The Top Diameter Limits in Integrated Forest Fuel Procurement System: Lithuanian Case Studies

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Abstract

Economic possibility of undelimbed stems parts usage for forest fuel production is analysed in this article. The aim of the research is to assess the top diameter limits in integrated cut-to-length and forest fuel wood procurement system. The article provides mathematical model for calculation of spruce, pine and birch stems delimbing time. Delimbing costs of 1 m^3 of wood, comprised from the same diameter stems parts, are presented in the article.

In order to reach the goal, study of time expenditures of spruce, pine and birch stems delimbing was carried out and delimbing costs were calculated. Delimbing time of 725 spruces, 733 pines and 1000 birches was observed by cumulative timing method. The top diameter limits were estimated by maximum difference in net income of integrated and cut-to-length wood procurement.

The top diameter limits depend on difference in prices of pulpwood and forest fuel. The top diameter limits were estimated for spruces, pines and birches in relation with diameter and development class of trees.

Key words: top diameter limits, forest fuel, delimbing, time expenditures, costs, net income

Introduction

Seeking to implement the tasks of the Kioto protocol in 2004 the Seimas of the Republic of Lithuania approved National strategy of 2004 – 2010, of which one of the objectives is to strive for renewable resources of up to 12% in the total primary energy balance by 2010 (*Programme*... 2004). The contribution of renewable energy sources represented 8.2 % of the total primary energy production in Lithuania in 2004 (Užšilaitytė 2005). Wood fuel composed the major part of renewable energy resources (92%).

The increasing demand for forest fuel motivates to improve the traditional cut-to-length wood procurement technology by integrating the forest fuel production. Forest logging residues may be used as wood fuel also. Lithuanian forest management and inventory institute calculated that annual amount of forest logging residues is 2.58 mil. m^3, and only 0.8 mil.m^3 of the annual amount might be used for production of wood fuel (Rutkauskas 2005).

The top part of the stems may be significant forest fuel source. The background of problem is to select the best alternative: to spent time and costs for delimbing the thin parts of stems with diameter between 6 and 14 cm for production of small amounts of pulpwood or to use undelimbed stems parts for forest fuel.

The aim of the research is to assess the top diameter limits in integrated wood procurement system. Integrated wood procurement system means that both timber assortments and forest fuel are produced on the logging site. The top diameter limit means that net income from the wood reaches the maximum when the top is cross-cut at such diameter.

The following aspects of the research were analysed in order to reach the goal:

- study of time expenditures of spruce, pine and birch stems delimbing was carried out;
- mathematical model for calculation of spruce, pine and birch stems delimbing time expenditures was formed;
- costs of spruce, pine and birch stems delimbing were calculated;
- the top diameter limits were estimated by maximum difference in net income between integrated and cut–to-length wood procurement systems.

Material and methods

Study of stems delimbing time expenditures

The aim of this study was to estimate the delimbing time of different diameter stem parts by tree species, DBH (diameter in breast height) and development class. The results were used for estimating the difference in delimbing time expenditures when the top diameter limit changes.

Delimbing time of 725 spruces, 733 pines and 1000 birches was assessed. The trees were selected according to their development class (Kairiūkštis 1972) in pure stands which may be compared as follows: vigorously-developed trees – class A' (class I by G. Kraft); well-developed trees – class A (class II by G. Kraft); weekly-developed trees -class B (class III by G. Kraft); trees developed in a depressed state – class C (class IV and V by G. Kraft) and DBH group (4 groups: DBH- up to 15 cm; 16-25 cm; 26-35; 36 cm and more).

The stems of felled trees were marked every 2 metres; the diameter of every stem part was measured and delimbing time was observed by cumulative timing method (*Forest Work Study Nomenclature* 1995). A skilled forest worker with a chainsaw performed the delimbing. The number of necessary observations was calculated by using statistical formulas and pilot study data (reliability –95%, accuracy – 5%).

