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ANALYSIS ABOUT THE PRODUCTIVITY AND FIELDS OF APPLICATION USING LIGHT WEIGHT FELLER BUNCHER HEADS IN EARLY THINNINGS

Alexander Eberhardinger
Technical University of Munich; Germany; eberhardinger@wzw.tum.de

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Abstract: *This paper deals with the performance of alternative harvesting methods using feller-buncher systems in early thinnings of Norway spruce. As a result of the small stem volumes and the high density of the studied stands, the harvesting conditions have been very difficult both from an economic and technical point of view. The felling and accumulating heads studied have been attached to the back of a tractor with a forest crane and a trailer used for extraction. Trees have been harvested in a combination of strip cutting and selective thinning.*
Due to the expected increase in productivity using an accumulating felling head and the low fix costs of the machinery, a hypothesis was passed that these advantages should lead to a cost-effective harvesting concept even under the given circumstances. According to the results of the productivity and cost analysis this hypothesis has been confirmed.
During the experiment the machine operator has managed to fell an average of 60 trees per hour. Thus the mean productivity of felling and bunching was 11,70 m³/pmh$_{15}$*. By reason of the high driving speed on the forest road and the concentrated bundles along the extraction line a productivity of 30,45 m³/pmh*$_{15}$ *was achieved. Considering the machine costs of 60,00 €/pmh*$_{15}$ *total costs of 7,10 €/pmh*$_{15}$ *have been calculated excluding chipping and transport.*

1. Introduction

Young stands at an age of up to 40 years represent an area of 29,7% of Germany`s total forestland. Especially in the small scaled private sector these stands are lacking thinnings.
In the past these forests were often neglected due to high harvesting costs caused by a very low stem volume. Hence traditional CTL harvesting systems, either manual or mechanised, have not been cost effectiv. This situation can consequently lead both to an increasing instability and reduced yield growth especially on sites with poor soils.
In recent years growing demand hit the European timber market. According to a surplus of growing stock published by the German forest resource inventury the timber industry invested in several huge projects in order to increase mill production capacity.
The bioenergy boom is representing another important driving force for the growing demand. As a result this process led to scarce timber resources. Despite higher prices, forest owners and chipping contractors are still looking for cost-effective fuel wood supply chains as the profit margins are limited. Apart from that the situation urges to explore wood resources for biomass customers which don`t compete for example with the fibre board or paper industry. Besides landscape tending operations, young thinning stands with small stem volumes that haven`t reached pulp wood or sawn wood assortments could be potential resources.

1.1. Aims of the study

Apart from evaluating cost and productivity models this study aimed at estimating a range between ideal and marginal working conditions. Particularly interesting was the direct loading into the tractor trailer. Finally possible fields of applications as well as optimum working methods should be found and defined. In order to identify technical problems and necessary upgrades required, the experiments wanted to provide a reliable data pool.
Combining our results with comparable experiments that include key variables determining the productivity this study can result in a decision support system for machine types and harvesting methods to be applied in early thinnings.

2. Material and Methods

The study was conducted at the Ebersberger Forst, a district of the Bavarian State Forest Company *Bayerische Staatsforsten* (Germany).

2.1. Stand Data

The analysed sites were young Norway spruce monoculture thinning stands aged between 15-30 years grown from natural regeneration.
Inspite of a remarkable differentiation there is a general stability risk due to the high stem density. A high proportion of red deer peeling damage has been noticed, too.
The experiments were located at two different sites. Alltogether three extraction lines were harvested and evaluated (table 1).

Table 1: Description of the harvesting sites

Stand Data	Line 1	Line 2	Line 3
Mean diameter at breast height (cm)	9,1	8,2	8,0
Mean height (m)	11,3	10,4	9,7
Length of extraction line (m)	250	75	100
Harvesting area (m²)	1.000	300	400
Trees harvested	584	251	263
Harvesting volume (m³ chips)	225	75*	
Cutting intensity (m³ chips per m)	0,9	0,43*	
Mean extrating distance (m)	245	570	210

* Line 2 and 3 were placed at one site. The trees of both lines were extracted to one big pile and chipped.

2.2. Machinery

The harvesting machinery included a Valtra forest tractor with a Kronos forest crane - attached to the back of the tractor - and a Farmi trailer (table 2).

