TECHNICAL AND ENVIRONMENTAL ISSUES OF STUMP HARVESTING FOR BIOFUEL PRODUCTION IN LATVIA

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Abstract

This article represents the results of the research project 'Forest energy from small-dimension stands, infra-structure objects and stumps' realized in cooperation between Joint stock company 'Latvijas valsts meži' (Latvia's state forests), SKOGFORSK (The Forestry Research Institute of Sweden) and Latvian State Forestry Research Institute 'Silava'. The article is covering issues related to the results of stump harvesting field study realized in November, 2008. A scope of the study was to estimate costs of stump harvesting and to evaluate working methods and influencing factors related to extraction of stumps.

Better harvesting conditions (flat landscape and lack of stones in soil) led to increased productivity of stump extraction in Latvian trials (5.2 t_{dry} (t_{dry} – tons of dry mass) of stumps per effective hour (E_0-h)) in comparison to average figures in Scandinavian studies. Load sizes of the forwarder ranged from 5.5 to 9.3 t which is about half of the maximum load of forwarder. Average productivity of forwarding was 6.3 t_{dry} E_0-h^{-1}. Productivity of stump transport (distance – 7 km) was 3.5 t_{dry} E_0-h^{-1}. Productivity of comminution was 10 t_{dry} E_0-h^{-1}. Prime cost of the stump harvesting, including extraction, forwarding, stump transport (7 km one direction), comminution and chip transport (50 km one direction) was 6.3 LVL LVm^{-3} (LV – loose volume). 'Environmental footprint' of the stump harvesting in terms of carbon (C) emissions was 2.5 kg C LVm^{-3} of wood chips at terminal. Stumps demonstrated considerably higher heat value (5.7 MWh t_{dry}^{-1} against 4.7 MWh t_{dry}^{-1} for the hog fuel from a slash).

Key words: stumps, biofuel, harvesting, productivity.

Introduction

Interest in forest bio-energy is growing rapidly in Latvia. Only few years ago industrial scale production of the so called 'hog fuel' from a slash from clear-cuts was initiated in private and state forests. Now piles of drying slash are a common elements of our landscape. Total production of hog fuel in Latvia is not estimated, but increasing amount of sales in Joint stock company 'Latvijas Valsts Meži', 107,500 LVm^3, including 5,000 LVm^3 of crushed stumps in the first half of 2009 (A/s 'Latvijas valsts meži', 2009), demonstrates, that this kind of biofuel becomes a significant player in the energy market. It is approved, that the production of hog fuel from slash in clear-cuts is feasible and can provide a significant amount of renewable fuel (80 m^3 of biofuel per ha, including firewood (9 m^3 ha^{-1}) corresponding to 25% of volume of roundwood assortments) (Thor et al., 2006). Indicates from the forest research results demonstrate that stumps are next in line after a slash from clear-cuts in the terms of cost efficiency of available technologies and potential of resources.

Stump biofuel can be produced in all clear-cuts after forwarding of roundwood assortments and slash if it's collected for the biofuel. There might be environmental limitations of the stump lifting in areas with high risk of an erosion, technical limitations associated with large dimensions of stumps or lack of area to store stumps during field drying, and climatic limitations, like warm winters, which makes complicated forwarding of stumps in wet sites. Potential effect of those limitations is not researched in Latvia; thus, it is hard to predict the actual amount of stumps, which can be produced in state forests from the clear-cuts. The evaluation of bio-energy resources in this paper is based on the assumption that an average harvestable amount of stumps in calculation to dry tons is 12% of the harvested volume of roundwood in m^3 under bark (Thor et al., 2008). This assumption corresponds to average Swedish and Finnish conditions (Laitila et al., 2008). The very rough calculation demonstrates that the potential of Latvian state forests is about 400,000 t_{dry} or 32 t_{dry} ha^{-1} of stump biofuel yearly, which corresponds to about 2.4 mill.MWh. It should be taken into account that no availability criteria are applied to this calculation. If we assume, that harvesting of stumps will not be implemented in pine (*Pinus sylvestris* L.), oak (*Quercus robur* L.) and ash (*Fraxinus excelsior* L.) stands, because of deep root systems, and grey alder (*Alnus incana* L.) stands because of a rather small average dimension of stumps, total harvesting stock of stumps reduces to about 237,000 t_{dry} yearly (60% of theoretically available amount in clear-cuts) (Thor et al., 2008).