The study data were grouped according to diameter of stem part, tree species, DBH and development class. The mean of delimbing time, standard error of mean, and accuracy were calculated for stems parts with diameter from 6 cm up to 14 cm (every 1 cm). The volume of stems parts was assessed using tables of wood volume (Kuliešis *et al*. 1999). Mathematical model for calculation of delimbing time expenditures was formulated by using the multiple regression analysis method.

Assessment of stems delimbing costs

Delimbing costs (C_{del}) of 1m^3 of wood, comprised from the same diameter (d) 2 metres long stem parts, were calculated according to Formula 1:

$$C_{del} = p * T_d * (k_w + z) \qquad (1)$$

where, p – coefficient for changing productive work time to operating time consumption (1.16);

T_d - productive work time of delimbing of 1m^3 wood, comprised of d diameter 2 m length assortments (the result of study), h/m^3;

k_w – wage costs, including social insurance costs and additional costs, Euro/h;

z – operating costs of chainsaw, Euro /h.

Operating costs of chainsaw were set at 1.04 Euro /h. Cost of 2.47 Euro/h was used as cost of forest worker to an employer.

The assessment of top diameter limits in integrated wood procurement system

Stems parts with diameter of 6-14 centimetres are used for pulpwood production in cut-to–length wood procurement technology. The economical availability to use such stems parts for forest fuel production was analysed.

The top diameter limit (TDL) means that undelimbed stem part above TDL is used for forest fuel production. Minimum pulpwood diameter is TDL. The top diameter limit was estimated by the maximum difference in net income between integrated and cut-to-length wood procurement, changing TDL from 6 to 14 cm in integrated wood procurement. The net income was calculated for 1 m^3 of wood, comprised from stem parts with diameter from 6 to 14 cm. All wood was used for pulpwood when TDL was equal to 6 cm. We assumed that in such case the volume of pulpwood was equal to 1 m^3.

$\Delta NI \rightarrow max$, when TDL changes from 6 to 14 cm.

$$\Delta NI = p_f * (\Delta C_{del} - \Delta P) \qquad (2)$$

where ΔNI – the difference in net income between integrated and cut-to-length wood procurement, Euro/m^3;

p_f – proportion of forest fuel volume with total wood volume. This proportion changes when TDL changes;

ΔC_{del} – the difference between delimbing costs when stems are delimbed from 6 cm and from TDL, Euro/m^3;

ΔP - the difference in prices of pulpwood and forest fuel, Euro/m^3.

The net income difference calculation and the TDL assessment example is presented in Table 1.

Table 1. The difference in net income and top diameter limit (spruce, A development class, DBH – up to 15 cm)

Top diameter, cm	Diameter of stem part used for forest fuel, cm	p_f	ΔC_{del}, Euro/m^3	Difference in prices of pulpwood and forest fuel (ΔP), Euro/m^3										
				0.3	0.6	0.9	1.2	1.4	1.7	2.0	2.3	2.6	2.9	3.2
6	-	0	0	0	0	0	0	0	0	0	0	0	0	0
7	6-7	0.06	0.2	0.2	0.1	0.1	0.1	0.1	0.1	0.1	0.0	0.0	0.0	0.0
8	6-8	0.13	0.4	0.3	0.3	0.2	0.2	0.2	0.1	0.1	0.1	0.0	0.0	-0.1
9	6-9	0.21	0.5	0.5	0.4	0.4	0.3	0.2	0.2	0.1	0.1	0.0	-0.1	-0.1
10	6-10	0.31	0.7	0.6	0.5	0.5	0.4	0.3	0.2	0.1	0.0	-0.1	-0.2	-0.3
11	6-11	0.44	0.9	0.8	0.7	0.6	0.4	0.3	0.2	0.0	-0.1	-0.2	-0.3	-0.5
12	6-12	0.60	1.2	1.0	0.8	0.6	0.5	0.3	0.1	-0.1	-0.2	-0.4	-0.6	-0.8
13	6-13	0.79	1.4	1.2	0.9	0.7	0.5	0.2	0.0	-0.2	-0.4	-0.7	-0.9	-1.1
14	6-14	1.00	1.6	1.3	1.0	0.7	0.4	0.1	-0.1	-0.4	-0.7	-1.0	-1.3	-1.6
Top diameter limit, cm				14	14	14	13	11	10	9	8	7	7	6

