New Holland Forage Harvester's Productivity in Short Rotation Coppice: Evaluation of Field Studies from a German Perspective

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Abstract

Modified forage harvesters are a common technology used to harvest short rotation coppice (SRC). This paper describes results of time studies from harvest trials with the New Holland forage harvester equipped with the cutting head 130 FB. Seven fields comprising a total of 13.6 ha SRC were harvested, and data from 22h 41 min were collected. In the studies, 0.77 hectares were harvested per productive machine hour (pmh^{-1}). The share of productive times was 74% of the total work time. The average harvesting productivity was 20.5 odt pmh^{-1}. Under good conditions, productivities up to 30 odt pmh^{-1} were reached. The harvesting costs were 19.70€ odt^{-1} on average, excluding the costs for the transport of the chips and of the harvesting machine to the fields.

Keywords: Short rotation coppice (SRC), harvest operation, productivity, forage harvester, New Holland, cutting head 130 FB.
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Introduction

Short rotation coppices (SRC) are commonly harvested in a combined cut and chip system with modified forage harvesters—used for maize and other annual crops—that are either self-propelled or tractor mounted. The standard cutting head is replaced by a special cutting head that is constructed to cut woody biomass (Figure 1, bottom). The plants are planted in rows, often in double-row systems with high plant densities when the focus is on high energy use of the biomass.

Different types of machines and cutting heads to harvest SRC have been developed and were analysed within the last decades. Within Europe, especially, the Claas Jaguar machines with their HS-2 and GB-1 cutting heads are well known and used. The typical work schemes of these machines are described in detail in FAO (2008): The modified forage harvesters are assisted by tractor-trailer units that travel by the side of the harvester. The stems are placed horizontally to enter the cutting heads and are chopped directly. Usually, the chips are blown into an accompanying tractor-pulled trailer, in which chips are transported to an interim or final storage (Sambra et al. 2008, FAO 2008).

Studies conducted in the 1990s analysing machines such as Claas, John Deere, and Austoft came to resulting working capacities of 0.25-0.66 ha per scheduled machine hour (smh^{-1}) (Forestry Commission 1998, Mitchell et al. 1999). Productivities of about 16 green tonnes (gt) smh^{-1} were reached (Danfors and Norden 1995). Machine development went on continuously, and studies showed that the trend is toward heavier machines (Spinelli et al. 2009). As a result, the harvesting productivities increased as well. Dawson (2007) came to working capacities of 5-6 ha day^{-1} for forage harvesters; Scholz et al. (2008) report even higher productivities. Spinelli et al. (2009) and Spinelli et al. (2008) measured gross machine productivities of 23 gt smh^{-1} and 22 gt smh^{-1}, respectively, for the Claas equipped with the HS-2 cutting head and 42 gt smh^{-1} and 34 gt smh^{-1}, respectively, for the Claas equipped with the GBE-1 cutting head. Productive working times are 70%-80% of the total working time, which is quite high (Spinelli et al. 2008 and 2009, Scholz et al. 2008), and reported harvesting costs are approximately 20€ per oven dry ton (odt) (Fiala and Bacenetti 2011, Spinelli et al. 2009).

However, harvesting systems with forage harvesters bring disadvantages as well. Reported delays are caused mostly by stems lying crossway to the rows; trees getting stuck in the saw blades (Scholz et al. 2008, Heinrich 2006); idle time for the foragers when too few trailers had been organised; or blockage time due to inflowing stems in second rotation (Spinelli et al. 2011a). Machines are heavy and cannot traffic on wet or steeper soils, and thus should be applied only to flat and solid terrain (FAO 2008), and a thorough organisation of the logistics is required to avoid idle times. Most of the existing cutting heads have limitations in cutting trees with diame-

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ters larger than 7-8 cm. Problems during harvest occur if diameters are at the upper limit and if plant densities are high at the same time. As a consequence, SRC needs to be harvested in shorter cycles, as long as diameters are small dimensioned. In that case, produced chips have high bark-to-fibre ratios and are very small in size, which is unfavourable when it comes to storage (Garstang et al. 2002).