Another important group of issues affecting stump harvesting is forest regeneration requirements. Organization of stump lifting should be synchronized with afforestation activities to avoid unnecessary costs of additional soil preparation and weed control (Saarinen, 2006). The results of this study demonstrated that additional time of soil scarification is about 13% of the total working time, thus this method at least from the point of view of cost efficiency of soil preparation is much more beneficial than trenching, but silvicultural effect of this operation should be estimated separately. Stump harvesting in coniferous stands has also significant silvicultural potential, for instance, to reduce distribution of root rot (*Heterobasidion annosum* (Fr.) Bref.) in next generation of forests by removing most of infected biomass (Lipponen, 2007).

This article is concentrated on technical issues of stump harvesting, which are important to understand economical accessibility of stump resources, as well as to predict requirements of technical development taking into account local conditions, both, at resource and consumption side.

Materials and Methods

The study included the extraction and forwarding of stumps. Machines used in the study were a Hyundai LB21Lc crawler excavator for lifting operation and a John Deere 1110D prolonged forwarder. The excavator was equipped with a CBI stump lifting head with a shear blade. The forwarder had a slash grapple. Both operators were experienced with their respective machines, but inexperienced with this particular work. The study was carried out near Jelgava in January, 2008. The study site area was a 4.2 ha in total, clear felling was finalized in November, 2006. Further details are in Table 1 and Table 2. Characteristics of study plots differs from the average characteristics of the stand, because time studies were done only in certain parts of stands.

Table 1

Stand Characteristics Before Clear-cutting

Forest site	Zemgale forestry, former Garozas forest district, block No. 177, parcel No. 1 (2.7 ha) and No. 5 (1.4 ha)
No. of stems per ha (in average)	500
Tree species	parcel No. 5: 5B1P1S[1] (82 years old) 3P (120 years old) + S (65 years old) in the second floor parcel No. 1: 7S2P1B (102 years old) + A, O (102 years old) + S in the second layer
Harvested stock	parcel No. 5: 279 m^3 ha^{-1} parcel No. 1: 348 m^3 ha^{-1}
Average diameter of trees at breast height	parcel No. 5: 28 cm parcel No. 1: 35 cm

[1] B – birch (*Betula pendula* Roth), P – pine, S – spruce (*Picea abies* (L.) H.Karst.), A – aspen (*Populus tremula* L.), O – oak.

Table 2

Characteristics of Study Plots Before a Stump Lifting

	Plot 1	Plot 2	Plot 3
Soil characteristics	Sand (low land)	Sand (ridge)	Peat (40 cm)
Plot area, m^2	1,950	2,000	1,250
No. of stumps	94	102	52
Species, % (P:S:B,A,O)	12:53:35	28:59:13	31:52:17
Average diameter of stumps (cm)	34	36	35
Gross weight, t_{dry}	8.4	8.6	3.9

All stumps were measured (average height and diameter) and marked with numbers to accumulate productivity data of harvesting for individual stumps according to the harvesting conditions and tree species. The amount of material lifted and forwarded was estimated theoretically before calculations of productivity. Equations published by L.G. Marklund (1988) were used to calculate an amount of dry weight of stumps of pine and spruce. For birch stumps and other deciduous formulas from J. Repola et al. (2007) were used (Table 3).

Since many stumps had been harvested several centimeters higher than was regarded as normal, some extra weight had to be ascribed to the stumps. In this case the volume of the butt-off was calculated as a cylinder and then multiplied by dry-weight – pine 476 kg m^{-3}, spruce 394 kg m^{-3} and birch 500 kg m^{-3}.

Table 3

Formulas Used to Estimate Amount of Dry Weight per Stump

Species	Formula[1]	r^2	Source
Pine, stump	EXP(a+b·[D/(D+15)])	0.95	Marklund, 1988
Roots > 5 cm	EXP(a+b·[D/(D+10)])	0.90	Marklund, 1988
Spruce, stump	EXP(a+b·[D/(D+17)])	0.96	Marklund, 1988
Roots > 5 cm	EXP(a+b·[D/(D+8)])	0.94	Marklund, 1988
Birch, stump	EXP(a+b·(2+1.25·D)/((2+1.25·D)+26)+(c+d)/2)	0.95	Repola et al., 2007
Roots > 1 cm	EXP(a+b·(2+1.25·D)/((2+1.25·D)+22)+c·Ln(H)+(d+e)/2)	0.91	Repola et al., 2007

[1] a...d – constants; D – diameter at breast height in centimetres. In this case the diameter was estimated from the stump diameter according to the formulas presented in the publications by L.G. Marklund (1988) and J. Repola et al. (2007); H – tree height in m.

