Agronomy Research **12**(1), 151–160, 2014

Efficient harvest lines for Short Rotation Coppices (SRC) in Agriculture and Agroforestry

R. Pecenka*, D. Ehlert and H. Lenz

Leibniz Institute for Agricultural Engineering Potsdam-Bornim (ATB), Max-Eyth-Allee 100, 14469 Potsdam, Germany; *Correspondence: rpecenka@atb-potsdam.de

Abstract. Wood from short rotation coppice (SRC) such as poplar, willow and black locust is a promising option for the sustainable production of biofuels and biomaterials. Provided that production technologies, logistic chains and end user structures are well designed in farmers' regional structures, these cropping systems may provide a secure source of income. One of the key problems at present is the lack of knowledge and powerful harvest machinery at practice. Although a lot of machines were developed and tested during the last 30 years, only a few have exceeded the prototype stage. Analysing the process chain for SRC, chip lines seem to be most cost-efficient for harvest, and the modification of forage harvesters for SRC is a promising option. But the high machine weight of forage harvesters is a serious disadvantage due to the limited trafficability of harvest plots in winter. Furthermore, for economic operation of these expensive harvest systems cultivation areas of more than 300 ha are required.
Therefore, ATB has developed a simple and low weight tractor-mounted mower-chipper for medium sized standard tractors (75–150 kW) together with the company JENZ (Germany). The chipper is designed for flexible harvest of wood from SRC and Agroforestry (max. stem diameter 15 cm). The total weight of the harvester (tractor and chipper) is less than 50% of the forage harvester combination resulting in much more flexible field operation and lower harvest costs. The machine has been successfully tested in the last two harvest seasons and is on the market available now.

Key words: Short rotation coppice, poplar, willow, harvest, mower-chipper, wood chips.

INTRODUCTION

Resulting from limited fossil energy resources, global warming, and safety problems in nuclear power stations, the material and energetic use of plant biomass comes more and more in the focus of public interest. Energy wood from farmland is a promising option for sustainable production of biofuels in agriculture and it may help to secure the income of farmers. Therefore, cultivation of fast growing trees (short rotation coppice – SRC), such as poplars (*Populus sp.*), willow (*Salix viminalis*), and black locust (*Robinia pseudoacacia L.*) is of increasing interest. In many European countries SRC plantations are introduced in common agricultural praxis. The cultivation area in Germany has been increased in the last five years from 2,000 ha to approx. 10,000 ha in year 2013 (Schütte, 2010; FNR, 2014). Analysing the current situation in the management of SRCs, several problems in cultivation and mechanization can be observed. In dependence to yield and cropping technology, harvesting cost is estimated to be 35 to 60% of the total costs of biomass production from SRC (Heiß, 2005; Bach, 2007; Scholz, 2007; Spinelli et al., 2009; Schweier & Becker, 2012a; Schweier & Becker, 2012b). Consequently, the optimization of harvest technologies is a prerequisite for the successful expansion of SRC plantations. Despite of more than 30 years of praxis experiences in several European countries, there is a lack of knowledge as well as efficient technical solutions for economic cropping of poplar, willow and black locust. A lot of machines were developed and tested during the last decades, but only a few have exceeded the prototype stage (Scholz et al., 2008).

Current status of harvesting technology

Basically, the existing harvest technology can be classified into the four groups: *Log Lines, Bundle Lines, Chip lines* and Bale Lines (Fig. 1). Numerous publications can be found about all these harvesting technologies in the last decades (Stokes & Hartsough, 1994; Hartsough & Stokes 1997; Scholz et al., 2008; Abrahamson et al., 2010; Schweier & Becker, 2012a; Schweier & Becker, 2012b, Savoie et al., 2012). Advantages and disadvantages, costs and harvest capacities were presented and discussed. Analysing the process chain in SRCs, it can be concluded that the high investment costs for suitable harvest equipment, low flexibility regarding tree variety and cultivation scenario as well as high machine weight accompanied by problems during harvest and low capacities are some of the most important obstructions at present.