Results

Time expenditures of stems delimbing

The delimbing time of 2458 stems was analysed and delimbing time expenditures were estimated according to the diameter of delimbed stem part, tree species, development class and DBH. According to experimental data the parameters of model for calculation of delimbing costs (3) were estimated (Table 2).

$$T_d = e^{(b0+b1*DC+b2*D+b3*d)}, \quad (3)$$

where T_d – the productive time of delimbing 1m³ wood comprised of d diameter and 2 m length assortments, h/m³;

b0, b1, b2, b3 – model parameters;

e – constant equals 2.71, the base of the natural logarithm;

DC - variable describing tree development class (DC =1, when tree development class is A'; DC = 2, when tree development class is A; DC = 3, when tree development class is B and DC = 4, when tree development class is C);

D – variable describing tree DBH group (D=1, when tree DBH is up to 15 cm; D=2, when DBH is 16-25 cm; D=3, when DBH is 26 –35 cm and D=4, when DBH is 35 cm and above);

d – diameter of stem part, cm.

Table 2. Parameters of model 3

Tree species	b0	b1	b2	b3	R
Spruce	0,6446	-0,0845	0,1596	-0,1562	0,87
Pine	0,5629	-0,1455	0,1604	-0,1645	0,82
Birch	0,5714	-0,1880	0,1475	-0,1987	0,85

When other factors are constant the influence of one factor can be described as follows: delimbing time expenditures of 1m³ wood, comprised of the same diameter and 2 m length assortments, increase when DBH or development class increases or diameter of stem part decreases. The largest delimbing time expenditures are typical of spruces, then pines and birches.

The costs of delimbing stems

The delimbing costs depend on the same factors as delimbing time expenditures: on tree species, DBH and development class. Delimbing costs of 1m³ wood, comprised of the same diameter and 2 meters long stem parts, vary from 4.9 to 0.9 Euro/m³ for spruces (Figure 1), from 3.8 to 0.7 Euro/m³ for pines and from 2.7-0.4 Euro/m³ for birches when diameter of stem parts increases from 6 to 14 cm (for trees of A development class). The delimbing costs decrease within decreasing of tree development class and DBH.

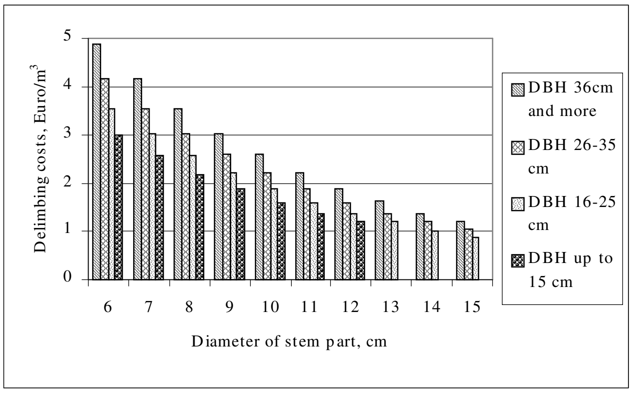

Figure 1. Delimbing costs of 2 metres long stems parts (spruce, A development class)

The top diameter limits in integrated wood procurement system

The maximum difference in net income was calculated and the top diameter limits were estimated for spruces, pines and birches in relation with their diameter and development class (Tables 3-5).

The differences in net income for spruces (A development class, DBH – up to 15cm) vary from –1.6 to 1.3 Euro/m³ (Figure 2).