Therefore, the development and optimization of harvesting techniques is ongoing, and also companies other than Claas developed special wood cutting heads that can be used for the harvest of SRC in combination with their standard machines. Forage harvesters out of the series FR 9000 developed by New Holland, for example, are very powerful. With the cutting head 130 FB, they are able to harvest larger-dimensioned trees (15 cm diameter). According to the manufacturer of the machine, seven cutting heads of the model 130 FB were sold around the world by the end of 2010.

This study aims to evaluate the productivity and costs of New Holland forage harvesters equipped with the cutting head 130 FB.

Materials and Methods

2.1 Description of Fields

In 2010 and 2011, data were collected from seven harvesting trials (5 willow and 2 poplar SRC). Field 4 was harvested with the New Holland FR 9050 (368 kW), and all other fields with the FR 9060 (435 kW). All machines were equipped with the wood cutting head 130 FB (Figure 1, bottom). The overall harvesting conditions were good. Machines could drive without problems or hindrance, and the soils were frozen. In one case, there was a little snow on the ground (Field 4).

Table 1 shows the main data of the harvested fields. The individual field size ranged from 0.31 to 4.94 ha net size, excluding turning areas. Trees were growing in the first rotation period and had few stems per root (often just one). All fields were almost flat (slopes less than 5%). The age of the harvested trees was between two and four years. The absolute amount of harvested biomass varied between 7 odt (Field 7) and 159 odt (Field 1). The average amount of harvested biomass per hectare was 27.4 odt. Fields 4 and 5 had triangle field designs, and the design of Field 2 was trapezoid. All other fields were planted in rectangle designs.

2.2 Machine Description

Detailed information about engine, feeding, cutting head and crop processor is given in Table 2. The feeding device has four feeding rolls with a feed opening width of 860 mm and variable adjustment of length of cut. The cutting head as such is equipped with two rotating knives that cut the stems; two slow-rotation feeding towers that center the stems; one paddle roll that lifts the stems; and two feeding rolls that pull and feed the stems into the chipper. The cutting head is hydraulically adjustable and guides and stretches the stems before they are cut off. As a feature, the speed of the individual components (knives, feeding towers, feeding rolls) can be adjusted independently and from the operator’s seat

2.3 Data Collection

Seven fields of poplars and willows were harvested, six in Germany and one in Switzerland. In two additional trials, the harvest was stopped after a few minutes—in the first case due to bad weather and difficult terrain conditions (20% slope, ice) and in the second case due to too little spacing between the double-row system (less than 150 cm), which led to a flat wheel. In total, 22h 41min of time studies with data from 13.6 ha were collected. The machines were studied while carrying out their scheduled activity. The harvests were undertaken by two different operators, both very skilled (Fields 1,2,3,5,7 by Operator 1 and Fields 4 and 6 by Operator 2). The assistant tractors were driven usually by farmers located close to the SRC.

Table 1. *Field data*

	Field						
Parameter	1	2	3	4	5	6	7
Date of harvest (MM/YY)	03/11	03/11	03/11	02/10	03/11	02/11	03/11
Location [1]	sw- DE	sw- DE	sw- DE	ne- DE	sw- DE	ne- DE	n- CH
Tree species	willow	willow	willow	willow	poplar	poplar	willow
Clone	Tordis	Tordis	Tordis	n.a.[2]	Max	n.a. [3]	n.a.
Net size (ha)	4.5	0.9	2.3	0.3	0.3	5	0.4
Age (years)	3	3	3	2	4	3.2[2]	3
Average diameter (cm)	3.4[5]	3.7[5]	2.9[5]	4.1[5]	6.9[4]	3.9[4]	2.5[5]
Plant density (1,000 trees ha^{-1}) [6]	13,2	12,5	12,5	13,5	10,5	14	13
Yield (odt yr^{-1} ha^{-1})	11.7	6.8	9.7	17	9.5	5.1	6.3
Harvested biomass, total (odt) [7]	159	18	66	11	13	80	7
Harvested biomass (odt ha^{-1})	35.2	20.4	29	34	38	16.3	18.8
Average length of row (m)	253	299	142	49	199	170	231
Average length of header (m)	9.4	9.0	11.7	n.a.	n.a.	10	9