Table 2: Specifications of the machinery

Tractor	***Valtra 120e***
Weight	7,5 t
Power	120 kW
Oil Pressure	80 l/min
Fuel consumption	5-7 l/h
Crane	***Kronos 5000***
Length	7,5 m
Lifting capacity	50 kNm
Felling Head	***NaarvaGrip 1500-25e***
Weight	360 kg
Cutting diameter	25 cm
Needed Oil flow	50 – 120 l/min
Grapple Volume	92 cm²
Trailer	***Farmi Vario 121***
Load capacity	13 t
Weight	2,0-2,2 t
Length	6,2 m
Width	2,3 m
Load area	2,6 m²

2.3. Harvesting procedure

The combined thinning concept consisting of strip cutting and selective felling should provide access to the stands as well as an increase in stability and growth.

During the planning stage of the project none of the felling heads commercially available have been applied in the forests. Thus a machine operator was chosen who had a lot of experience in handling the basic machine but no skills in running feller-buncher heads. This was taken into account and the time studies started after reaching a certain practice threshold.

With focus on the felling process, four working methods have been defined and analysed:

1.) Single trees were cut and directly felled to the ground without using the bundling function. Depending on the tree height the felled trees were trimmed twice or trisected to a length of 5-7 meters regarding the capacity of the trailer. Finally the trees were accumulated and placed down to loose stacks along the extraction line.

2.) One tree after another was cut using the bundling grapple of the felling head. The whole bundle was placed to the ground. After accumulating several bundles, the trimming and placing to loose piles was done as described in the first case.

3.) Several trees are simultaneously cut at the root collar. This method can also be combined with further cutting using the bunching grapple. The felling to the ground as well as the cutting to length was done analogically to the other methods.

4.) The cutting is separated into two steps: First the crown is cut and then the trunk. There are mainly four different ways of working with this method:

a) Putting the crown directly onto the pile – cutting the trunk afterwards.
b) Putting the crown to the ground and cutting to length – analogically with the trunk
c) Cutting more crowns after another using the bunching grapple - analogically with the trunk
d) First the the crown gets cut, then the trunk is cut directly using the bunching grapple.

Picture 1: Forest tractor doing strip-cutting: felling, bunching and concentrating to lose piles

2.4. Data collection procedure

The data collection procedure was done according to the routine time-study concept. However the characteristics of the sites, especially the small stem volume, has forced an upgrade of the volume measurement and marking method:

The diameter at breast height of every tree on the extraction line as well as the trees of the selective thinning was measured. The trees were to small to be marked with a specific tree number and later identified.

According to the diameter the trees were marked with different colour rings. Thus each single diameter class was defined by a specific code using eight different colours with a maximum of three rings per colour. Hence each diameter between 7 and 23 cm was specifically marked. The colour code was easily identified during the time study. Because of a high percentage all trees under 7 cm were averaged to 5 cm. A control sample was measured which confirmed the estimated value of 5 cm.

All time elements (productive and non-productive times) were recorded with a Palm hand-held running the UMT time-study software. Considering the different felling alternatives each working step was programmed. The activities *positioning* and *cutting* were combined in one working step. This was done due to the very short time period elapsed especially when using the bundling function.

3. Results

As the density of the stands was very high the machine operator often decided to cut the crown first and then the trunk. 41% of the marked trees were felled in that way because it was easier to place the trees to the ground respectively directly onto the lose piles. Felling of crown and trunk in two separated workings steps, however was not restricted to a particular range of tree diameters.

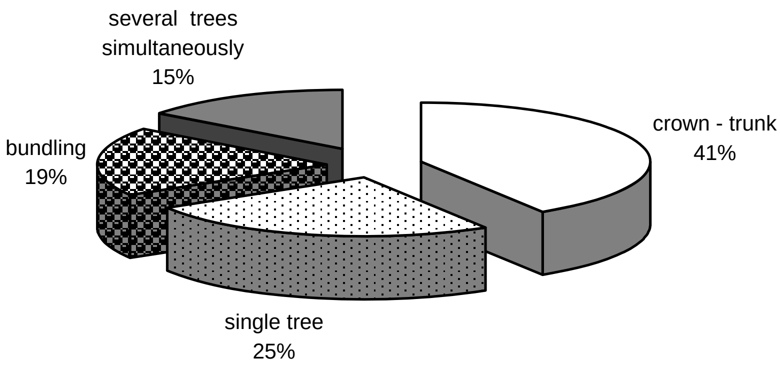

Figure 1: Proportion of trees harvested with the different cutting variations.

Whereas bundling as well as cutting several trees in one step has been determined by the distance between two marked trees and the diameter of the root collar. The single tree method has mainly been used when bundling wasn`t possible anymore or when there have been gaps so that the trees could have been placed down easily.

During the experiment an average productivity of 60 harvested trees/h respectively 11,70 m³/pmh_{15} was recorded. Regarding the statistical analysis of the time study, differences between the alternative working methods have been found (table 3).