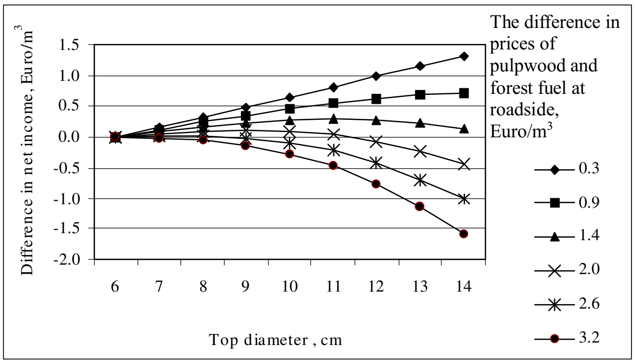

Figure 2. The difference in net income between integrated and cut-to-length wood procurement (spruce, A development class, DBH – up to 15 cm)

When the difference in prices of pulpwood and forest fuel is 0.3-0.9 Euro/m³, the maximum difference in net income is reached when the top diameter limit is 14 cm (A development class, DBH – up to 15 cm). When the difference in prices of pulpwood and forest fuel increases from 1.2 to 2.9 Euro/m³, TDL decrease from 13 to 7 cm. If difference in prices of pulpwood and forest fuel exceeds 2.9 Euro/

Table 3. Top diameter limits in integrated wood procurement system (spruce) (cm)

The difference in prices of pulpwood and forest fuel at roadside, Euro/m^3	Tree development class															
	A'				A				B				C			
	DBH, cm															
	< 15	15-24	25-34	>35	< 15	15-24	25-34	>35	< 15	15-24	25-34	>35	< 15	15-24	25-34	>35
0.3	14	14	14	14	14	14	14	14	14	14	14	14	14	14	14	14
0.6	14	14	14	14	14	14	14	14	14	14	14	14	14	14	14	14
0.9	14	14	14	14	14	14	14	14	14	14	14	14	13	14	14	14
1.2	13	14	14	14	13	14	14	14	12	13	14	14	12	13	14	14
1.4	12	13	14	14	11	12	13	14	11	12	13	14	10	11	12	13
1.7	11	12	13	14	10	11	12	13	10	11	12	13	9	10	11	12
2.0	10	11	12	13	9	10	11	12	8	10	11	12	8	9	10	11
2.3	9	10	11	12	8	9	10	11	8	9	10	11	7	8	9	10
2.6	8	9	10	11	7	8	9	11	7	8	9	10	6	7	8	9
2.9	7	8	9	10	7	8	9	10	6	7	8	9	6	7	8	9
3.2	7	8	9	10	6	7	8	9	6	7	8	9	6	6	7	8
3.5	6	7	8	9	6	7	8	9	6	6	7	8	6	6	7	8
3.8	6	7	8	9	6	6	7	8	6	6	7	8	6	6	6	7
4.1	6	6	7	8	6	6	7	8	6	6	6	7	6	6	6	7
4.3	6	6	7	8	6	6	6	7	6	6	6	7	6	6	6	6
4.6	6	6	6	7	6	6	6	7	6	6	6	6	6	6	6	6
4.9	6	6	6	7	6	6	6	6	6	6	6	6	6	6	6	6
5.2	6	6	6	7	6	6	6	6	6	6	6	6	6	6	6	6
5.5	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6

Table 4. Top diameter limits in integrated wood procurement system (pine) (cm)