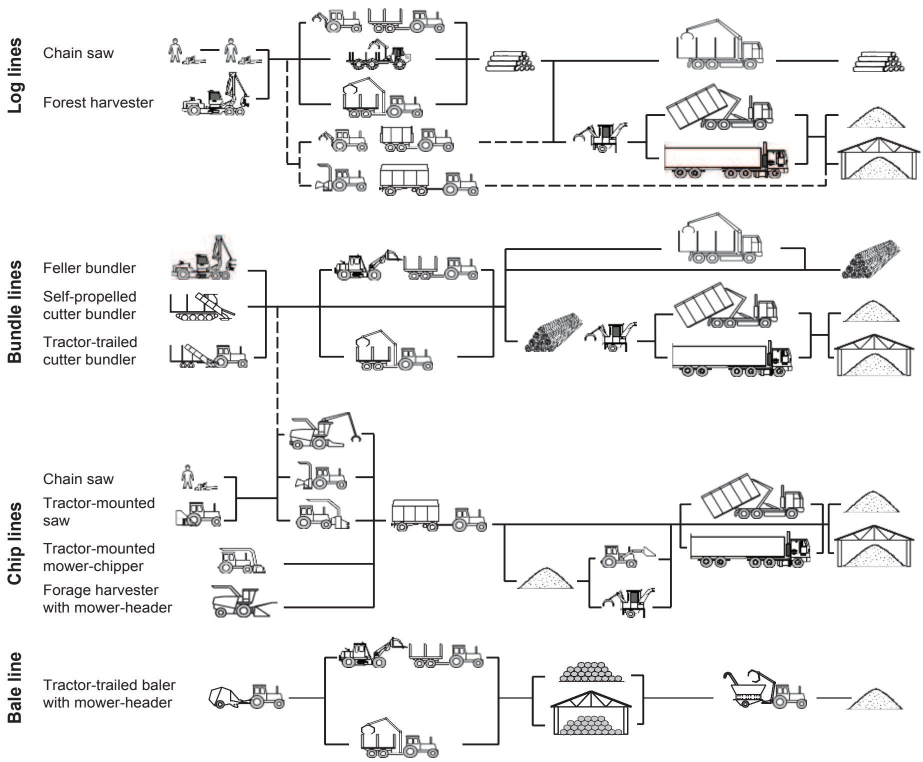

Figure 1. Systematics of harvest and post-harvest technologies for short rotation coppices.

Table 1. Forage harvester-based mower-chippers for SRC

Basic vehicles/ recommended power (KW)	Mower-feeder	Mass (kg) Harvester/ mower	Price (€) Harvester/ mower	Cutting width (mm)	Max. stem diameter (mm)
Class Jaguar 900-830 / 255	Salix HS2	11,000/1,200	337,000/98,000	1000	80
Krone Big X / 380	Woodcut	14,000/2,800	353,000/89,500	1500	< 150
New Holland FR 9000 / 450	130 FB	12,900/2,100	327,000/124,000	Double row with 750 mm distance	150
John Deere 7050 / 350	CRL	14,000/1,500	260,000/95,000	Double row row 750 mm distance	100
Mean value		Mass: 14,870	Price: 420,880		

As shown in Table 1, the mass of basic forage harvester vehicles range from 11 to 14 t. Together with the header units, a forage harvester equipped for SRC averages approximately 15 t in total mass and costs approximately 420,000 €. In addition, for the economic operation of these highly productive harvest systems, cultivation areas of more than 300 ha are required (Scholz et al., 2009), if the harvester is used for SRC cropping alone. The required minimum acreage will be reduced, if the harvester is used for forage during summer. But the reduction will be small taking into account that a high-power forager is necessary to realize satisfying working speeds at harvest of SRC, forest tires are indispensable to avoid damages, a enforced chipping drum is recommended and the cost of the SRC header alone is approximately 100,000 €.

