^{-1}, the chips leave the discharge opening with a speed of approx. 40 ms^{-1} in direction of the discharger chute (9). Other than in conventional choppers in forestry and agriculture, this solution features not only a single material stream deflection by 90°, but two material stream deflections by nearly 90° each. The cross section width of the discharge chute is 175 x 175 mm.

The grabber unit

During the tests of the unit it occurred that the cut trees fell sidewise and forward, and could not be chipped by the chipper knifes. Moreover, it became apparent that without additional modification the mower-chipper unit could not facilitate the feeding of the trees until their complete chipping. Particularly effective feeding of tree crowns as well as bigger branches appeared to be problematic.

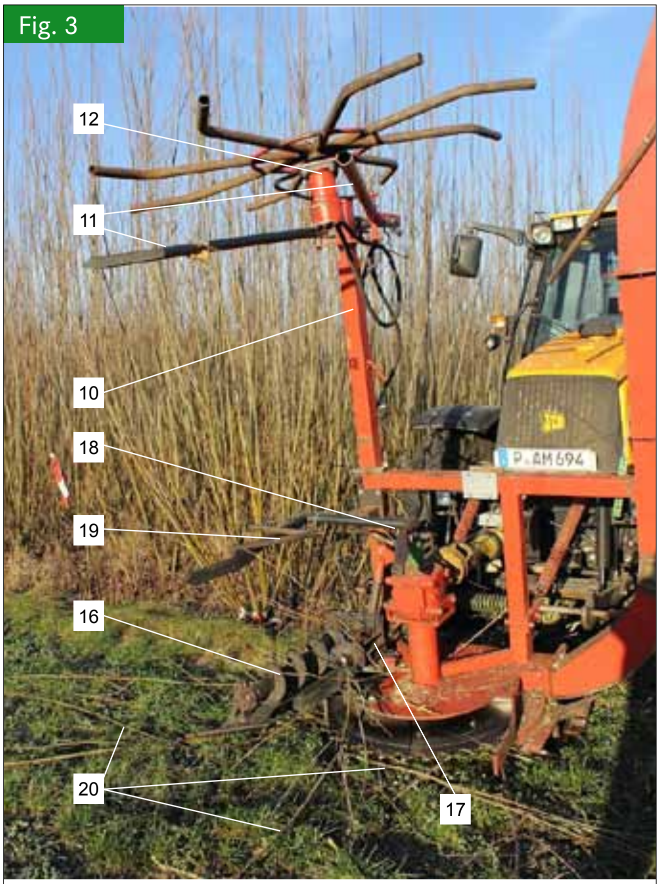
A telescopic mast (10) made from square tube was installed to prevent the cut trees from falling (**Figure 2**). In a first design this was just equipped with V-shaped extension arms (11), which prevented the sidewise falling of the cut trees. These extension arms, however, could not prevent the trees from falling forward. Therefore, to enhance the stabilisation capacity, both extension arms were additionally fitted with star wheels. In one arrangement, clamp roller freewheels were used, which on the one hand facilitated the turning of the star wheels on contact with the trees and the forward movement of the mower-chipper, but on the other hand should prevent the forward falling by the clamps blocking in opposite direction. Tests showed that the conveying momentum of the passively moving star wheels was not sufficient to hold the cut trees safely in the vertical position. In a second arrangement both star wheels were powered by two hydraulic orbital motors to enhance the conveying momentum of the star wheels. This significantly improved the feeding effect. However, it occurred that the right forward star wheel entangled in the remaining adjacent row in double row SRCs and single row SRCs with low row clearance. To avoid this, the respective star wheel was removed and the extension arm was fitted with an arrestor hook preventing the forward falling of the cut trees (**Figure 3**). The described arrangement, consisting of a telescopic mast, extension arms and star wheels (12) provided for holding the cut trees in upright position to subsequently feed them in vertical direction towards the chipper knives.

The feeder unit

Despite this receiving arrangement, secure feeding of the cut wood to the chipper knives could not be facilitated by the applying gravity alone. Therefore, a solution had to be found that would render the horizontal movement of the cut wood into a vertical forward motion. This proved to be the most complicated challenge in developing the new mower-chipper principle.

A first solution variant to support the vertical forward movement was the arrangement of an auger (13) with vertical rotation axis above the counter bracket. Since the respective feeding power was not sufficient, a second counter-rotating auger (14) was installed (**Figure 2**). This variant did not provide for the required feeding power either. Another variant consisted of a hydraulically powered spiked roller (15) with horizontal rotation axis, arranged directly above the counter bar (**Figure 4**). This was supposed to cause the chipping force to press the stem and branches in the spikes and consequently generate the necessary forward motion. A certain forward motion effect could be observed, which was frequently interrupted though, since stems and branches rebounded in the chipping process and thus moved off the grip of the spikes.