The difference in prices of pulpwood and forest fuel at roadside, Euro/m^3	Tree development class															
	A'				A				B				C			
	DBH, cm															
	< 15	15-24	25-34	>35	< 15	15-24	25-34	>35	< 15	15-24	25-34	>35	< 15	15-24	25-34	>35
0.3	14	14	14	14	14	14	14	14	14	14	14	14	14	14	14	14
0.6	14	14	14	14	14	14	14	14	14	14	14	14	12	14	14	14
0.9	13	14	14	14	13	13	14	14	12	13	14	14	11	12	13	14
1.2	12	13	13	14	11	12	13	14	10	11	12	13	9	10	11	12
1.4	10	11	12	13	9	10	12	12	9	10	11	12	8	9	10	11
1.7	9	10	11	12	8	9	10	11	8	8	9	10	7	8	9	10
2.0	8	9	10	11	7	8	9	10	7	8	8	8	6	7	9	9
2.3	7	8	9	10	7	8	8	10	6	7	8	9	6	6	7	8
2.6	7	7	9	10	6	7	8	9	6	6	7	8	6	6	6	7
2.9	6	7	8	9	6	6	7	8	6	6	6	7	6	6	6	6
3.2	6	7	7	8	6	6	7	8	6	6	6	7	6	6	6	6
3.5	6	6	7	8	6	6	6	8	6	6	6	6	6	6	6	6
3.8	6	6	6	7	6	6	6	7	6	6	6	6	6	6	6	6
4.1	6	6	6	7	6	6	6	6	6	6	6	6	6	6	6	6
4.3	6	6	6	7	6	6	6	6	6	6	6	6	6	6	6	6
4.6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6

Table 5. Top diameter limits in integrated wood procurement system (birch) (cm)

The difference in prices of pulpwood and forest fuel at roadside, Euro/m^3	Tree development class															
	A'				A				B				C			
	DBH, cm															
	< 15	15-24	25-34	>35	< 15	15-24	25-34	>35	< 15	15-24	25-34	>35	< 15	15-24	25-34	>35
0.3	14	14	14	14	14	14	14	14	14	14	14	14	14	14	14	14
0.6	13	14	14	14	12	13	14	14	11	12	12	13	10	11	12	12
0.9	11	12	12	13	10	11	12	12	9	10	11	11	8	9	10	10
1.2	9	10	11	12	9	9	10	11	8	8	9	10	7	7	8	9
1.4	8	9	10	11	7	8	9	9	6	7	8	9	6	6	7	8
1.7	7	8	9	10	7	7	8	9	6	6	7	8	6	6	6	7
2.0	7	7	8	9	6	7	7	8	6	6	6	7	6	6	6	6
2.3	6	7	7	8	6	6	7	7	6	6	6	6	6	6	6	6
2.6	6	6	7	8	6	6	6	7	6	6	6	6	6	6	6	6
2.9	6	6	6	8	6	6	6	6	6	6	6	6	6	6	6	6
3.2	6	6	6	7	6	6	6	6	6	6	6	6	6	6	6	6
3.5	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6

m^3 then pulpwood production from stems parts with diameter 6 cm is economically useful (Figure 3).

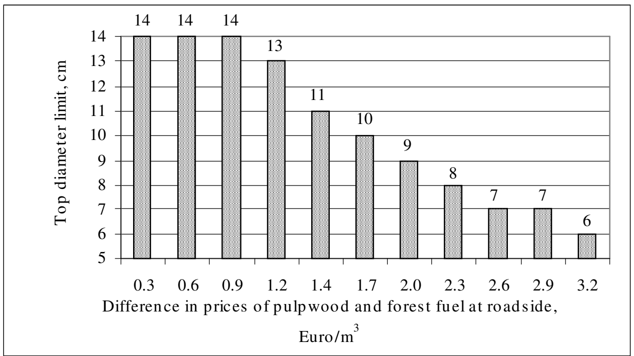

Figure 3. The top diameter limits in integrated wood procurement system (spruce, A development class, DBH – up to 15 cm)

The difference in net income for pines (A development class, DBH – up to 15 cm) is lower than for spruces and it varies from 0.9 to –2.0 Euro/m^3 (Figure 4). When the difference in prices of pulpwood and forest fuel is 0.3-0.6 Euro/m^3, the maximum difference in net income is reached when the stems parts from diameter 6 to 14 cm are used for forest fuel. When the difference in prices of pulpwood and forest fuel increases from 0.9 to 2.3 Euro/m^3, TDL decrease from 13 to 7 cm. If difference in prices of pulpwood and forest fuel exceeds 2.3 Euro/m^3 then pulpwood production from stems parts with diameter 6 cm is economically useful.