Another group of mower-chippers is based on the use of common agricultural tractors (Table 2). These machines are mounted in front or at the back of the tractor. The required tractor power is up to 400 kW (KWF 2013). Most of these chippers also use a push bar to bend the trees and bring them in a horizontal position before chipping. Only a few developments have focused on harvest and chipping with mower-chippers of trees from SRC in an upright position (Stuart et al., 1983; Wieneke, 1993; Döhrer, 1995). In contrast to forage harvester-based solutions, the cutting unit (drum, cone or disc) is integrated in the tractor-mounted machine. To provide the required power and efficiency, the chipping units are mostly PTO driven. To drive the mowing and feeding units (screws, rollers or rotors), numerous hydraulic components, such as pumps, motors, valves, lines and oil tanks, are necessary. All these mechanical and hydraulic parts add up to machine masses from about 1 to 4 t. Together with the suitable basic tractor the complete harvesting unit can vary in mass and price over a wide range (Table 2). It should be noted that the maximum trunk diameter is very different for the various models. According to the working principle, e.g. the JF harvesters from NY VRAA are limited to 6 cm. Therefore, only willows with an age of 2 or 3 years can be harvested.

Table 2. Tractor-mounted mower-chippers for harvest in SRC

Machine	Mass (kg)	Price (€)	Field layout/ max. stem diameter
JENZ GMHT 140	3,500	85,000	Single or double row (1,400) / 140 mm
NYVRAA JF 192	900	21,000	Single row / 50–60 mm
NYVRAA JF Z20	1,500	28,000	Double row / 30–40 m
EBF Dresden	3,500	> 100,000	170 mm
SPAPPERI model RT	1,800	unknown	Double row / 180 mm
Required standard tractors 75–400 kW	6,000–10,000	75,000–200,000	

A few other prototypes of mower-chippers have been developed using the chassis from self-propelled vehicles or tractors without a standardised three-point linkage. In 1986, a Gandini forage harvester prototype was designed for black locust and poplar plantations, but due to several technical problems the project was terminated in 1994 (Hartsough & Yomogida, 1996). In 1994, Salix Maskiner presented a concept of a special mower-chipper for willow named the Bender (Baldini & Di Fulvio, 2009), and an enhanced version, the Bender 5, has been offered. The Austoft 7700/240 is an Australian harvester for sugar cane adapted for willow harvest (Hartsough & Yomogida, 1996; Kofman, 2012). The BR 600 biomass harvester, based on a self-propelled crawler tractor, has been presented by Plaisance Equipment (PLAISANCE 2013).

Based on the analyses of the current status of harvesting equipment for SRC, the following can be concluded:

- High harvest costs are one of the most limiting factors for increasing SRC acreage in Europe;
- There is no universal low-cost harvester for SRC available at a practical scale. Such harvester should be flexible regarding variety (poplar, willow, and black locust), tree size (stem diameter 2–15 cm), and field conditions (e.g., small fields, difficult soil conditions);
- A new principle for low-cost mower-chippers should be developed to support and increase the production of biomass in SRC.

DEVELOPMENT OF A TRACTOR-MOUNTED MOWER-CHIPPER

Basic requirements

Due to the unsatisfactory situation in SRC harvesting technology, a research project was initiated at the Leibniz Institute for Agricultural Engineering, Potsdam-Bornim, Germany (ATB) to develop a simple and low weight universal mower-chipper for stem diameters at base up to 15 cm. The mass of the unit should be less than 1,000 kg, and it should be mounted in front of medium-sized standard tractors (75–150 kW). To avoid problems with uprooting or breaking of trees while mowing and chipping, the stem should remain in the upright position. Based on own harvest experiences and especially serious problems during harvest of older double row plantations of poplar in Germany it has been decided to develop a unit for harvest of single row plantations only (Ehlert & Pecenka, 2013). For economic and trouble-free harvesting from a long-term perspective, only single-row SRC should be established in the future.

For the systematic development of a new working principle for a tractor-mounted mower-chipper, the following four main features must be realised:

- Simple and robust design of the mower-chipper unit;
- Simple and safe feeding of the mower-chipper with trees of different sizes;
- Avoid felling the trees in a horizontal position before chipping;
- Simple and sure conveying of the chips to the transport units.

