LITHUANIAN FOREST RESEARCH INSTITUTE

Studies on forestry, technology and economy of forest fuel production in Rokiskis forest enterprise

Final report

Financed by Swedish Energy Agency

Girionys – 2002

CONTENT

INTRODUCTION

Currently in Lithuania attention to logging residues as fuel in boiler-house is increasing. It is dependent on objective to decrease using of expensive fossil fuels as oil, gas and coal which usually is imported from foreign countries. At the same time it will decrease the emissions and improve the environment conditions. In resolutions of international conferences as Madrid declaration it is recommended increased use of local renewable energy sources to 12-15 %. Striving to accelerate forest fuel production in Lithuania in 2000 it was done first research. In this research it was involved Swedish and Lithuanian specialists.

This research is input of Lithuanian Forest Research Institute to the Joint Swedish-Lithuanian Wood Fuel Development Project Phase II. The main tasks in this research:

1) estimation of forest fuel resources potential to be used for boiler houses in Rokiskis forest enterprise

2) establishment of demonstration objects in pre-commercial, commercial thinnings, final cuttings and ash utilization areas of Rokiskis forest enterprise;

3) assessment of technological and economical aspects of forest fuel production in different types of cuttings;

4) evaluation of ash handling methods.

Preparation of forest fuel production demonstration objects in pre-commercial, commercial thinnings, final cutting and ash utilization in the Rokiskis forest enterprise is one of the most important objectives. In this work Swedish experience in forest fuel production was used. The estimation of work expenditure as well cost in traditional and forest fuel production technologies and estimation of wood fuel resources is very important from practical point of view in the future forest fuel production development in Rokiskis forest enterprise as well in other forest and energy enterprises.

1. ASSESSMENT OF FOREST FUEL RESOURCES IN ROKISKIS FOREST ENTERPRISE (A.Kuliesis, J.Saladis)

1.1. METHODICS FOR ESTIMATION OF FOREST FUEL RESOURCES

Stem-wood resources were assessed using data of stand-wise forest inventory. The amount of wood in final cutting areas was assessed according to the area of mature stands. The area of mature stands for the next two decades was forecasted using the model of forest resources dynamics "Kupolis" (Kuliesis, Petrauskas, 2000). Specialists of State Forest Inventory and Management Institute and Lithuanian Agricultural University created this model and designed it for forest resources and use forecast. The newest data of stand-wise forest inventory as well as Lithuanian National Forest Inventory data were used for the forecast of forest resources development. In this model was ignored influence of forest area increase, climate changes and natural disasters. The amount and structure of non-merchantable wood was separately assessed in final cuttings, commercial and pre-commercial thinnings.

For the estimation of volume of removable wood, bark and branches from final cutting and commercial thinning areas merchantable volume and assortment tables were used. For this assessment average tree diameters in stand and adequate distribution of removable timber by tree species and percentage of branch volume were ascertained. According to the analysis of data the share of non-merchantable wood from stem volume was estimated. In final cuttings it comprises 13% and in commercial thinnings - 17%.

The area of precommercial thinnings increases with increasing area of young stands and management intensity. It was assumed that after reforestation of cutting areas, new young stands up to 20 years of age would be cleaned 3 times. It means that during10 years every young stand will be cleaned 1-2 times. In some very fertile forest sites cleaning will be necessary every 3-5 years, while in poor sites with pure pine or birch stands such a silvicultural measure will not be necessary at all. It was determined that up to 10 year-old stands during one cleaning could be removed 4 m^3/ha of wood and in 11-20 year old stands - 12 m^3/ha of small stems and 2.4 m^3/ha of branches. Another important source of forest fuel is bark from industrial assortments. Some assortments, like pulpwood, saw-logs forest enterprises are selling with bark. It was estimated, that 60% of industrial assortments from final cuttings and 40% from commercial thinnings could be debarked and this bark could be used in Lithuania as forest fuel.

In Lithuania it is not worthwhile or even impossible to take from forest all the amount of non-merchantable wood. E.g., taking out from forest stumps of trees is very expensive. It is even not possible in commercial thinnings. Forest soils after taking out all wood will be exhausted and such area should be fertilized. Due to this reason it is allowed to take out from the forest all merchantable branches and up to 30% of volume of non-merchantable branches. The amount of non-merchantable branches, which can be used for fuel-wood in thinnings, it is advisable to reduce down to 20%.

1.2. THEORETICAL STUDIES ON FOREST FUEL RESOURCES ASSESSMENT

Volume of firewood as well as logging residues were assessed for 2 decades – 2001-2010 and 2011-2020 for all stands of Rokiskis forest enterprise in industrial and protective III-IV groups forest stands growing on normally irrigated or temporarily wet sites. The same parameters were assessed for the state forests of Rokiskis forest enterprise. The calculations were made for every forest district and forest tree species.

At present for fuel usually is used firewood. The most important additional resource is logging residues. Logging residues from all cuttings in all forests contain 60 thous. solid m^3 (Table 1.1). More than a half of this volume (31.3 thous. solid m^3) is in final cutting areas (Table 1.1). In 2011-2020 it is forecasted increasing of the amount of logging residues up to 71.5 thous. solid m^3 . The volume of possible to take out logging residues in all forests from all cuttings in 2001-2010 contain 19.6 thous.

solid m^3 (Table 1.1). It makes 33 % from the total volume of logging residues. In final cuttings it is possible to take as forest fuel 13.8 thous. m^3 or 44 % of the whole volume of logging residues. The volume of firewood in all cuttings is almost the same as the volume of logging residues possible to take as forest fuel (Table 1.1). In final cuttings the volume of firewood contain 11.5 thous. solid m^3, to compare to 13.8 thous. solid m^3 of logging residues.

Table 1.1. Distribution of fuel wood in 2001-2010 and 2011-2020 from industrial and protective forests of Rokiskis forest enterprise on normally irrigated and temporarily wet sites by cutting and user categories.

Object	Cuttings	Logging residues, in thous. solid m^3					Firewood, thous. solid m^3
		Total	From them possible to take out as fuel wood				
			Bark	Non-merchantable branches	Other	Total	
2001-2010							
State forests	All	21.7	4.2	2.2	1.0	7.4	7.8
	final	12.5	3.0	1.8	0.7	5.5	4.3
All forests	All	60.0	10.9	6.1	2.6	19.6	20.0
	final	31.3	7.3	4.6	1.9	13.8	11.5
2011-2020							
State forests	All	28.0	5.3	2.9	1.3	9.5	8.9
	final	15.8	4.0	2.1	1.0	7.1	4.9
All forests	All	71.5	13.0	8.0	2.9	23.9	25.6
	final	40.7	9.5	6.0	2.3	17.8	15.7

The volume of total logging residues in 2001-2010 from all cuttings in all forests contain 60.0 thous. solid m^3 while in state forests – 21.7 thous. solid m^3 (Table 1.1). In final cutting areas of all forests was estimated 31.3 thous.m^3 volume of total logging residues. From this amount 12.5 thous. solid m^3 of logging residues are in the state forests. The volume of possible to take out logging residues from state forest is 7.4 thous. m^3. In final cutting areas could be extracted 5.5 thous. m^3 (Table 1.1). The percentage of possible take out logging residues in state forests will contain 34 % from total amount of logging residues. The biggest volume of possible to take out logging residues and fire wood is in Juodupe and Rokiskis (1.4-1.5 thous.m^3) as well as in Vyzuona and Kamajai (1.3 thous.m^3) forest districts (Table 1.2).