Fig. 3

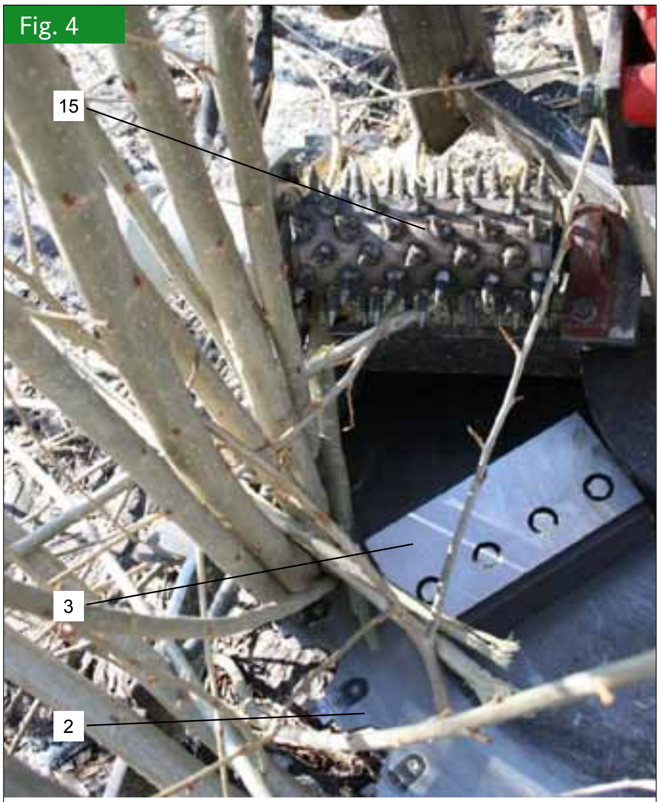


Arrangement of elements for uptake and feeding of material

After realizing that an absolutely forced feeding of the material to be chipped was inevitable, a hydraulically powered pair of rollers was arranged in the area of the counter bar (**Figure 3**). The outer roller (16) was mounted in a fixed position while the inner roller was mounted on a rocker (17). The rocker was fitted with a load adjustable spring, to generate a defined contact pressure. To facilitate reception of the cut tree between these vertical feeding rollers, a screw shaped coil made from round steel rods was welded to the heeling rollers, providing for the opening of a gap between both the feeding rollers. With this solution both the horizontal feeding of the tree between the feeding rollers as well as the vertical forward motion could be realized. To improve the feeding momentum of the roller pair, the outer roller was extended with a robust auger (16) instead of the steel rod coil. The auger is arranged before the roller on the same rotation shaft and with the same outer diameter, so in the first stage the cut trees are force-fed through the auger colds of the roller (**Figure 3**).

During testing it was observed that the material to be chipped was not sufficiently guided after leaving the area between the extension arms. In order to improve the guiding of the material below the extension arms, an additional guiding arrangement was installed above the feeding rollers (**Figure 3**). This guiding arrangement consists of a u-shaped tubular frame (18) with a catcher (19) that is opened by the pressure of the fed-in trees. After the tree has passed the catcher, it snaps shut again building a nearly closed guiding frame that prevents the material to be chipped from falling.

Fig. 4



Roller with spikes for feeding of material

Conclusions

The research model mower-chipper unit for tractors with the technical data as outlined in **Table 2** was tested in various SRCs in Germany. It has been proved advantageous to position the trees nearly vertically during mowing and chipping. Breaking and uprooting of trees could be avoided, since unlike in most other solutions; the trees are not bent in forward direction during the mowing. The stumps showed clear cut surfaces and insignificant roughness. In the test mowing campaigns, poplars with heights of up to 10 m and diameters of up to 15 cm were harvested. Since only two chipper knives and distance blocks, resulting in a clearance of the knife edges of 75 mm above disc, were used in test harvest, relatively long chips were generated. Exact vertical alignment of the material to be chipped is critical for the proportion of excess length. Keeping vertical the stems of tall and strong trees in the receiver arrangement and thus generating chips without excess lengths is usually not a problem. However, receiving shorter and thinner rods or branches at the chipper knives may cause the risk of the material loosing its vertical alignment, getting into bank attitude (20) (**Figure 3**). The result is excess length of chips which may lead to problems in subsequent feeding and dosing processes (e.g. in heating plants). Hence, improvements must be made in the future by respective design of feeding rollers or by additional measures to guide in the material.

Table 2

Table 2: Technical data for the mower-chipper (ATB-research version)

Parameter/*Parameter*	**Wert/*Value***
Ausführungsform *Basic type*	Traktoranbaugerät (Frontanbau) *Tractor front mounted*
Eigenmasse *Weight*	approx. 600 kg
Durchmesser der Mähscheibe *Diameter of mowing disc*	1,020 mm
Drehzahl des Werkzeugträgers *Rotation speed of tool rotor*	1,000 min^{-1}
Anzahl der Zähne *Number of teeth*	34
Gesamt-Antriebsleistungsbedarf *Total power consumption*	> 75 kW
Max. Stammdurchmesser *Max. diameter of trunks*	15 cm
Fahrgeschwindigkeit im Hackvorgang[1)] *Ground speed while chipping[1)]*	3 … 5 kmh^{-1}
Spezifischer Energieaufwand[1)] *Specific energy consumption[1)]*	3 … 5 kWh · tTM^{-1}

[1)] Ermittelt in 2- und 4-jährigen Pappelbeständen/*estimated in 2- and 4-years old poplars*.

From the machine weight of the research model of only 600 kg it can be concluded that it was not designed for permanent service in praxis, but only served as research model for the development of a new harvesting principle. A unit for permanent service in praxis conditions requires a machine weight of approx. 1–1.5 t.

Based on the convincing unit parameters and the achieved application results of the research model first steps have been undertaken to have the mower-chipper integrated in the product range of a MSE in the future.

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