Development of a simple and robust mower-chipper unit

The basic idea for the new mower chipper unit is shown in Fig. 2. To minimise the number of powered parts, the functions of mowing, chipping and conveying of chipped material were realised by a compact and simple unit (tool rotor) rotating in a robust housing. For tree mowing, the tool rotor of the prototype is designed as a disc saw with an outer diameter of 1,000 mm. For chipping of the severed stems, knives set on spacer blocks are installed on the upper side of the disk saw. Contrary to most mowing disks in other harvesters, the tool rotor is solid rather than slotted, thus avoiding chips falling on the ground of the field. As a result of this arrangement, the theoretical maximum chip length is limited by the sum of the height of the spacer block and the chipping knife. For an optimal chipping process, a counter bar is installed on the housing. After chipping, the comminuted material is accelerated and moved to the outer edge of the housing at a rotation speed of 1,000 rpm towards the discharge opening.

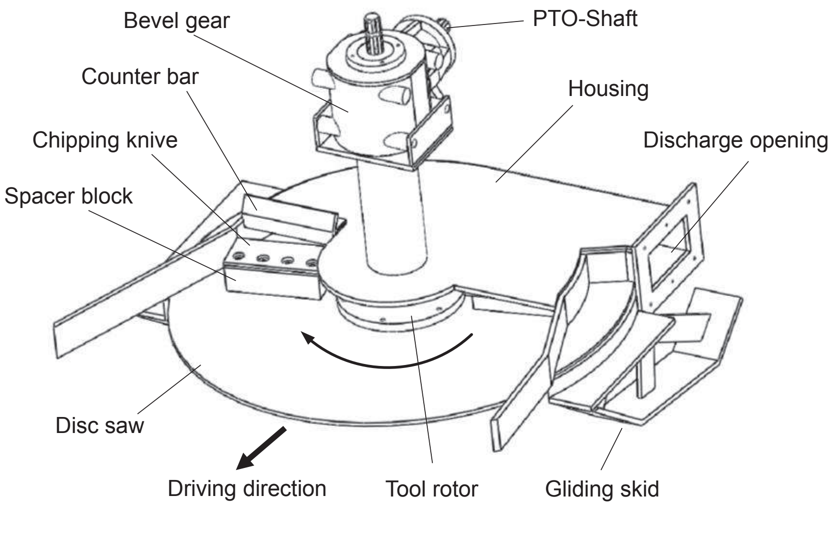

Figure 2. Principle of the ATB mower-chipper unit.

Development of the periphery for safe feeding of trees in upright position and conveying of chips to transport vehicles

The development of a means for failure-free feeding of the mower-chipper unit proved to be the most complicated task. Finally, safe feeding of trees with diameters of up to 150 mm can be realised by a combination of a fixed feeding auger and a spring loaded counter roller (Fig. 3). The field tests showed that trees after mowing sometimes fell ahead and sideways into horizontal positions, resulting in significant yield losses and poor chip quality (over length). To reduce these problems, the trees must be fixed before mowing. SRC trees can grow up to 10 m and more; therefore, they must be supported above their centre of gravity, which can be realised by using a telescoped mast with additional guiding elements. The best guiding and conveying effect was achieved during the tests with the combination of an active hydraulically driven star-wheel and a guiding arm with a barb.