The lowest difference in net income is for birches (A development class, DBH – up to 15cm) in comparison with spruces and pines. It varies from – 1.2 to 0.5 Euro/m^3 (Figure 5). The pulpwood price should be no more than 1.7 Euro/m^3 higher than the price of forest fuel that forest fuel can compete for some amount of stems useful for pulpwood. The top diameter limit is equal to 14 cm when the difference in prices of pulpwood and forest fuel is 0.3 Euro/m^3. When the difference in prices increases from 0.6 to 1.7 Euro/m^3, TDL decrease from 13 to 7 cm. If the difference in prices exceeds 1.7 Euro/m^3 then pulpwood production from stems parts with diameter 6 cm is economically useful.

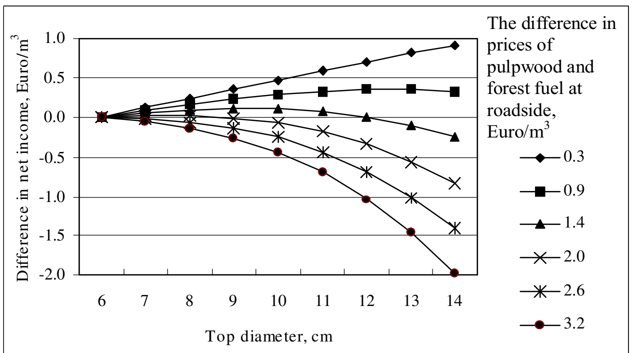

Figure 4. The difference in net income between integrated and cut-to-length wood procurement (pine, A development class, DBH – up to 15 cm)

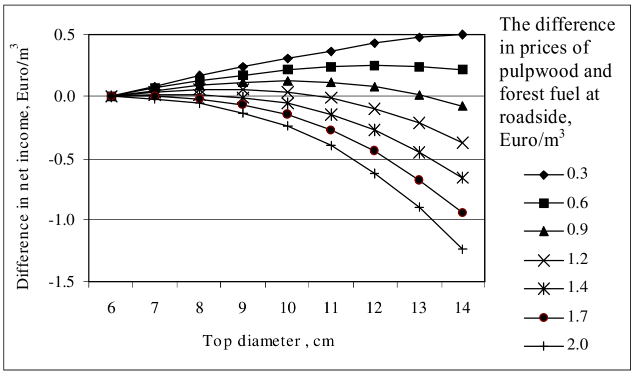

Figure 5. The difference in net income between integrated and cut-to-length wood procurement (birch, A development class, DBH – up to 15 cm)

Discussion

There have been no investigations of dependence of delimbing time expenditures and costs on stems parts diameter in Lithuania so far. Although delimbing time expenditures of mean 1 m^3 of wood are studied widely in Lithuania and abroad, the results cannot answer how delimbing costs change when some parts of undelimbed stems are used for forest fuel. Delimbing time expenditures vary from 1.4 to 0.1 h/m^3, when the average stem volume shifts from 0.05 to 1.9 m^3 (Andrikonis *et al.* 1988). These figures additionally include time expenditures for moving from one tree to another. Our results (1.03-0.04 h/m^3) are similar to the data stated above having in mind that moving time is not included. Šakūnas (1997) considers that delimbing time of spruces is 0.828 h/m^3.

Our results indicated that delimbing costs of thin parts of stems are very costly (2.7-4.9 Euro/m^3) taking into account that the average cost of 1 m^3 of roundwood production (without forwarding) is about 4.3-5.2 Euro/m^3. In respect that demand for forest fuel and price are increasing, that the forest sector faces overfull employment, probability of increasing of minimal diameter of pulpwood is very high.