Logging residues of spruce trees contain the biggest total volume - 21.9 thous. m^3 (Table 1.3). In all forests of Rokiskis forest enterprise birch logging residues in 2001-2010 will contain 17.1 thous.m^3 and pine logging residues - 10.7 thous. m^3 (Table 1.3). Comparing the volume of possible to take out logging residues and firewood we have a slightly different situation. The highest volume of logging residues and firewood together - 9.5 and 12.7 thous. m^3 can be produced from spruce and birch trees (Table 1.3). Pine logging residues contain 6.6 thous. m^3. Logging residues of these tree species contain 73 % of all possible to take out logging residues and firewood.

Table 1.2. Amount of total and possible to take out logging residues and firewood in 2001-2020 from Rokiskis forest enterprise industrial and protective state forests (III-IV gr.) on normally irrigated and temporarily wet sites by districts

District	Cuttings	Volume in thous. m^3 per year			
		2001-2010		2011-2020	
		Total logging residues	Possible to take out logging residues and firewood	Total logging residues	Possible to take out logging residues and firewood
Giria	All	1.2	0.9	1.5	0.8
	final	1.0	0.6	0.9	0.6
Juodupe	All	4.2	2.7	4.7	3.0
	final	2.5	1.9	2.7	1.9
Kamajai	All	2.4	2.1	4.0	3.1
	final	1.2	1.3	2.2	2.1
Kazliskis	All	0.9	0.5	1.2	0.8
	final	0.6	0.4	0.9	0.5
Obeliai	All	1.8	1.0	2.2	1.8
	final	1.0	0.7	1.2	1.2
Pandelys	All	0.7	0.5	1.3	0.7
	final	0.4	0.4	0.5	0.4
Rokiskis	All	4.3	2.4	4.6	2.8
	final	2.5	1.6	2.5	1.9
Selyne	All	2.1	1.4	3.4	2.3
	final	1.2	1.0	2.0	1.5
Suvainiskiai	All	0.7	1.2	1.5	0.8
	final	0.4	0.7	1.0	0.5
Vyzuona	All	3.5	2.4	3.7	2.3
	final	1.7	1.3	1.9	1.4
In all forests	All	21.7	15.2	28.0	18.4
	final	12.5	9.8	15.8	12.0

Table 1.3. Distribution of firewood and logging residues by tree species in 2001-2010 planned all cuttings from Rokiskis forest enterprise industrial and protective forests (III-IV gr.) on normally irrigated and temporarily wet sites

Tree species	Volume in thous. m^3 per year			
	All forests		State forests	
	Total logging residues	Logging residues possible to take out and firewood	Total logging residues	Logging residues possible to take out and firewood
Pine	10.7	6.6	4.7	2.9
Spruce	21.9	9.5	9.2	4.5
Oak	0.7	0.3	0.1	0.1
Ash	0.4	0.3	0.1	0.1
Birch	17.1	12.7	5.3	4.3
Black alder	1.3	0.9	0.4	0.3
Aspen	2.5	4.1	1.3	2.4
Grey alder	5.2	5.0	0.5	0.5
Other	0.2	0.2	0.1	0.1
Total	60.0	39.6	21.7	15.2

In state forests was estimated the biggest volume of spruce logging residues 9.2 thous.m^3, while volume of birch and pine logging residues is very close (5.3 and 4.7 thous. m^3). More than a half of possible to take out volume of logging residues in state forests contain stem bark and 1/3 - non-merchantable branches. They contain 4.2 and 2.2 thous. m^3 (Table 1.1). The volume of merchantable branches and small stems is not so high. It contain from 6 to 7% from the whole volume of possible to take out logging residues for every of these categories.

In 2011-2020 the volume of possible to take out logging residues and firewood will be by 22% higher. Mostly it will be caused by an increase of total cuttings in private forests. In period from 2011 till 2020 the highest annual volumes of fuel wood can be got in state forests of Kamajai forest district (2.1 thous. m^3) as well as in Juodupė and Rokiskis (1.9 thous. m^3) forest districts (Table 1.2).

Currently heat producers pay not for the amount of fuel wood but for energy content. The energy content of fuel wood depends on tree species, density of wood and mostly on wood humidity. In Lithuania most buyers of wood chips control that the humidity of wood-chips must be not higher than 50%. We have calculated the amount of energy that could be produced in Rokiskis forest enterprise. The results are presented in Table 1.4. The humidity of fuel wood can be easily reduced from 50 to 35% while drying in paper covered piles for 6-12 months. This decrease of humidity can raise the energy content by almost 17%. It shows that the estimation of forest fuel resources is highly dependent on the technology used and other conditions.

Table 1.4. The amount of possible to take out fuel wood (logging residues + firewood) and energy content in Rokiskis forest enterprise forests

Object	Volume, in thous. m^3		Energy content under humidity of wood 50 % (1 m^3 =2,23 MWh)		Energy content under humidity of wood 35 % (1 m^3 =2,60 MWh)	
	Final cuttings	All cuttings	Final cuttings	All cuttings	Final cuttings	All cuttings
2001-2010						
State forests	9.8	15.2	21854	33 896	25480	39 520
All forests	25.3	39.6	56419	88 308	65 780	102 960
2011-2020						
State forests	12.0	18.4	26 760	41 032	31 200	47 840
All forests	33.5	49.5	74 705	110 385	87100	128 700

1.3. CONCLUSIONS

1. The annual volume of total logging residues in all cuttings of 2001-2010 from all forests of Rokiskis forest enterprise contain 60 thous. m^3. The volume of possible to take out logging residues contain 33% from all residues or 19.6 thous. m^3. In 2011-2020 the amount of possible to take out logging residues will increase by 22%.
2. The annual volume of fuel wood (firewood and possible to take out logging residues) in all cuttings of 2001-2010 from all forests of Rokiskis forest enterprise can contain 39.6 thous. m^3. It is forecasted increasing of this volume up to 49.5 thous. m^3 in 2011-2020.
3. The highest concentration of possible to take out logging residues and firewood was estimated in the forests of Juodupė, Rokiskis , Vyzuona and Kamajai forest districts. The biggest volume of possible to take out logging residues and firewood will be got from spruce, birch and pine forest stands.
4. The biggest volume from possible to take out logging residues contain bark (56 – 57 %) and non-merchantable branches (30 – 31 %). Small stems as well as merchantable branches comprise 6 – 7 %. The amount of possible to take out logging residues in final cuttings comprises 70%, while in intermediate cuttings it makes only 30 %.

References

1. Kuliesis A., Petrauskas E., 2000. Lietuvos miško naudojimo XXI amžiuje prognozė. (Lithuanian forest resources in the XXI century). Kaunas, 146 p.

2. STUDIES ON FORESTRY AND TECHNOLOGY OF FOREST FUEL PRODUCTION (V.Miksys, R.Budrys, R.Sadauskas, J.Saladis)

2.1. METHODS OF INVESTIGATION IN PRECOMMERCIAL, COMMERCIAL THINNING AND FINAL CUTTING DEMONSTRATION AREAS

For every precommercial and commercial thinning demonstration area as big as possible area of homogenous forest stand according to density and species composition was singled out. In final cutting demonstration areas all trees were measured.