The validity of above formulas under Latvian conditions is not known. It seems that they will underestimate the weights, especially for a pine but probably also for a spruce. Average results of productivity data were recalculated later according to the actual amount of produced wood chips. During unloading from the forwarder every grapple was weighed by the boom-tip mounted scale. Total weight achieved that way included soil and in-wood moisture. To adjust to this, the registered gross weight was corrected, first with a factor 0.5 (Thor et al., 2008) to adjust for moisture then with a factor 0.7 (Jonsson, 1985) to adjust for impurities (net weight = gross weight multiplied by 0.5...0.7). Allegro field computers with SDI software were used for time studies.

The time studies were conducted as work element studies, in which the work cycle was divided into short, well-defined work elements. The time consumption per work element was recorded throughout the study. Results from earlier studies were used for road transport figures in cost calculation – transport of wood chips to 40 km distance costs 1.06 LVL m^{-3} (Thor et al., 2006).

The prime cost calculation were done on the base of a cost of machine hour (estimated using questionnaire method) and average productivity (estimated in the field trial). The machine hour cost included depreciation, fuel, service costs and salaries, based on averages from the questionnaires. Productivity of extraction and comminution were calculated in cubic meters per working hour, productivity of all kind of transport (terrain forwarding, road transport of stumps and wood chips) were divided to loading, unloading and driving to see effect of distance.

Several quality parameters of solid biofuel were evaluated during this study, including gross and net energy content in calculation to cubic meters (MWh LVm^{-3}) according to CEN/TS 1514918, relative moisture according to LVS CEN/TS 14774-1, total carbon according to LVS CEN/TS 15104, ash content according to LVS CEN/TS 14775 and bulk density according to LVS CEN/TS 15150. Undergrowth trees weren't evaluated separately.

'Environmental footprint' of biofuel production were calculated on the base of assumptions from Table 4.

Table 4

Input Data for the Environmental Assessment

Input data	Value
Terrain transport distance, m	300
Stump road transport distance, km	7
Stump trailer volume, m^3	70
Road transport distance, km	50
Chip trailer volume, m^3	70
Bulk density of chips, LVm^3 t_{dry}^{-1}	5

Results and Discussion

The site chosen for the study was very good stump extraction place – with a flat terrain and with no ground obstacles. Sandy soil simplified extraction of stumps and gave advantage when cleaning them, because sand didn't stick to the material, as clay does, therefore productivity of stump lifting was rather high in compare to average results in Scandinavian countries – 4.4 t_{dry} E_0-h^{-1}) (Laitila et al., 2008). Productivity in the stump lifting in the trials ranged between 4.5 and 6.5 t_{dry} E_0-h^{-1} (Table 5). Average productivity for different species was 2.9 (P), 5.8 (S) and or 6.1 (B) t_{dry} E_0-h^{-1}.

Table 5

Time Consumption and Productivity in a Stump Lifting (cmin t_{dry}^{-1})[1]

Operations / calculations	Plot 1	Plot 2	Plot 3
Craning out	133.40	184.67	190.32
Gripping	103.47	108.48	117.45
Lifting	203.25	350.75	307.52
Splitting/cutting	31.36	70.27	60.64
Cleaning	52.86	66.78	97.32
Craning in	92.66	105.57	117.20
Drop	91.23	97.44	104.71
Scarification	124.97	178.05	148.79
Moving to next stop	113.57	164.46	123.06
Other work time	3.44	2.09	2.04
Total cmin t_{dry}^{-1}	950.21	1,328.56	1,269.05
Time consumption per stump, cmin	2.00	3.50	3.00
T_{dry} E0-h^{-1}	6.31	4.52	4.73
Cost, LVL t_{dry}^{-1} [2]	5.97	8.33	7.96
Cost, LVL ha^{-1} [3]	191.04	266.56	254.72

[1] cmin – centi-minutes, one hundredth part of minute.

[2] The costs are calculated under the assumption of 38 LVL per machine hour.

[3] average stock – 32 t_{dry} ha^{-1}.

Total volume of roundwood assortments produced in the studied stands was 1,131 m^3 under bark or 269 m^3 ha^{-1}. An alternative way of calculating the output of stump volume is from the amount of roundwood, by mass or by volume, according to simple rules of thumb. Actual volume of stump biomass was 698 LVm^3 or 166 LVm^3 ha^{-1} after comminution (Table 6). The estimated biomass of stump from functions was 38 t_{dry} ha^{-1}, whereas actual measured mass was 32 t_{dry} ha^{-1}.