Production of forest fuel from thin trees (DBH 8-12) or thin stems parts can be economically advantageous in the nearest future. However, current pulpwood and forest fuel price ratio is negative for the forest fuel production from stem wood in Lithuania. The average pulpwood price was 4.9 Euro/m^3 higher than the price of forest fuel in 2005. However a high possibility of forest fuel price increases exist. Additionally a scheme for greenhouse gas emission allowance trading can promote the use of forest fuel and increase its price.

Economic investigations of usage of whole trees or small stems parts, usable for pulpwood, as forest fuel are widely carried out in foreign countries. Heding (1990) writes that integrated harvesting is less profitable than whole tree chipping in second thinning and 20% less profitable than harvesting only shortwood and pulpwood in the third thinning in Denmark. From 1980 a system for harvesting fuel chips has been used in Denmark for thinning young softwood stands. This system was applied in older stands when pulpwood prices decreased (Suadicani 2003). Röser *et al* (2003) maintains that due to low pulpwood price, a part of pulpwood has been used as a forest fuel and this amount may increase in future.

Tantuu (2005) claims that in Finland integrated harvesting is not competitive option compared to industrial roundwood harvesting with today's pulpwood and forest chip prices, but competitiveness is very sensitive to the price changes of pulp and energy wood. Junginger *et al* (2005) also see a possibility to decrease forest fuel production costs by using fraction currently used as pulpwood for forest fuel production. Costs might be reduced as much as by 16 %. From the economic point of view profitability of forest fuel production depends on various factors as economic state of the country, level of wood prices, wages, subsidy and tax systems. Therefore profitability differs between different countries.

Our research also indicates that economical viability of the use of wood fraction usable for pulpwood as forest fuel depends on the difference in prices of pulpwood and forest fuel.

Conclusions

The research has revealed that delimbing time expenditures of thin stem parts are several times higher than there of thicker stem parts. Mathematical model for calculation of spruce, pine and birch delimbing time was developed in this study.

Increasing of top diameter leads to decreasing of stems delimbing costs. Delimbing costs of 1m^3 wood, comprised of the same diameter and 2 metres long stem parts decrease from 4.9 to 0.9 Euro/m^3 for spruces, from 3.8 to 0.7 Euro/m^3 for pines and from 2.7-0.4 Euro/m^3 for birches when the diameter of stem parts increases from 6 to 14 cm (for trees of A development class).

Wood fuel can compete for thin stem parts with diameter 6-14 cm if pulpwood price is 0.3-0.9 Euro/m^3 higher than wood fuel price for spruces (A development class, DBH – up to 15 cm), 0.3-0.6 Euro/m^3 for pines and 0.3 Euro/m^3 for birches. When the difference in prices increases, the top diameter limits decrease.

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ПРЕДЕЛЫ ДИАМЕТРА ВЕРШИН В КОМПЛЕКСНОЙ ЗАГОТОВКЕ ДРЕВЕСНОГО ТОПЛИВА В ЛИТВЕ

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Резюме

В статье анализируется экономическая возможнось использовать необрубленные части ствола деревьев для загатовки щепы. Цель этого исследования – определить пределы диаметра вершин дерева в комплексной заготовке круглых сортиментов, при которых экономически оправдана заготовка топливного сырья. Затраты времени на обрубку сучьев 725 стволов ели, 733 сосны и 1000 берёзы определены методом хронометрирования. Расходы для обрубки сучьев рассчитаны, используя данные исследования. Пределы диаметра вершины были определены по максимальной разнице в чистом доходе между комплексной и сортиментной лесозаготовками.

В статье представлена математическая модель определения затрат времени обрубки сучьев стволов елей, сосен и берёз. Определены затраты обрубки сучьев, когда 1 m^3 древесины составляют части стволов одинакого диаметра, в зависимости от минимального диаметра сортиментов.

Пределы диаметра вершин зависят от разницы цен баланса и древесного топлива. Пределы диаметра вершин определены для елей, сосен и берёз в зависимости от диаметра и класса развития деревьев.

Ключевые слова: пределы диаметра вершин, древесное топливо, обрубка сучьев, затраты времени, расходы, чистый доход.