Objects for precommercial and commercial thinning demonstration areas were chosen in forest stands typical for Rokiskis forest enterprise according to species (birch, spruce and pine), normally irrigated, on less and medium fertile sites. The chosen stands were homogenous according to species composition and stocking level, in sanitary cuttings – according to the amount and distribution of trees to be felled. The intensity of thinning in demonstration areas was compared to other commercial thinning areas in Rokiskis forest enterprise.

Two variants of forest stand handling were designed in every **precommercial thinning** demonstration area: traditional handling, based on Lithuanian thinning standards (traditional variant) and handling according to Swedish precommercial thinning and biofuel outtake regulations (forest fuel variant). In every demonstration area at least four sample plots were singled out. For every variant two neighbouring sample plots were chosen. One of these plots was cuted using manual instruments, the other– using a brush-cutter as the traditional variant or a motor-saw with felling handle “Apuri” or hand tools as biofuel outtake variant. The first assessment of forest stand parameters was done before thinning in one 100 m^2– size temporary sample plot per one sample plot of demonstration area. In temporary sample plots the dbh of every tree thicker than 2 cm and the height of every 7^{th} tree for every tree species were measured. During the thinning process the work time expenditure and the volume of felled trees in m^3/ha were assessed. After thinning another measurement of forest stand parameters was done. The measurement was done in two systematically placed 100 m^2-size temporary sample plots per one sample plot of the demonstration area. The same parameters as prior to the thinning were measured.

The **commercial thinning and final clear-cutting** demonstration areas were adjusted to the existing or newly planned system of technological corridors. The minimum width of each research area was not less than the minimal distance between two corridors – 25 m. After delimitation of demonstration areas all the trees to be felled were marked and their dbh was measured. The trees felled to establish the new technical corridors were accounted separately. For the measurement of stand parameters in every demonstration area 4-6 temporary sample plots of 400 m^2 each were measured. In a sample plot the dbh of every tree and 3 or more tree heights for the main element in each storey and 1 or more tree heights for each other element were measured.

All standard procedures of cutting were done: felling of trees, pruning etc. The tops for the forest fuel were left without pruning. These tops and thick branches were stacked into piles near technical corridors. The size of these piles should be not less than necessary for single manipulators to take out forest fuel. Some amount of branches from trees felled directly on technical corridors were left there to preserve the soil.

After piling of tops and other cutting residues the amount of forest fuel was accounted according to volume tables. The cutting residues meant for forest fuel will be left in the piles for drying when the leaves and needles will fall down. The forest fuel transportation was done using a tractor with a trailer or a forwarder. During thinning and transportation time measurement for all operations was made: felling of trees, pruning, piling of tops and branches, loading into a trailer, driving with and without load, unloading of forest fuel.

Calculation of the main stand parameters was done using the unified volume and yield assessment software (Kuliesis, 1993). Age, species composition, average dbh, height and other common parameters were calculated. For every variant, traditional and forest fuel, the arithmetic average was calculated. For commercial thinning and final clear-cutting demonstration areas additionally were calculated the main parameters of felled trees, such as average dbh, average height, average tree volume.

2.2. MAIN CHARACTERISTICS OF RESEARCH OBJECTS

Intermediate cuttings. Trials 1E and 2E were established in 65-years-old pine stand with birch admixture and the second storey of spruce, growing in normally irrigated site. The cutting intensity in trial 1E was low – just 10%. In this stand all birches, suppressed pines and some damaged spruces were felled. In traditional commercial thinnings, like the above-mentioned trial, the production of wood fuel is not perspective. In trial 2E birches, suppressed pines and damaged spruces were felled, but intensity of cutting was much higher – 33%. Cutting of mature birches led to higher cutting intensity. Wood fuel amount in this stand was much higher.

Trial 1S was established in a mixed pine-spruce-birch stand with the second spruce storey. Dears intensively damaged the 2nd storey. In this stand technical corridors were made and during cutting additionally 28 m^3/ha were felled. In this stand damaged spruces, mature birches and suppressed pines were felled. Higher amount of wood fuel was also due to a bigger felled volume.

Trial 3E was established in 65-year-old highly stocked pine stand. In this stand suppressed pines, mature soft broadleaves and also some damaged and/or suppressed spruces were cut. In this stand a big amount of low quality wood was cut. The stand has an average dense understorey, which was cut only in technical corridors and other places where it was necessary.

The most important parameters, such as dbh, height of trees, volume distribution by categories, amount of branches and logging residues are shown in table 2.1.

Final cuttings. For trials in clear cutting areas 4 stands were selected. The data of trials is shown in table 2.2.

Trial 1P was established in a wet part of clear-cutting area. In this trial only traditional cutting was performed, because in this place it was necessary to use logging residues for technical corridors. In this trial work expenditure for the handling of traditional logging residues was measured. These data were used for comparison with work expenditure for forest fuel production.

Trial 2P was established in a stand, where spruce trees dominated. The understorey in this trial was sparse. In this trial low-experienced workers were employed. Most felled trees were spruces with a big amount of small-sized branches. This caused the situation that the workers left a big amount of branches on the technical corridor, especially from trees felled directly on it.

Trial 3P was established in soft-broadleaved tree stand. In this trial there was a dense and big-sized understorey, mostly hazelnut. In the less-stocked part of the stand this understorey was very dense. This understorey and a big amount of firewood, especially big-sized hazelnut bushes, have led to a high amount of forest fuel.

Trial 4P was established in pine stand with spruce admixture. The understorey in the trial was sparse. For technical corridors was used minimal amount of branches. It shows that forest fuel production potential was used optimally.

Compared to the traditional technology, when all the branches and tops are used for technical corridors, the technology with integrated wood fuel production is very promising. This is caused by a situation, when work expenditure for forest fuel production replaces work expenditure for putting logging residues into technical corridors. Additional work expenditure for forest fuel production in intermediate cuttings is low, while in clear-cuttings is equal or even less than work expenditure for the traditional handling of branches. A reduced distance of handling branches and eliminated work expenditure for firewood pruning cause this.

Table 2.1. Main characteristics of felled trees, volume distribution and amount of produced forest fuel in intermediate cutting trials (1 ha)