Table 3: Summary of the time consuption analysis for the different working methods

harvesting methods	trees	average dbh [cm]	time per tree [s]	trees per hour
crown – trunk	451	10,4	88,70	40,59
single whole tree	279	9,0	68,72	52,39
bundling several trees	206	6,2	45,46	79,20
more Trees simultaneously	159	5,6	38,01	94,72
average	-	**7,82**	**60,22**	59,78

When several trees were bundled using the accumulating grapple, crane movements have been spared. Thus the time per tree has been reduced by 38 % compared to the single tree method. Time consumption models have confirmed these results. Figure 2 is showing the difference between the four different harvesting methods. The volume was calculated with biomass functions refferring to Wirth et al.

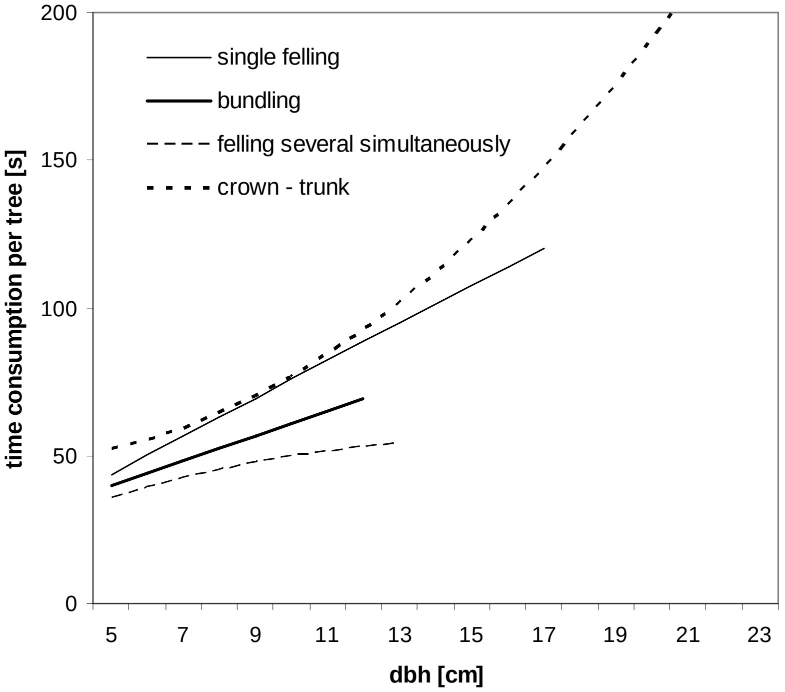

Figure 2: Variation of time consumption models according to different working methods.

The time consumption models estimate the biggest advantage of the two accumulating methods ("bundling" and "felling several trees simultaneously") within a range of 9 - 13 cm dbh. However, the experiments showed with those stem diameters, bundling was limited by the capacity of the cutting knife as well as the cutting grapple. Looking at the average productivity, it is obvious that both the bundling and the simultaneous felling method have not achieved a higher productivity level than the other felling methods.

This was due to the higher stem volumes within the single tree and the crown - trunk felling method hence the higher time consumption has to be spread over a higher volume output.

Table 5: Data basis for calculating the average felling productivity

Harvesting volume	300 m³
Complete working time (including miscelleanous times < 15 min)	21,35 h
Setting up time (1,0 h per day)	3,0 h
Changing time (felling head - loader grapple)	1,50 h

Calculating with the real product output that was measured at the study the whole volume as well as all time consumption values have to be included (table 5). According to this data the average felling productivity was 11,70 m³/$pmh_{15.}$

As explained the bundling capacity of the grapple is limited to a range of 5-12 cm dbh. Reaching a dbh of 15 and higher bundling cannot efficiently be done anymore (figure 3).

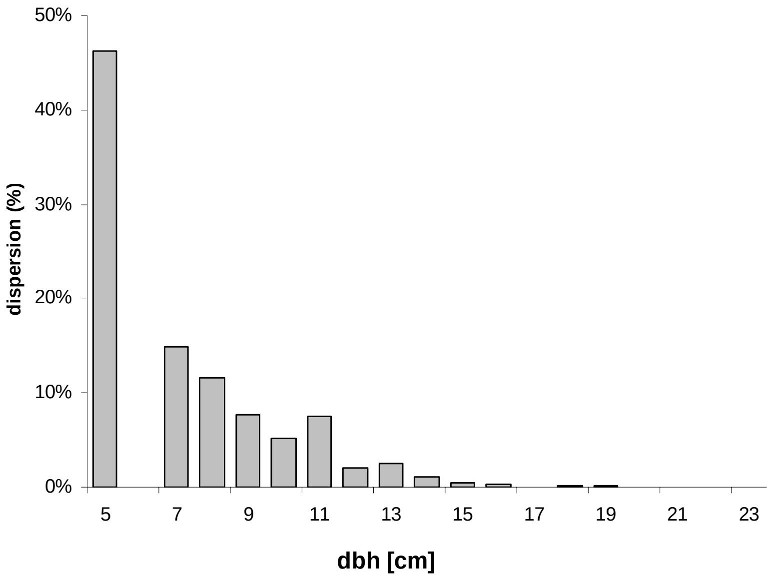

Figure 3: Dispersion of dbh during accumulating more than one tree respectively several parts of a tree.