Table 6

Calculations of the Volume of Stumps

Parameter	Units	Value
Volume of stumps calculated accordingly to the volume of roundwood (*20% by volume or 14% by mass*)	m^3	226
Theoretical output of stumps	LVm^3	678
Calculated volume of stump storage	LVm^3	1,194
Volume of transported stumps	LVm^3	1,505
Calculated comminuted volume	LVm^3	631
Actual volume and calculated mass of chips in a lorry	LVm^3	698
	LVm^3 ha^{-1}	166
	t_{dry} ha^{-1}	32

Costs for the stump excavating averaged in 237 LVL ha^{-1}, assuming a machine cost of 38 LVL E_0-h^{-1}, or 7.4 LVL t_{dry}^{-1}. Productivity of the forwarding of stumps ranged between 5.6 and 7.7 t_{dry} E_0-h^{-1} depending on estimation of the amount of impurities in the material. Actual capacity of forwarder load is 10 t_{dry}. In Table 7 wood material has been assumed 70% of total weight, mainly based on old Swedish studies (Jonsson, 1985). To get dry mass, another 50% were subtracted.

Table 7

Time Consumption and Productivity of Forwarding in cmin t_{dry}^{-1}

Operation	cmin t_{dry}^{-1}
Crane out	91.78
Gripping	112.54
Crane in	109.77
Drop	75.20
Arrange (on load)	7.67
Move to next stop	36.70
Reload[1]	15.61
Other work time	3.48
Driving empty	71.46
Driving loaded	82.62
Unloading	294.29
Total forwarded, t_{dry}	16.00
Total, cmin t_{dry}^{-1}	901.13
T_{dry} E0-h^{-1}	6.66
Total cost, LVL t_{dry}^{-1} [2]	3.10

[1] The work element "Reloading" is time to pick up dropped pieces of stumps or roots that has been but slipped off the load carrier.

[2] Costs are calculated on a machine cost of 18 LVL E_0-h^{-1}.

Sump transportation to the terminal and crushing took place right after forwarding, which isn't normal practise in an industrial scale production, but was necessary to estimate the actual amount and quality trends of biofuel produced from stumps. A Specialized lorry equipped with two containers (35 m^3 both) and crane with slash-grapple were used for stump transportation. The average productivity of the stump transport was 3.5 t_{dry} E_0-h^{-1}. Such a low productivity was caused by low load density – it was more than twice looser than load density of wood chips. Stump road transport seems to be one of the key elements, where technical development is needed to increase efficiency. Another solution would be to avoid the stump transport at all by introduction of lighter mobile crushers, which can work directly beside piles of stumps at roadsides. It is also important to have the loaders with as long as possible cranes to be able to make wider piles of stumps at roadsides.

The average productivity of the crushing machine was 10 t_{dry} E_0-h^{-1}. It is at least 4 times less, than in case if the crusher is fed with roundwood. At the same time, the fuel consumption was rather high – about 2 l LVm^{-3} (this number might be overestimated, as it is based on average figures of fuel consumption, not on measurements during the field trials). Considerably low productivity of comminution leads to the conclusion that other type of crushers – with less 'horse powers' and feeding system suitable for irregular material might be more beneficial in the stump comminution.

The prime cost of the biofuel production was estimated using machine hour cost and the productivity based spreadsheet model, which includes the main positions of machine costs and salaries, but doesn't include administrative costs and profit. Total cost of all operations (extraction, forwarding, stump transport to 7 km distance, comminution and chip transport to 50 km distance) were 6.3 LVL LVm^3. Distribution of costs is presented in Figure 1.

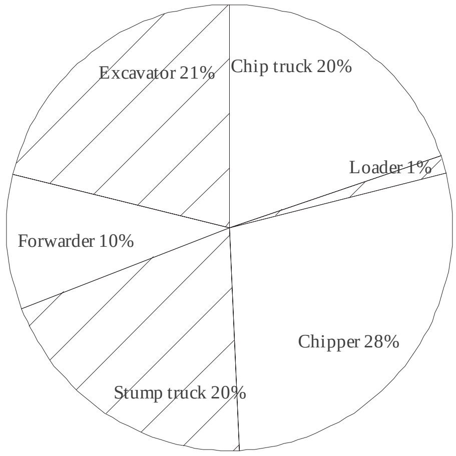

Figure 1. Percentage of prime costs of stump harvesting and chip production.