Species	Dbh	Height. m	Mean volume, m^3	Stem volume, m^3	Volume of industrial wood, m^3	Volume of firewood, m^3	Merchantable volume, m^3	Logging residues m^3	Branches' volume, m^3	Amount of produced woodfuel, m^3/ha
1E. Rokiskis forest enterprise, Kamajai distr., 136 block, 16 comp., area 0.18 ha, 65-years old										
Spruce	24.0	24.3	0.55	3.1	2.7	0.1	2.8	0.3	0.6	
Pine	17.8	20.2	0.25	9.7	8.4	0.2	8.6	1.0	0.4	
Birch	24.4	24.1	0.50	16.7	12.8	1.4	14.2	2.5	2.5	
Total			**0.38**	**29.4**	**23.9**	**1.7**	**25.6**	**3.9**	**3.5**	**5.3**
2E. Rokiskis forest enterprise, Kamajai distr., 136 block, 16 comp., area 0.18 ha, 65-years old										
Spruce	19.9	20.2	0.32	7.2	6.1	0.4	6.5	0.7	1.6	
Pine	17.7	20.2	0.24	21.7	18.9	0.5	19.3	2.3	1.0	
Birch	22.5	23.2	0.42	53.7	41.0	4.6	45.6	8.1	8.0	
Total			**0.35**	**82.5**	**66.0**	**5.4**	**71.4**	**11.1**	**10.6**	**13.3**
3E. Rokiskis forest enterprise, Selyne distr., 58 block,18 comp., area 1.2 ha, 65 years old										
Spruce	13.2	15.2	0.12	16.0	9.5	4.7	14.2	1.8	4.1	
Pine	18.4	20.5	0.30	17.2	13.3	2.1	15.4	1.8	1.1	
Birch	22.8	23.2	0.48	35.2	25.0	4.8	29.8	5.4	5.4	
Aspen	25.6	25.7	0.66	5.5	2.8	2.1	4.9	0.6	0.5	
Alder	16.4	19.3	0.19	4.5	0.3	3.9	4.2	0.3	0.7	
Total			0.27	**78.4**	**50.9**	**17.6**	**68.5**	**9.9**	**11.8**	**30.5**
1S. Rokiskis forest enterprise, Selyne distr., 54 block. 11 comp., area 0.64 ha. 75 years old										
Spruce	15.2	20.1	0.17	22.0	16.3	3.4	19.7	2.3	5.3	
Birch	25.1	25.1	0.56	59.9	46.3	4.6	50.9	9.0	9.4	
Pine	25.7	27.5	0.51	19.3	17.3	0.1	17.4	1.8	1.7	
Total			**0.37**	**101.2**	**79.9**	**8.1**	**88.0**	**13.1**	**16.4**	**20.4**

As far as the intensity of cutting in commercial thinnings or sanitary cuttings is low, then handling of logging residues and unpruned firewood for forest fuel makes no technological problems. When the concentration of forest fuel and felled volume is high (especially in the case of clear cuttings) then piles of forest fuel a little disturb the felling operations. In this case it is worth to execute cutting and forwarding in several stages.

The trials in clear-cutting areas showed, that in such areas could be produced from 64 to 98 solid m^3/ha of forest fuel (from 58 to 112 in different less experimental plots). The amount of produced forest fuel is mostly dependent on the felled volume and their distribution, i.e. amount of firewood, logging residues and the volume of understorey. In coniferous stands the amount of produced forest fuel is less, because in such stands there is a smaller amount of firewood, logging residues, there is less understorey. The amount of produced forest fuel in typical commercial thinnings with low cutting intensity and established technological corridors are small. The amount of produced woodfuel in commercial thinnings increases with increasing thinning intensity. It increases with greater amount of firewood and logging residues, or it is necessary to establish their new technological corridors.

Forest fuel production in normally irrigated sites helps to solve some technological problems, such as broadening of technical corridors. The broadening of technical corridors is caused by a big amount of branches in these corridors. After forwarding of produced assortment the corridor can become 6-7 m wide and make problems during planting. With the extraction of tops and branches as woodfuel out of a stand, this problem can be solved very successfully and cost-effectively.

Table 2.2. Main tree characteristics, volume distribution and amount of produced forest fuel (1 ha) in clear-cutting trials

Species	Coefficient of species composition	Dbh	Height, m	Mean volume, m^3	Stem volume, m^3	Volume of industrial wood, m^3	Volume of firewood, m^3	Merchantable volume, m^3	Logging residues m^3	Branches' volume, m^3	Amount of produced woodfuel, m^3/ha
1P. Rokiskis forest enterprise, Selyne distr., 62 block, 4 comp, (traditional technology). Area 0.6 ha, 85 years old											
Spruce	7.3	21.9	20.1	0.41	286.1	246.4	13.2	259.5	26.5	59.5	
Birch	2.2	25.9	25.1	0.58	87.3	65.7	8.5	74.2	13.1	13.8	
Pine	0.3	34.6	27.5	1.15	13.4	12.2	0.1	12.3	1.1	1.7	
Alder	0.1	19.7	20.0	0.31	3.1	1.3	1.3	2.6	0.5	0.4	
Oak	-	12.3	15.0	0.09	0.6	0.4	0.1	0.5	0.1	0.0	
Total				**0.45**	**390.4**	**326.0**	**23.1**	**349.1**	**41.3**	**75.4**	**-**
2P. Rokiskis forest enterprise, Selyne distr., 62 block, 7. 11 comp. Area 2.2 ha, 85 years old											
Spruce	6.4	23.1	20.9	0.46	239.2	204.8	12.5	217.3	21.9	49.1	
Birch	2.2	32.6	26.2	0.95	82.8	64.9	5.4	70.4	12.3	13.8	
Pine	1.3	33.2	27.2	1.06	49.5	45.0	0.3	45.3	4.2	6.3	
Aspen	0.1	21.9	24.3	0.46	3.5	1.7	1.5	3.2	0.3	0.3	
Oak	-	16.0	17.2	0.17	0.1	0.1	0.1	0.1	0.0	0.0	
Alder	-	8.0	13.6	0.03	0.0	0.0	0.0	0.0	0.0	0.0	
Total				**0.57**	**375.2**	**316.5**	**19.8**	**336.3**	**38.8**	**69.5**	**64**
3P. Rokiskis forest enterprise, Selyne distr., 62 block, 12, 13 comp. Area 2.0 ha, 65 years old											
Birch	4.0	31.7	26.4	0.89	123.1	96.5	8.2	104.7	18.4	20.4	
Spruce	3.1	17.4	16.6	0.24	95.5	77.7	8.3	86.1	9.5	21.3	
Aspen	2.3	31.7	27.5	1.03	71.4	49.6	14.9	64.5	6.9	7.6	
Alder	0.3	18.7	18.7	0.25	10.6	3.6	6.2	9.8	0.8	1.7	
Pine	0.2	29.5	25.5	0.73	5.8	5.3	0.0	5.3	0.5	0.6	
Oak	0.1	17.2	17.5	0.21	4.0	2.7	0.6	3.3	0.7	0.1	
Total				**0.46**	**310.4**	**235.4**	**38.3**	**273.7**	**36.7**	**51.7**	**98**
4P. Rokiskis forest enterprise, Rokiskis distr., 158 block, 3 comp. Area 0.37 ha, 110 years old											
Pine	6.9	35.6	26.8	1.23	235.5	214.3	1.3	215.6	19.9	30.9	
Spruce	3.0	17.6	19.0	0.25	103.3	78.6	14.7	93.3	10.0	22.7	
Birch	0.1	28.0	25.0	0.68	1.8	1.4	0.1	1.5	0.3	0.3	
Total				**0.56**	**340.6**	**294.3**	**16.1**	**310.5**	**30.1**	**53.9**	**69**

2.3. FOREST FUEL EXTRACTION AND CHIPPING TRIALS

The extraction of forest fuel. The trials of forest fuel extraction were done using 2 mechanisms – a forwarder "Valmet-840" and a selfloading trailer "Weimer WE-8" with a tractor MTZ-82.