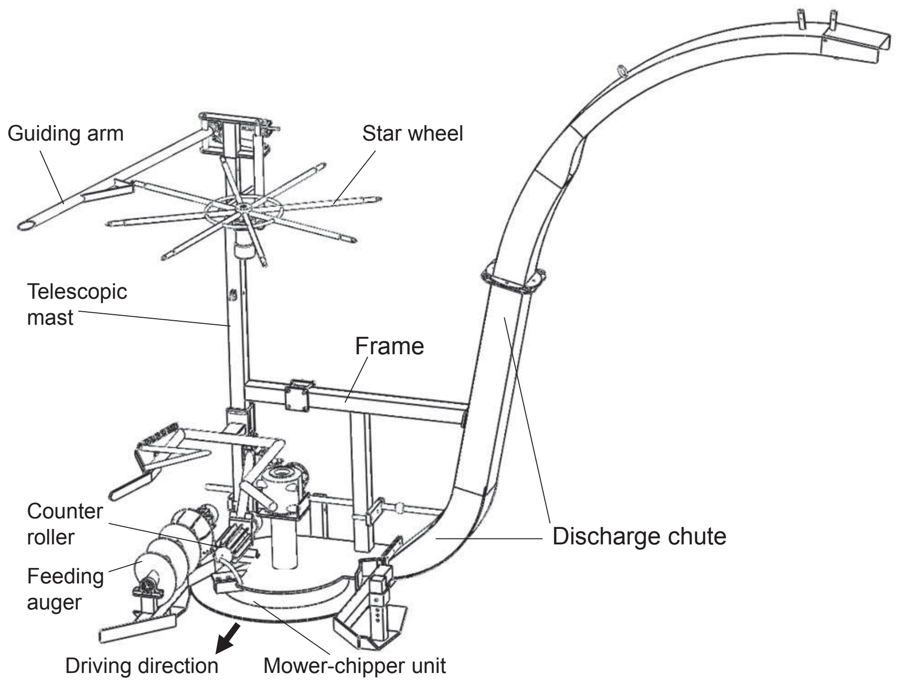

Figure 3. Principle of the ATB mower-chipper unit.

As shown in Fig. 2, the chips of the cutter-chipper unit are thrown off horizontally via the discharge opening. As a result, the material has to be deflected two times for nearby 180°for filling transport units. Tests under real conditions were performed to assess the conveying features of such a discharge shoot with two arcs (Fig. 3). The test results were surprisingly good. In spite of both arcs and a spout cross section area of only 175x175 mm blockages in the discharge shoot were not observed.

RESULTS AND DISCUSSION

The field tests have shown that the basic working principle of mowing and chipping trees in an upright position has significant advantages. The breaking and uprooting of trees during cutting can be completely avoided. The stumps showed a clear cut surface after mowing with the circular saw.

The weight of the complete tractor-mounted mower-chipper, tested until March 2013, was about 600 kg (Fig. 4). Tests performed in SRC with poplars and willows demonstrated the high potential of the new concept as a low cost mower-chipper for practical use on farms. The tool rotor was equipped with only one pair of knives for chipping during the tests. According to the height of the spacer blocks and chipping knives, the theoretical maximum length of the chips was 80 mm. Trees with base diameters of up to 15 cm and a height of 10 m were harvested during the tests. As shown in Fig. 5, the chips had a good quality for later drying during storage and firing in large-scale heating plants. Fig. 6 shows a comparison of coarse chips produced with the novel mower-chipper and typical fine chips produced with a forage harvester. If shorter chips similar to fine chips from forage harvesters have to be produced by the mower-chipper, the height of the spacer blocks can be reduced as well as the number of knifes can be increased.

Figure 4. ATB mower-chipper at harvest of poplar (2013).

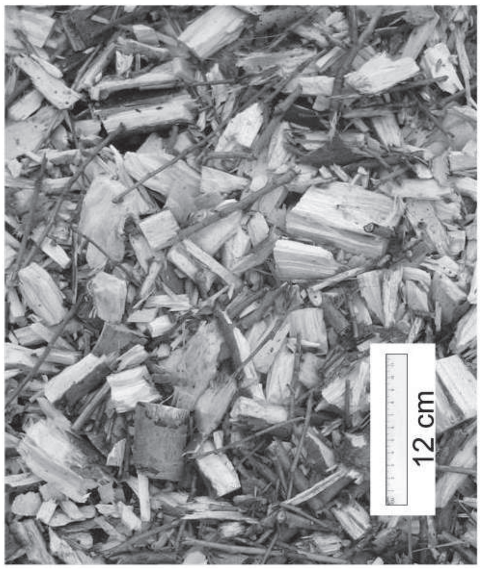

Figure 5. Example of wood chips from poplar harvested with the prototype.