[1] sw-DE = south-west Germany, ne-DE = north-east Germany, n-CH = north Switzerland, [2] n.a. = not applicable
[3] one plantation was established with 10 different clones that were uneven aged (3 and 4 years), [4] diameter at breast height (1.3 m), [5] diameter at stump height (0.1 m), [6] counting the amount of roots, [7] odt = oven dry ton

Figure 1. *New Holland FR 9060 while harvesting 3-year-old willows in double-row system (top) and cutting head 130 FB (bottom). Photo: Janine Schweier.*

The time was measured by using a stopwatch. The length of the rows and size of the fields were measured by measuring tape and GPS. The volume of harvested biomass was measured by the use of a weigh-bridge (Field 6), by counting the volume in the filled containers (all fields), and by the use of biomass functions (Fields 1,2,3) according to Hartmann (2010) and Röhle et al. (2010). This was conducted by project partners from FVA Baden-Württemberg. These functions have been developed for SRC growing in Germany. The required input data that are necessary to assure an error rate less than 5% are described in detail in Hartmann (2010). Trials performed in the project confirmed that measured and calculated amounts of biomass were differing less than 5%. The moisture content was 55% on average. It was determined in accordance with the ISO standard (DIN 52 183. 1977), which means the fresh material was measured before and after drying for 72 hours at a temperature of 103°C in a ventilated oven.

2.4 Data Analyses

The following working processes were identified and observed during the seven studies: cutting, turning of machine, changing of container, waiting for container, discussing, machine disturbance, and other delay. The working process "waiting for container" implies that the harvesting machine cannot continue the harvest and is forced to wait. In contrast, the working process "changing of container" means both the harvesting machine and the tractors carrying the containers are available, but there are delays because the change of tractors does not work fluently. No personal delays, such as operator rest, could be identified because the drivers generally used the time while waiting for a container to take a rest. The working processes were summarized according to the scheme of REFA (1991) into productive and non-productive times, which together add up to the total working time. The productive times include only the work time that is spent contributing directly to the completion of the harvest (Rickards and Björheden 1995), which means rest and personal times or disturbance times are excluded. In this study, the working processes of cutting, turning of machine, and changing of container constitute the productive times.

If the recorded times (h) of the working processes building the productive working times differed more than 2.5 times from the standard deviation of the mean value, they were treated as outliers and were replaced by the median value. This occurred in 16 out of 815 cases. Correlations were analyzed and regressions were performed to identify factors influencing the productivity. Namely, the influence of the variables of tree diameter, length of rows, type of machine, species, size or design of the fields, age, and biomass per hectare were analysed. The critical significance level was set to 5%. Data analyses were carried out using SPSS 19.0 and Microsoft Excel 2003.

Table 2. *Machine data of New Holland FR 9060 and FR 9050 equipped with the cutting head 130 FB (New Holland 2011).*

Parameters	FR 9060	FR 9050
Cylinders/displacement (n°/litres)	6 in-line/12.9	6 in-line/12.9
Rated power ISO 14396—ECE R120 at 2100 or 2000 rpm [kW/hp (CV)]	400/544 or 435/591	343/466 or 368/500
Max. torque ISO 14396—ECE R120 at 1500 rpm (Nm)	2470	2145
Fuel tank capacity (standard) + additional tank (l)	1100 + 285	1100 + 285
Turn radius (m)	6.1	6.1
Height and width on 650/75R32 tyres (m)	3.78/2.98	3.78/2.98
Wheel basis (m)	3.2	3.2
Width on 650/75R32 tyres (m)	2.98	2.98
Wheel basis (m)	3.2	3.2
Mass (kg) + mass of cutting head (kg)	12600 + 2100	12500 + 2100