The main parameters of extraction using forwarder "Valmet-840" and selfloading trailer "Weimer WE-8" are shown in table 2.3. Average load was assessed after measuring produced forest fuel piles, calculating amount of the forest fuel and counting loads. The table also shows data on the transportation of traditional assortments. The data shows that in the transportation of woodfuel the time of loading and unloading is twice or more less than in transportation of traditional assortments. The volume of woodfuel load is twice less than that of traditional assortment too.

Table 2.3. The comparison of work expenditure in transportation of forest fuel and traditional assortment, using forwarder "Valmet 840" and selfloading trailer "Weimer WE-8"

Parameter	Valmet 840	Weimer WE-8
Forest fuel transportation		
Loading duration, min.	**12.9**	**11.8**
Unloading time, min.	**5.8**	**3.4**
Volume of load, m^3	**4.0**	**1.7**
Traditional assortment		
Loading duration, min.	**27.1**	**14.0**
Unloading time, min.	**11.4**	**10.1**
Volume of load, m^3	**7.9**	**3.8**

Ordinary workers having no special experience did forest fuel extraction. In the work of forwarder "Valmet-840" no problems were observed. More problematic was the work of a selfloading trailer – loading and unloading were much slower and the piles were less regular.
Forest fuel chipping was done using the drum chipper "BRUKS 604 CT", with an agricultural tractor "K-700". In the first two trials extraction was done using the forwarder "Valmet-840" (trials 1. 2) and for the remaining two trials – the selfloading trailer "Weimer WE-8" (trials 3 and 4).
Data in table 2.4 show that the effectiveness of forest fuel chipping is highly dependent on the extraction mechanism. Chipping of forest fuel extracted using forwarder "Valmet 840" was more productive than chipping of forest fuel extracted using the selfloading trailer "Weimer WE-8". This was caused by a more precise order in forwarder-loaded piles. The piles extracted using a selfloading trailer were more disordered and this caused problems for the chipper operator.

Table 2.4. Main data on forest fuel chipping

Trial No	Chipping duration in min	Volume of chips, m^3	Amount of fuel, l	Consumption of fuel in l/m^3	Consumption of fuel in l/hour	Work expenditure min/ m^3
Forest fuel extraction using forwarder "Valmet 840"						
1	80	9.6	22	2.29	16.5	8.3
2	84	9.6	28	2.92	20.0	8.8
Ave-rage	**82**	**9.6**	**25**	**2.60**	**18.25**	**8.5**
Forest fuel extraction using a selfloading trailer "Weimer WE-8"						
3	130	9.6	40	4.17	18.5	13.5
4	135	9.6	40	4.17	17.8	14.1
Ave-rage	**133**	**9.6**	**40**	**4.17**	**18.1**	**13.8**

The data from these trials was obviously very preliminary and unprecise. Due to a low skill of the chipper operators even minimal productivity of the chipper was not reached.

2.4. POSSIBLE CHANGES IN SILVICULTURAL SYSTEMS WITH THE PURPOSE TO USE WOOD AS A FUEL FOR HEATING PLANTS

Lithuanian stand thinning models are made so that the maximum stand productivity would be guaranteed (Kairiukstis, Juodvalkis, 1985). Therefore, there is no particular need for radical changes in stand thinning systems, because maximum productivity guarantees optimal use of grown wood, including preparation of forest fuel.

Despite this, some possibilities for modifications of thinning systems still remain. This refers not to the intensity of cutting, but to the aspects of stand species composition regulation. Fast growth is characteristic to young soft deciduous trees such as birch, asp, and alder. Comparing of the same age hard deciduous or conifer trees, soft deciduous trees produce higher volume wood. However, an admixture of soft deciduous trees reduces the productivity of conifers. Therefore, it is advisable to try to harmonise the fast growth of young soft deciduous trees with a sufficient productivity of purposeful conifer stands.

In order to solve this problem we used earlier created mathematical models, designed to reflect the influence of soft deciduous trees on the productivity of spruce storey and general stand productivity (Miksys, 1997). We used data of earlier investigations (Kairiukstis, 1969; Kairiukstis, 1973; Kairiukstis, Juodvalkis, 1985) on the dependence of crown density on the stand age, dependence of light amount in deciduous storey on crown density and data on spruce growth dependence on lighting. Tables of spruce growth process were also used.

Using the models when deciduous trees are felled at different ages, calculations of general stand productivity were made. We assume that until felling of deciduous trees spruce trees grow dependently on the light amount they get while after cutting – according to the consistent patterns of growth process of one-storey spruce stand.

Values of growth process rates are pure (one-storey) spruce stands or the second storey of spruce which all the time grows under birch and asp cover.

Analysis of the general stand productivity, when the storey of deciduous trees is felled in different age, shows, that in the most common of habitats birch and spruce we can get up to 530 m^3/ha when birches are felled being 10-15 year old. If all the birches are felled during the early thinning, the general stand productivity is about 20 m^3/ha less. When birches are felled in older age, the general stand productivity gradually decreases (Fig. 2.1). Birch stand produces more wood, but it doesn't cover the mass loss caused by a slow growth of spruce.

In aspen stand we see almost an identical situation. However, the light amount under the aspen cover, comparing to the birch stand, is slightly higher. Thus, the productivity of aspen-spruce stand is higher. Analysing the general growing stock per hectare, when aspen storey is felled at different age, the variation of this parameter is more complex (Fig. 2.2).

Fig. 2.1. Change of the total wood volume received during a rotation period in birch-spruce stands with different stocking level when birch storey is felled at different age

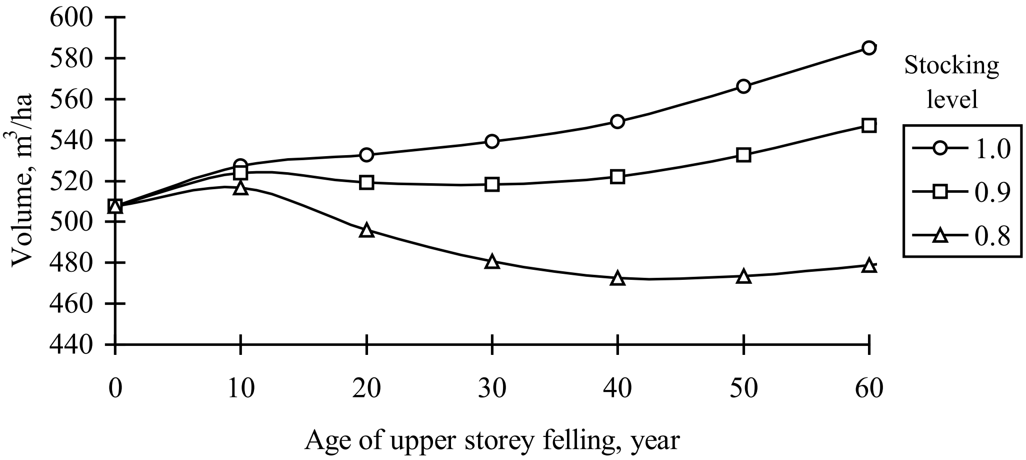


Fig. 2.2. Change of the total wood volume received during a rotation period in unthinned aspen-spruce stands when aspen storey is felled at different age

When aspen storey is felled in the age of 10-15 years, the general productivity increases comparing to pure spruce stand. If aspen trees are felled even older, the general amount of wood depends more on the stand stocking level of the aspen storey. If the aspen stand's stocking level is 1.0, the general volume increases, The volume is almost the same or even decreases if the stocking level is less than 1.0. However, because of small commercial volume of older aspen stands, the timber volume is distinctly smaller comparing to the receivable amount of that wood when aspen trees are felled in young age and pure spruce stand is planted after that.