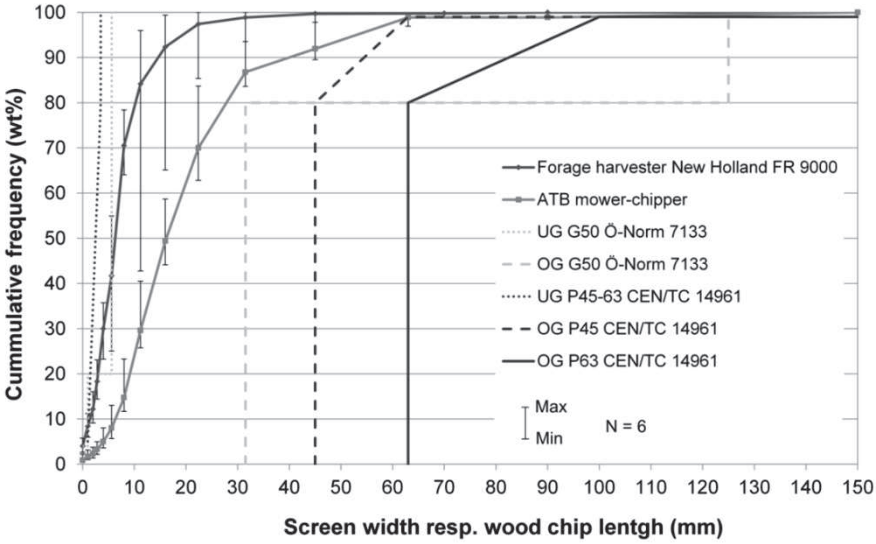

Figure 6. Particle size distributions of wood chips from poplar produced with different harvesters in 2013: Forage harvester New Holland FR 9000 … fine chips P 45/G30; ATB tractor-mounted mower-chipper … coarse chips P 45/G50.

The estimated economic advantages of tractor-mounted mower-chippers in comparison to forage harvesters presented in earlier studies (Ehlert & Pecenka, 2013) were based on effective speeds at harvest of approx. 3 km h^{-1}, versus effective harvest capacities of 0.4 to 0.8 ha h^{-1}. As shown in Table 3, effective speeds of 3 to 5 km h^{-1} were realized with the test unit. The tests were very promising for the future exploitation of the economic advantages of tractor-mounted mower-chippers in practice. Moreover, the full capacity of the mower-chipper unit couldn't be used completely during the field test because of the limited power of the tractor with 110 kW only.

Table 3. Technical data of the mower-chipper (prototype)

Machine parameter	Details
Embodiment	Tractor-mounted at front
Total mass	approx. 600 kg
Mower disk diameter	1020 mm
Tool rotor speed	1000 rev·min^{-1}
Number of teeth of the mower disk	34
Total power requirement	> 75 kW
Max. hydraulic pressure	180 bar
Hydraulic flow rate	45 l min^{-1}
Max. stem diameter	15 cm
Driving speed during chipping*	3–5 km h^{-1}
Specific energy demand*	3–5 kWh $t^{-1}{}_{d.m.}$

* measured at harvest of two and four years old poplars.

Based on these tests, important conclusions for enhancements of the investigated research machine to a prototype for tests at the practice scale were made. A commercial model of this mower-chipper is available since winter 2013/2014 (company JENZ - Germany, model: GMHS 100, Fig. 7).

Figure 7. JENZ Mower-chipper GMHS 100.

REFERENCES

Abrahamson, L.P., Volk, T.A., Castellano, P., Foster, C. & Posselius, J. 2010. Development of a Harvesting System for Short Rotation Willow & Hybrid Poplar Biomass Crops. *SRWCOWG MEETING*, Syracuse – NY, USA.

Bach, H. 2007. Willow Production and marketing in Denmark. *Bornimer Agrartechnische Berichte* **61**, 152–157.

Baldini, S. & Fulvio, D. 2009. Short Rotation Forestry: Mechanization for the conditions of Italy. *Mondo Macchina* **18**, 36–43 (in Italian).