2.5 Harvest Cost Calculation

The cost calculation was based on machine costs of the FR 9060 and followed the instructions of the German "Association for Technology and Structures in Agriculture" (KTBL 2010). Input parameters used are shown in Table 3. A transport of the wood chips to a plant or storage and further conditioning of the material, such as drying, was not considered. The fuel consumption of the forager was reported by one of the contractors.

Table 3. *Input parameters for cost calculation.*

Item	Metrics
Investment costs (1,000€) (tractor/cutting head)	295/80
Annual utilisation (h) (tractor/cutting head)	600/200
Depreciation period (a)	8
Interest rate (%) [a]	5
Labour cost (€ h^{-1})	20
Repair factor (%)(tractor/cutting head) [b]	32/34
Fuel consumption (l h^{-1})	70
Fuel costs (€ l^{-1})	1.14
Lubricant (% of fuel consumption)	1
Insurance & technical control (€ a^{-1})	95
Placing (% of investment)	1
Organisation, others (% of investment)	1

[a] 100% lean capital, [b] The repair factor shows what percentage of the investment in machinery is needed to maintain its functionality during its lifetime (Nemecek and Kägi 2007)

Results

3.1 Distribution of Working Time

Figure 2 shows the share of each working process of the total working time per study in percentages. During all harvests, no machine preparation time (e.g., engine warm-up) was observed. Usually, the driver started to harvest directly. A 5-to-10-minute machine check and maintenance was performed at the end of each working day.

The average share of productive working time was 74% (53% cutting, 18% turning, and 3% changing of container). The time requirements of the working processes "cutting" and "turning of machine" per oven dry ton are shown in Table 4. The required cutting time per oven dry ton decreased significantly with the increasing amount of biomass per hectare ($p < 0.01$).

The remaining 26% of the total working time adds up to the non-productive working times. They were distributed to the processes waiting for container (16%), discussing (5%), machine disturbances (2%), and other delays (3%). Almost no machine disturbances occurred.

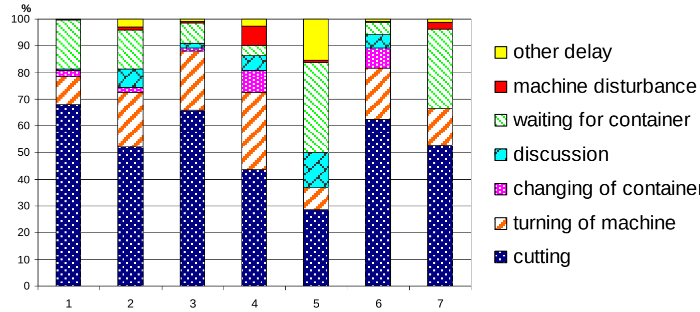

Figure 2. *Average distribution of total working time, in percentage.*

In Field 7, there was a relatively high share of the working process "waiting for container" (30%). Here, the change of the hook lift container was time consuming. In Field 5, there was a high share of waiting time (33.5%) as well, because there were not enough containers available for the given transport distance between field and storage. In both cases, the harvesting machine needed to stop and wait for an empty container, but there was no additional waiting time devoted to "changing of container." In both cases, the harvesting machine continued the harvesting process when the empty container was located, ready on the field.

In general, it was observed that the drivers of the tractors often had difficulties following the harvesting machine in a smooth way (especially in Fields 2,3,6) due to time-consuming turning manoeuvres caused by the design of the field (Fields 2,4), snow (Field 4), or misunderstandings in communication. In particular, the organisation of the harvest and the communication during the harvest seemed to influence the amount of delay times. It could not be proven directly that there was a statistical correlation between diameter of trees and delay times because available tree data were partly stump and partly breast-height diameters in different trials. However, more delays occurred with increasing diameter.