The productivity of spruce storey depends on two factors: growth conditions of the spruce stand under the cover of deciduous trees and on the duration of growth under deciduous cover. Data on the productivity of spruce stand, which grows under soft deciduous cover, is presented in table 2.5. The longer spruce storey grows under the highly stocked first storey the smaller is the productivity of such a stand. However, a 10-15-year long period under deciduous trees decreases the productivity of spruce storey.

Table 2.5. Relative productivity (in % from spruce stand) of spruce stands formed from the second storey covered by soft deciduous trees during deciduous felling

First storey stocking level	Volume in 90 years-age, in % from pure spruce stand						
	Felling age of the 1st soft deciduous storey						
	1	10	20	30	40	50	60
	Birch stands						
1.0	100.0	96.3	77.2	61.0	49.2	40.7	34.4
0.9	100.0	96.5	78.3	63.0	51.8	43.5	37.6
0.8	100.0	96.5	79.7	65.4	54.7	46.9	40.9
0.7	100.0	96.7	81.1	67.9	58.1	50.6	45.1
0.6	100.0	96.7	82.9	70.9	61.8	55.1	49.8
	Aspen stands						
1.0	100.0	96.3	79.3	64.8	54.1	46.3	40.6
0.9	100.0	96.7	80.9	67.5	57.5	50.2	44.7
0.8	100.0	97.0	82.7	70.5	61.4	54.5	49.6
0.7	100.0	97.2	84.6	74.0	65.7	59.6	55.1
0.6	100.0	97.6	87.0	77.8	70.9	65.7	61.6

According to the above-presented data we can state, that it's not necessary to cut all the soft deciduous trees till 10-15 years of age. It is recommended to reduce the density of deciduous trees in order to

make their smothering for spruces minimal. In this case the loss of productivity of spruce storey is minimal. The biggest part of soft deciduous trees should be felled until 15 years of age. In this case it is possible to get from the deciduous storey a significant amount of wood suitable for heating plant fuel and have a productive spruce stand in the future.
Today the delay of pre-commercial thinning is quite often. If the necessary cuttings are delayed, it is very difficult to form a desirable species composition in the stand. On the other hand, we may think that the problem of delayed young stand cutting can more successfully be solved by forest fuel production. That is because one of the main reasons for a delayed young stand cutting is high cost of pre-commercial thinning, which can be reduced by the production of forest fuel.

2.5. Conclusions

1. For forest fuel production the traditional technology with added operations for logging residues and unprunned firewood piling near technical corridors can be used. In forest fuel production the productivity of work increases with the increasing amount of logging and firewood as well skilfulness of workers.

2. The amount of produced forest fuel in intermediate cutting trials was 5-31 solid m^3. The smallest amount was produced in typical commercial thinnings where technical corridors were made in previous cuttings. The highest amount was produced in a stand with a big part of firewood.

3. The amount of produced forest fuel in clear cutting areas was 58-112 solid m^3/ha. The biggest amount of forest fuel was produced in aspen stand with a dense understorey. A smaller amount was produced in spruce and pine stands.

4. The amount of forest fuel is mostly dependent on the felled volume and its structure, especially the amount of firewood and branches. Most promising for forest fuel production are stands of soft broadleaves, such as birch, aspen, alder with a dense understorey.

5. The following advantages were observed in cuttings with integrated forest fuel production:

- In final cuttings for technical corridors less amount of branches was used, and it allowed to avoid the so called “widening” of technical corridors;

- Firewood production allows non-commercial cuttings, thus increasing the yield and the quality of those stands, also reconstruction cutting in traditionally less profitable forest stands are available.

6. In conflict stands of spruce with broadleaves some amount of broadleaves can be left until 15 years of age. Therefore, we can get an additional amount of wood and keep the productivity of stand on the same level.

References

1. Kairiukstis L., Juodvalkis A, 1985. Etaloniniai medynai ir jų formavimas (Standard stands and their forming). Vilnius: Mokslas, 244 p.

2. Kairiukstis L. 1973. Mišrių medynų formavimas ir kirtimai (Mixed stands' forming and thinning). Vilnius: Mintis. 358 p.

3. Kuliesis A. 1993. Lietuvos medynų prieaugio ir jo panaudojimo normatyvai (Forest yield models and tables in Lithuania). Kaunas. 383 p.

4. Miksys V. 1997. Dviardžių beržynų ir iš antrojo ardo suformuotų eglynų augimo eigos modeliavimas ir produktyvumo įvertinimas (Growth modelling and productivity evaluation of two-storey birch stands and spruce stands formed from the second storey). Miškininkystė. 40. p. 92-103.

5. Кайрюкштис Л. 1969. Научные основы формирования высокопродуктивных елово-лиственных насаждений (Scientific fundamentals of forming maximally productive spruce-deciduous stands). М.: Лесн. пром-сть. 208 с.

3. STUDIES ON ECONOMICAL FACTORS (P.Danuseviciene, R.Budrys, A.Gustainiene, D.Mizaraite, S.Mizaras, L.Sadauskiene, J.Saladis)

3.1. METHODS OF ECONOMICAL INVESTIGATION

Methods for time expenditure assessment. Workday time was divided into work time and break time. Work time could be divided into preparatory-finishing time, operational time and time for workplace service. Measured time expenditure was compared to standard.

Workday expenditure was assessed using Work Time Photography method (WTP). Workday structure, current expenditure for work and breaks could be assessed by (WTP) as well. Using these figures we could rationally plan the work. One worker was observed by the individual WTP. Observation was divided into four steps: 1) preparation, 2) observation, 3) data calculation and 4) analysis and conclusions.

Collected information was recorded onto special observation blanks. Observer had to measure time expenditure (in minutes) for all operations during observation and register them. If any operations took less than 1 minute, they were not observed separately. All categories of expenditure were marked, summarized and current balance of work time expenditure as well as the absolute and percentage for every time expenditure category were calculated.

The objective of observation data analyses is to assess the irrational and not productive expenditure under current work organization schedule. The mean current work time expenditure balance is calculated as an arithmetical mean of all observations. Using these data we can calculate current work time balance, analyse how productively the working time is used, how big are the losses of work time and can project the standard work time balance.

The photo timing was used to investigate time expenditure, used to produce 1 unit of production. It is the method of observations containing photography and timing elements, Some categories of time expenditure were observed separately from others in the process of WTP, it means that work operations timing for some elements were done. If observation results are sufficiently accurate, they could be used for further calculations. The tables of Sarkisoff V. and Shelechoff V. were used to achieve the necessary number of observation. Photo timing data analysis starts from creating the variation row and assessing row permanence coefficient. Statistical parameters (average time expenditure, standard deviation, variation coefficient, standard mean error and accuracy) were calculated.

Methods for costs assessment. Several types of costs are used to evaluate forest fuel production. They are: forest fuel production expenditure in cutting plots, extraction to roadside, chipping and transportation of chips into boiler house.