Döhrer, K. 1995. Harvest technique for wood fields. *Die Holzzucht* **49**, 15–17 (in German).

Ehlert, D. & Pecenka, R. 2013. Harvesters for short rotation coppice: Current status and new solutions. *International Journal of Forest Engineering* **24**, 170–182.

FNR 2014. Fachagentur für Nachwachsende Rohstoffe – Cultivation area of renewable resources 2013. http://mediathek.fnr.de/grafiken/anbauflache-fur-nachwachsende-rohstoffe-2013-grafik.html. 31.01.2014.

Hartsough, B.R. & Stokes, B.J. 1997. Short rotation forestry harvesting–systems and costs. In Proceedings of the *1997 International Energy Agency: Bioenergy task 7, activity 2.1 and activity 4.3 workshop*, Melrose, (GB).

Hartsough, B.R. & Yomogida, D. 1996. Compilation of state-of-the-art mechanisation technologies for short-rotation woody crop production. *Research Report*, University of California, Biological and Agriculture Engineering Department, Davis (US).

Heiß, M. 2005. Auf Achievable gross margins from SRC in Austria. In Proceedings of the *Fachtagung Energieholzbereitstellung*, Wieselburg, AT (in German).

Kofman, P. 2012. Harvesting Short Rotation Coppice Willow. *COFORD Harvesting/Transport* **29**, 1–6.

KWF. 2013. Think first than invest, KWF- market overview for harvest technique for SRC. Groß-Umstadt: Kuratorium für Waldarbeit und Forsttechnik e.V., http://www.kwf-

online.org/fileadmin/dokumente/Bioenergie/Dokumente/Kup-Ernter_2011.pdf. 22.05.2013.
PLAISANCE: mulchers, broyeur-récupérateur. Plaisance Equipments. http://www.plaisance-equipements.com. 22.05.2013
Savoie, P., Current, D., Robert, F.S. & Hébert, P.L. 2012. Harvest of natural shrubs with a biobaler in various environments in Québec, Ontario and Minnesota. *Applied Engineering in Agriculture* **28**, 795–801.
Scholz, V. 2007. Mechanization of SRC production. *Bornimer Agrartechnische Berichte* **61**, 130–143.
Scholz, V., Block, A. & Spinelli, R. 2008. Harvesting Technologies for Short Rotation Coppice – State-of-the-Art and Prospects. In Proceedings of the *Agricultural Engineering 2008 Conference and Industry Exhibition*, Crete, (GR).
Scholz, V., Eckel, H. & Hartmann, S. 2009. Processes and costs of SRC cropping on agricultural land. In *Die Landwirtschaft als Energieerzeuger. KTBL-Schrift* **476**, 67–80 (in German).
Schütte, A. 2010. Research and development for cultivation and utilization of wood from agriculture. In Proceedings of the *Symposium Agrarholz 2010*, Fachagentur für Nachwachsende Rohstoffe, Berlin, DE (in German).
Schweier, J. & Becker, G. 2012a. Harvesting of short rotation coppice-harvesting trials with a cut and storage system in Germany. *Silva Fennica* **46**, 287–299.
Schweier, J. & Becker, G. 2012b. New Holland forage harvester's productivity in short rotation coppice: Evaluation of field studies from a German perspective. *International Journal of Forest Engineering* **23**, 82–88.
Spinelli, R., Nati, C. & Magagnotti, N. 2009. Using modified foragers to harvest short-rotation poplar plantations. *Biomass and Bioenergy* **33**, 817–821.
Stokes, B. & Hartsough, B.R. 1994. Mechanization in short rotation intensive culture (SRIC) forestry. In Proceedings of *6th National Bioenergy Conference*, Reno-Sparks, (US).
Stuart, W.B., Marley, D.S. & Teel, J.B. 1983. A prototype short rotation harvester. Proceedings of the *7th International FPRS Industrial Wood Energy Forum '*83, Nashville, (US).
Wieneke, F. 1993. Mower-chipper for energy plantations of poplar and willow. *Landtechnik* **48**, 646–647 (in German).