3.2 Machine Productivity and Harvesting Costs

During 22h 41 min of time studies, an average productivity of 0.77 ha per productive machine hour was reached, varying from 0.51 ha pmh^{-1} (Field 4) to 0.97 ha pmh^{-1} (Field 7) (Table 5).

The productivity (ha pmh^{-1}) of the machines was also related to the harvested volume (odt). Lowest productivities were observed in Field 6 (14.6 odt pmh^{-1}) and Field 2 (15.7 odt pmh^{-1}), and highest productivities in Fields 1 and 5 (both 27.6 odt pmh^{-1}) (Table 5). The productivity was 20.5 odt pmh^{-1} on average. There were no significant differences between the productivity reached using the FR 9060 or FR 9050 ($p= 0.598$).

Table 4. *Required working time for the working processes "cutting" and "turning of machine," in minutes per oven dry ton.*

Working process	Field 1	2	3	4	5	6	7	Mean
Cutting	1.8	3.2	2.1	2.1	1.8	3.0	2.6	2.4
Turning of machine	3.1	1.1	0.7	1.4	0.5	1.3	0.6	0.8

Table 5. *Machine productivities per productive machine hour.*

	Field							
Productivity	1	2	3	4	5	6	7	Mean
ha pmh^{-1}	0.79	0.77	0.76	0.51	0.73	0.90	0.97	0.77
odt pmh^{-1}	27.6	15.7	22.1	17.5	27.6	14.6	18.2	20.5

The variables of species, size or design of the fields, length of the rows, or age of trees did not show significant influences on reached productivities, but productivities in terms of odt pmh^{-1} were significantly dependent on the amount of biomass per hectare, according to

$$\mathbf{Y = 6.75 + 0.501\ b}$$

where Y is the productivity in terms of odt pmh^{-1} and b is the harvested biomass per hectare. The equation is significant ($p < 0.05$, $F= 9.723$,) and explains 66% of the observed variance.

The variables diameter (d 0.1/ d 1.3) and plant densities had influence on the productivity (odt pmh^{-1}), but not significantly ($p= 0.340$ respectively $p= 0.147$). In tendency, the productivity increased with increasing diameter and with decreasing number of plants per hectare (plant densities).

Costs resulted in 281€ smh^{-1}. When using the average productivity per scheduled machine hour (14.2 odt smh^{-1}), harvesting cost resulted in 19.70€ odt^{-1}. Analysis showed that, in addition, the costs per ton were significantly dependent on the total amount of harvested biomass per field ($p <0.05$).

Discussion

During harvesting, an average share of productive working time of 74% was reached (Figure 2). Often, unproductive times were caused by waiting times and not by technical disturbances such as trees sticking in the saw blades. Therefore, we assume the share of productive times can easily be increased if the communication and organisation of the harvests is improved.

The productivity of the harvesting machines was expressed both in area and tons per productive machine hour (pmh). On average, 0.77 hectares were harvested pmh^{-1} (Table 5), which is in the same range as results of studies analysing other forager harvesters (Dawson 2007). Over all time studies, 20.5 odt pmh^{-1} were harvested on average. Values ranged from 14.6 odt pmh^{-1} in fields with moderate amounts of standing biomass per hectare (Field 6) to 27.6 odt pmh^{-1} in fields with large amounts of biomass per hectare (Fields 1,5). These results are in line with average productivities reported in other studies as well (Spinelli et al. 2008). According to Scholz et al. (2008) and Spinelli et al. (2009), forage harvesters can harvest up to 70-80 gt pmh^{-1} (60% moisture content, equal to about 30 oven dry tons) when harvesting conditions are appropriate. Fields with favourable harvesting conditions (for example, good organisation in terms of chip transport) easily reached productivities of up to almost 30 odt pmh^{-1} as well (e.g., Field 1), which shows New Holland foragers are very competitive with other foragers.