The evaluation of environmental effects of the stump harvesting within the field study included estimation of C emissions against gains according to the fuel consumption in different operations. Total C emissions to extract and to bring 1 LVm^3 of wood chips made of stumps to the terminal located in 50 km distance is 2.5 kg, in other words – 30 g of C has to be released to produce 1,000 g of C in renewable wood fuel. Figure 2 demonstrates, that the comminution and transport of stumps are very important working elements, where significant savings of emissions, as well as costs, are possible.

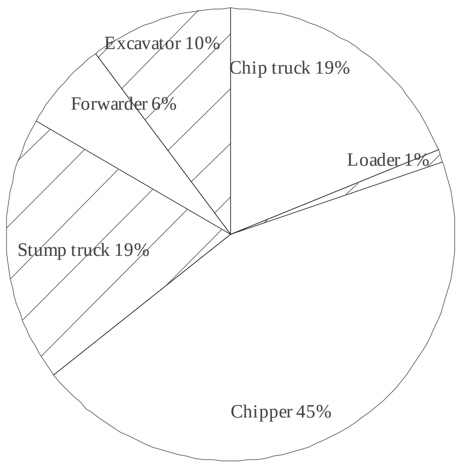

Figure 2. Percentage of C emissions during stump extraction, production and transportation of chips.

Stumps have considerably high gross energy content (5.7 MWh t_{dry}^{-1}), but due to high moisture, net energy content in stump chips is lower, than in chips produced from the slash (Table 8). Analysis of the particle size distribution shows significant share of small size particles (up to 7 mm in diameter), which reduces the quality of biofuel. This might be associated with a large share of sand in chips, because comminution was done directly after extraction and transport due to research needs, in spite of the fact that normal practise would be to leave stumps for 6...12 months in piles to wash out residual soil. The most significant qualitative issue found in the study was high ash content – 8.9% in average. According to literature data, proper management and storage of stumps may reduce ash content to 1.5% (Hakkila, 2003 and Kärhä, 2007).

Table 8

Comparison of Quality of Certain Types of Solid Biofuel (Data about Full Trees from Forest Infrastructure, Slash from Clear-cuts and Willows are Taken from Research Projects Elaborated by LSFRI Silava and Skogforsk (Thor et al., 2006, 2008))

Fractions	Stumps (data from field trials)	Full trees from forest infrastructure[1]	Slash from clearcuts[1]	Willows
Particle size distribution				
45...63 mm, g kg^{-1}	16	10	0	0
16...45 mm, g kg^{-1}	289	517	433	96
8...16 mm, g kg^{-1}	252	243	230	533
3.15...7 mm, g kg^{-1}	281	150	179	246
below 3.15 mm, g kg^{-1}	151	78	157	125
Energy content				
Gross, MWh t^{-1}	5.68	5.42	4.71	5.26
Net, MWh LVm^{-3}	0.71	0.67	0.90	0.51
Other options				
Relative moisture, g kg^{-1}	530	430	320	560
Total carbon, kg t^{-1}	431	414	414	454
Ash content, g kg^{-1}	8.9	0.8	4.2	1.7
Bulk density, kg LVm^{3}	220	181	218	170

[1] Naturally dried material.

Conclusions

The time studies indicated high productivity in a comparison to average Swedish conditions, which means that this working method is easy to learn, but still more attention has to be paid to splitting of stumps to do in such a way, which simplifies further forwarding and comminution operations.

The most significant difference between plots was found for one work element – lifting. In the plot No. 2 it took more than 3.5 min on average per stump compared to 2 min in the plot No. 1 and 3 min in the plot No. 3. Second plot was situated on a sand ridge where the stumps often had deep roots, which took more time to lift them up. From peat soil (plot No. 3) stumps were easier to lift, but more difficult to 'clean'.

Forwarding has significant potential to increase efficiency, because load sizes during studies were 5.5...9.3 t which is slightly more than a half of the maximum load of the forwarder.

Road transport of stumps is costly and time consuming operation due to the low density of loads and significant time consumption for loading and unloading; therefore, this operation should be eliminated by using lighter mobile crushers suited for irregular biomass and direct transport of chips to end use site.

The prime cost of the stump biofuel (6.3 LVL LVm^3) is comparable to the market price of wood chips, but it should be reduced to left space for profit and additional costs, which arises in 'real world' conditions. Significant reduction may be reached by the optimization of transportation and comminution of stumps.

The field study may a give wrong impression about the quality of chips produced from stumps, because they were comminuted fresh; consequently, moisture and ash (mostly residual soil) content were high, but the net energy content – low.

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