According to the categories the expenditure is divided into expenditure for work, materials and service of mechanisms. The costs is calculated according to the formula:

$$S = \sum\left[(t_j * d_j)\right] + \sum(m_{ij} * k_i) + \sum(n_{ej} * z_e)\,, \qquad (1)$$

where: S –costs to produce forest fuel, Lt / m^3 ; t_j – time expenditure proper to do the work *j,* hour; d_j – labor costs per time unit (hour), including social insurance, Lt/hour; m_{ij} – amount of material *i* used for work *j* ; k_i – market price of material *i,* Lt; n_{ej} – time expenditure of mechanism *e* to do work *j,* hour; z_e – cost per working hour of mechanism *e,* Lt/hour.

Calculation of machine costs. Costs per working hour for machine were calculated according to the formula:

$$z_e = (V_p - V_l) / E + R / E + \sum (D_{ed} * k_d) + I, \quad (2)$$

where: Z_e – costs of machine *e* per working hour, Lt/hour; V_p – purchase price of machine, Lt; V_1 – salvage value (≤10% of purchase price), Lt; E – lifetime of machine, hour; R – repair and service costs, Lt. These costs were assessed for the whole machine lifetime; D_{ed} – fuel or lubricant consumption, liters/hour; k_d – fuel or lubricant price, Lt/liter.

Machine costs per working hour are given in the table 3.1.

Table 3.1. Machine costs

Machine	Cost, Lt/hour
Motor-saw "Jonsered 2150 Turbo" with “Apuri”	4.1
Motor-saw "Husquarna 254XP”	3.6
Brush-cutter “Husquarna 250 R”	2.8
Forwarder "Valmet 840Y”	60.8
Tractor “MTZ-82” with „Weimer WE-8”	42.0
Tractor “T-150“	49.8
Tractor "K-700"	72.1
Manipulator "LOGLIFT F 70 L"	36.3
Chipper "BRUKS 604 CT"	72.2
Lorry "MAZ 5516"	60.4
Trailer	7.9

Monetary evaluation of labour time. Labour price can not be less than the minimal rate certified by the Government of the Lithuanian Republic. Currently the minimal rate is 2.53 Lt/hour. The actual rate of working hour was assessed considering payment rates in Rokiskis forest enterprise. Following rates were used to calculate: manual work – 3.53 Lt/hour in pre- commercial thinnings and 4.12 Lt/hour in other cuttings; moto – manual work – 5.29 Lt/hour, for mechanized work – 8.14 Lt/hour. Additionally 12% were added for holidays, safety instructions, etc. from the rate, and 31% were added for social insurance.

Assessment of profitability of forest fuel production

Net income was calculated as income from production minus logging costs, calculated according the conditions mentioned in the technology.

Economic effectiveness was calculated comparing net income from traditional technology with net income from the integrated technology.

3.2. FOREST FUEL PRODUCTION WORK TIME

3.2.1. Pre-commercial thinings

Work time usage for traditional and forest fuel production technologies of pre-commercial thinnings was collected from Rokiskis forest district plot No.14 in the block No. 74 and plot No. l in the block No. 80.

In every demonstrative area two forest stand handling variants were designed: traditional handling, based on Lithuanian thinning standards (traditional variant) and handling according to Swedish pre-commercial thinning and forest fuel outtake recommendations (Forest fuel variant). At least four sample plots were singled out in every demonstration area. Two neighbor sample plots were chosen for every variant. One of these plots was cut using manual instruments, two others– using a brush-cutter in the traditional variant and a motor-saw with felling handle "Apuri" in the forest fuel variant.

Manual tools (sabre) or brush-cutter are used for cutting; brushwood is spread in cutting place in traditional thinnings technology. When manual tools were used for cutting the work could be divided into the stages: giving of work tasks to workers, getting familiar with work task, cutting the brushes, spreading brushwood cuttings, moving from one brush to another sharpening of tools.
Worker has additional work to do when brush cutter is used: to prepare brush cutter for work, to fill in it with fuel, to sharpen the cutting disk and to do daily maintenance.

Technologies contributory developed together with Swedish supervision were used for forest fuel production in pre-commercial thinnings. These technologies consist of brushwood cutting, piling, extraction, chipping and transportation of chips to boiler house must be done.

When machinery is used for forest fuel production the technology involves work task studies, motor saw preparation for work, brush cutting, crosscutting, piling, moving from one brush to another, filling the fuel, chain sharpening, motor saw daily maintenance. Motor saw "Jonsered 2054" with felling handle "Apuri" was used for this technology.

Individual work time photography was applied to analyse four technologies: traditional pre-commercial thinning when manual tools and machinery are used, pre-commercial thinning for forest fuel production when manual tools and machinery are used as well.

Work time expenditure balance has been drawn when work time photography was done. According to the balance pre-commercial thinnings when sabre is used are rational in comparison with normative time (Table 3.2.).

The work time usage coefficient in pre-commercial thinnings when sabre is used is 0.98. Preparatory - finishing time, operational time and workplace servicing time are close to normative ones. Breaks of the violation of work ethics (coming back late to the work after lunch) make up to 1.7%. If breaks could be eliminated work productivity could increase till 2%.

Table 3.2. Actual and normative work time expenditure balance in traditional pre-commercial thinnings when sabre is used

Index	Time expenditure category	Actual expenditure		Normative expenditure		Time expenditures to be removed (min.)
		min.	in %	min.	in %	
t_{pb}	Preparatory – finishing time	5	1.0	4	0.8	1
t_{op}	Operational time	413	86.0	425	88,5	
t_a	Work place servicing time	10	2.1	10	2.1	
t_{prd}	Breaks of the violation of work ethics	8	1.7	-	-	8
t_{po}	Time for rest and personal needs	44	9.2	41	8.6	3
Total		480	100.0	480	100.0	12

The duration of operational time could increase till 12 minutes and make up to 88.5 % of workday duration if waste of work time was eliminated and irrational expenditure have been decreased (less time for rest).

Work time photography in pre-commercial thinning when brush cutter is used shows, that operational time duration increase till 44 minutes if waste of work time was eliminated and irrational expenditure have been decreased (Table 3.3.). The prolonged operational work time would make up to 76.2% of the workday duration.

Table 3.3. Actual and normative work time expenditure balance in traditional pre-commercial thinnings when a brush cutter is used

Index	Time expenditure category	Actual expenditure		Normative expenditure		Time expenditures to be removed (min.)
		min.	in %	min.	in %	
t_{pb}	Preparatory – finishing time	22	4.6	27	5.6	
t_{op}	Operational time	327	68.1	366	76.2	
t_a	Work place servicing time	33	6.9	30	6.3	3
t_{pt}	Breaks of technical reasons	19	4.0	-	-	19
t_{prd}	Breaks of the violation of work ethics	10	2.1	-	-	10
t_{po}	Time for the rest and personal needs	69	14.4	57	11.9	12
Total		480	100.0	480	100.0	44

Work time usage coefficient in the pre-commercial thinnings by using brush cutter is 0.94. Preparatory - finishing time, operational time and workplace servicing time are close to the normative ones. The breaks of the violation of work ethics (coming late to work in the morning) made up to 2.1%, breaks caused by technical reasons such as the brush cutter engine failure - 4.0%. Elimination of mentioned breaks would increase work productivity till 8.9%.