It was proven that productivities increased significantly with increasing field stocking, which is affected by the variables tree diameter, stems per root, and plant densities. The number of stems per root, as well as the density, did not show influences at the machine's driving speed or productivity, probably due to the heavy engine. The harvest is limited only in terms of tree diameter (15 cm at stump height) due to technical restrictions of the cutting head. This limiting effect could not be observed in the present studies because the maximum diameter cut was 6.9 cm. However, the aim should be to perform the harvest when high amounts of biomass per hectare are reached to assure a cost-efficient harvest (*see also* Spinelli et al. 2011a).

Through regression analysis, it was tested which variables influenced the non-productive times, but no significances could be proven. The main reasons for the lack of significance likely are the difficulties in the evaluation of single events that were not measured in nominal scales—e.g., when the driver of the tractor decided to drive a full cycle around the field for turning because of the weather conditions, or lack of communication between involved individuals. Other studies point out that the organisation—e.g., of the trailers—also is a very crucial point regarding idle times (Fiala and Bacenetti 2011, Spinelli et al. 2011a). Experiences strongly support these observations.

Because this study has emphasized the productivity of the harvesting process only, the quality of the wood chips produced by this cutting head was not analysed. However, there might be differences in the quality among different machines—e.g., grinder vs. chipper (Spinelli et al. 2011b). Future studies should consider the properties of the material and the utilisation pathway of the wood when analysing a harvesting system and a specific harvesting machine.

The calculation of machine costs resulted in harvesting costs of 19.70€ odt^{-1} wood chips on average, excluding logistics or further conditioning of the material. As with productivity, costs were comparable to results of other studies (Dawson 2007, Fiala and Bacenetti 2011, Spinelli et al. 2009 and 2011, Wagner et al. 2009). It is the most cost-efficient option to cut and chip the material directly by using forage harvesters, compared to other systems, such as manual cutting or mechanised harvesting with whole-stem harvesters where chipping occurs independently from the cutting (Dawson 2007, Schweier and Becker 2012). The market for wood chips is very locally oriented, and prices differ enormously. The German coordinating office for renewable resources estimates that 90€ t^{-1} is the current market price for wood chips from SRC delivered to a plant 20 km away (assuming a MC of 35%) (C.A.R.M.E.N. 2012).

To calculate the overall economic performance, upstream processes like costs for cultivation and plant material and for downstream processes such as transportation and stool removal need to be included in an overall economic assessment. Furthermore, it has to be considered that the transportation of the harvesting machine to the field site was not taken into account. The New Holland forage harvesters are permitted to drive short distances on public roads, but generally a low-loading truck is used for transportation of the machine to the fields. First experiences in 2010 and 2011 in Germany showed that contractors charged transport costs up to 200€ per 100 kilometres transport distance. These costs are quite high and influence the costs per unit. Harvesting becomes more efficient if the transport distance is as short as possible, or if adequate amounts of biomass are harvested. The critical mass needed to assure a cost-efficient harvest was not defined because the number of studies was limited. Future studies can contribute to define a minimum of biomass that should be harvested to reach economy of scale effects. However, highest productivity can be reached when extending the rotation period until a cutting diameter of 15 cm is reached. We are convinced that cost-efficient harvests are possible, either when harvesting larger fields of 2-3 hectares, or if farmers make agreements and organise harvesting of several fields in close distances to reduce the transport costs per unit.

Conclusion

The New Holland forage harvesters can be used cost-efficiently to harvest SRC. They are a reliable system that might be established at market in the future. Both costs and productivities were comparable with similar machines. Only a few machine disturbances occurred, and unproductive times were caused in most cases by unfavourable organisation, a lack of tractors and containers, or misleading communications between the drivers. Therefore, an increase in productive times seems realistic for future harvesting operations. In this case, New Holland forage harvesters equipped with the cutting head 130 FB might become more competitive than other machines.

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