Thus bundling bigger trees decreases productivity as the trunk cannot be felled with one single cut but forces a second positioning step. The missing data at the dbh of 6 cm goes back to the measuring concept, where all trees under 7 cm dbh were averaged to 5 cm.

3.1. Extracting

It was not possible to measure and mark the volume of each lose pile. Because of that the extracting productivity was calculated on basis of the whole harvesting volume. Due to the measurement of the chipping contractor all in all 300 m³ have been harvested and extracted. So the average load volume was 14,3 m³/pmh_{15}. The mean extracting distance has differed in the three stripping lines. According to the real production output a productivity of 30,45 m³/pmh_{15} was recorded.
The high productivity level has been reached due to a short extracting distance (figure 1), the concentration of the material in lose piles and the high speed of the tractor on the forest road. The steerable towing bar of the Farmi trailer turned out to be a very convenient tool on the narrow extracting lines.

3.2. Cost calculation

The machinery was calculated with 60 €/pmh_{15} including a efficiency factor of 2.000 machine hours per year. The produced chips summed up to 300 m³. Due to a mean productivity of 11,77 m³/pmh_{15} the felling costs were 5,13 €/m³. With the extraction costs of 1,97 €/pmh_{15} the total harvesting costs of 7,10 €/pmh_{15} have been calculated.

This project focused on felling and extraction. No time studies have been compiled about chipping and transport. According to the records of the contractor chipping was 3,00 €/m³ and transport was 3,10 €/m³. Compared with WITTKOPF and STAMPFER et al these values are within a realistic range. All in all the costs sum up to 13,20 €/m³.

4. Discussion

Looking at the latest price developments of forest wood chips the hypothesis can be confirmed that the shown harvesting methods are enabling a cost-effective supply chain of forest wood chips.

As shown in other studies, too, the presented results reveal that both the machinery and the circumstances of the sites do effect the felling productivity. SPINELLI et al have recorded a productivity of 100 to 200 trees per hour representing 47-65 m³/pmh_{15} due to a tree volume of 0,29-0,49 m³/tree. These levels were accomplished with harvesters on fast-growing eucalyptus stands. However WITTKOPF et al have recorded a felling productivity of only 7,60 m³/pmh_{15} using a harvester in early thinning of Norway spruce with an average dbh of 10 cm. Taking this into account the productivity level achieved by the machine operator who just had started to work with the accumulating head is quite impressive. Nevertheless a machinery with stronger oil pressure and a higher felling capacity should result in higher productivity but causing higher fixed costs.

Because of the high density and the crane motion (crane mounted to the back) direct loading into the trailer was not possible. However this can be materialized in other fields of application like tending actions within landscape management or road and railway building. These sites are often not lacking space thus higher productivity can be expected.

The cutting grapple seemed to be either too small or not aggressive enough. When cutting larger root collars the grapple slipped and could not stay closed. May be skids or claws should be adapted at the end of each grapple finger. The power might be caused by the lower oil pressure of the tractor compared with the higher one of a harvester or forwarder. Cutting trees over 20 cm dbh often required two cuts in order to fell the tree properly. These problems were also experienced when trying to bundle several trees with a dbh higher than 12 cm.

Thinking about fields of applications and recommendations silvicultural aspects have also to be considered. If waiting a few more years it may be become more efficient to do the first thinning with a usual fully mechanized CTL method, as pulp or paper wood assortments can be sold. Moreover the total harvesting volume will also increase so that the higher fixed can easily be compensated.

Finally it has to be mentioned that all wholetree harvesting methods cause significant nutrient losses which may effect nutrition availability and growth especially on sites with a poor nutrient supply. Looking into the future several further machine configurations using feller-buncher heads might be studied.

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7. Appendix

pmh_{15}	=	Productive machine hour including all delays < 15 minutes
m^3	=	Cubicmeters of wood chips; cube with a side length of 1 m
CTL	=	cut-to-length harvesting concept producing shortwood using a harvester