Over time photography establishment, we accepted that normative work time expenditure for forest fuel production will be the same as for traditional pre-commercial thinning technologies.

When work time photography for the thinning and forest fuel production by using the sabre was established, it was identified that the workday time is almost the same as the normative. After reducing irrational work time expenditure, which makes up to 4 minutes, the duration of the operational work time could be increased up to 88.5% of the workday duration (Table 3.4.). The work time usage coefficient is 1.0.

When work time photography for the forest fuel production by using machinery was established, it was identified, that the work time usage coefficient is only - 0.89 (Table 3.5.). The time close to the normative is only for the preparatory - finishing and workplace servicing works. The breaks of the violation of work ethics (coming back later to the work after the lunch) make up 1.7%. The breaks of technical reasons influence work productivity. Breaks of technical reasons were due to the new machinery; worker was not used to do. After eliminating these breaks the productivity of work would increase by 18%. The duration of operational time could increase till 78 minutes and make up to 76.2% of workday duration if the waste of work time was eliminated and irrational expenditure have been decreased.

Table 3.4. Actual and normative work time expenditure balance of forest fuel production in pre-commercial thinnings by using a sabre

Index	Time expenditure category	Actual expenditure		Normative expenditure		Time expenditures to be removed (min.)
		min.	in %	min.	in %	
t_{pb}	Preparatory – finishing time	6	1.3	4	0.8	2
t_{op}	Operational time	421	87.6	425	88.5	
t_a	Work place servicing time	10	2.1	10	2.1	

t_{po}	Time for rest and personal needs	43	9.0	41	8.6	2
Total		480	100.0	480	100.0	4

Table 3.5. Actual and normative work time expenditure balance of forest fuel production in pre-commercial thinnings by using a motor-saw with handle

Index	Time expenditure category	Actual expenditure		Normative expenditure		Time expenditures to be removed (min.)
		min.	%	min.	%	
t_{pb}	Preparatory – finishing time	28	5.8	27	5.6	1
t_{op}	Operational time	288	60.0	366	76.2	
t_a	Work place servicing time	34	7.1	30	6.3	4
t_{pt}	Breaks technical reasons	44	9.2	-	-	44
t_{prd}	Breaks the violation of work ethics	8	1.7	-	-	8
t_{po}	Time for rest and personal needs	78	16.3	57	11.9	21
Total		480	100.0	480	100.0	78

Cut stems are spread in the cutting place if traditional pre-commercial thinning technology is used, while they are piled in the forest fuel production technology. Time expenditure studies were carried out in two trials of Rokiskis forest enterprise forest where hand tools and machinery were used. Time expenditure differed insignificantly in both trials by using the same technologies. Time expenditure of cutting and spreading studies results according to the traditional technology as well as cutting and piling according to forest fuel production technology are presented in table 3.6.

Table 3.6. Work expenditure in pre-commercial thinning areas

Stand characteristics, thinning intensity and technology		Work expenditure, hour/m^3
Traditional thinning	Spruce stand with broad-leaved trees admixture; hand tools; thinning intensity – more than 181 loose m^3/ha, height of trees more than 4 m	1.10
	Spruce stand with broad-leaved trees admixture; brush-cutter “Husqvarna 250 R”; thinning intensity – more than 181 loose m^3/ha, height of trees more than 4 m	0.74
Forest fuel production	Spruce stand with broad-leave trees admixture; hand tools; Thinning intensity – more than 181 loose m^3/ha, height of trees more than 4 m	2.76
	Spruce stand with broad-leaved trees admixture; motor-saw “Jonsered 2150 Turbo” with felling handle “Apuri”; thinning intensity – more than 181 loose m^3/ha, height of trees more than 4 m.	1.70

3.2.2. Commercial and final cuttings

Time expenditure was estimated in selected research plots. Time is divided into the time for the assortments logging, forest fuel logging, preparation and clearing-out of cutting area. Preparation of cutting area consists of understorey cutting and piling in the traditional technology. During the forest fuel production the understorey cutting is assigned to the fuel preparation time expenditure. Part of the branches that fall down on technological corridors are left there. Work time observation data is presented in table 3.7. The volume of assortments and forest fuel was calculated according to volume cut of trees per study time. There were volume structure differences when this method was used in comparing with trial characteristics presented in chapter 2.2.

Table 3.7. Work expenditure for production of traditional assortments and forest fuel

Cutting category and trial No	Area of trial, ha	Mean stem volume, m^3	Volume, m^3		Work expenditure, hour/ m^3	
			Traditional assortment	Forest fuel	Traditional assortment	Forest fuel
Commercial thinning (1E)	0.18	0.378	4.6	0.9	0.976	0.450
Commercial thinning (2E)	0.07	0.345	5.3	1.5	1.013	0.380
Commercial thinning (3E)	0.49	0.251	30.3	15	0.948	0.309
Sanitary thinning (1S)	0.34	0.374	27.0	4.2	0.446	0.294
Clear-cutting (3P)	0.22	0.252	44.5	24.7	0.893	0.274
Clear-cutting (2P-1)	0.19	0.327	44.7	11	0.635	0.348
Clear-cutting (2P-2)	0.17	0.489	32.7	10.3	0.786	0.349
Traditional clear-cutting	0.11	0.392	33.4	-	0.535	

3.2.3. Extraction of forest fuel to roadside

Forest fuel extraction was done by using 2 techniques: 1) forwarder "Valmet-840" 2) self loading trailer "Weimer WE-8" aggregated with agricultural tractor MTZ-82.

Workers having no special experience did forest fuel extraction. There were no problems in forwarder "Valmet-840" work. More problematic was work of a self-loading trailer; loading and unloading were much slower and the brushwood piles were less regular.

Identified work time expenditure of assortment and forest fuel extraction to roadside are presented in the table 3.8.

Table 3.8. Work expenditure for extraction of traditional assortment and forest fuel

Distance and machinery	Work expenditure, hour/m^3				
	Forest fuel in pre-commercial thinnings	Clear-cutting		Commercial thinning	
		Traditional assortment	Wood-fuel	Traditional assortment	Wood-fuel
Up to 200 m "MTZ –82" with "Weimer WE-8"	0.205			0.119	0.169
Up to 200 m "Valmet 840Y"		0.109	0.104	0.142	0.135
201 - 500 m "MTZ –82" with "Weimer WE-8"	0.286			0.127	0.219
201 - 500 "Valmet 840Y"		0.121	0.132	0.157	0.172
501- 1000 m "MTZ –82" with "Weimer WE-8"	0.416			0.143	0.299
501- 1000 m "Valmet 840Y"		0.140	0.175	0.182	0.228
> 1 km "MTZ –82" with "Weimer WE-8"	0.580			0.174	0.399
>1 km "Valmet 840Y"		0.164	0.230	0.213	0.299

3.2.4. Forest fuel chipping and transportation

Wood is chipped by using drum chipper "BRUKS 604 CT", aggregated with agricultural tractor "K-700". The chipper worked inconstantly during the observation due to technical reasons. Chipping work time input has been identified according to the chipper potential productivity (table 3.9). The observation data of the productivity of the chipper was only 6m^3/hour.

Table 3.9. Work expenditure for forest fuel chipping

Chipper productivity	Time expenditure, hours/m^3
10 m^3/hour	0.120
20 m^3/hour	0.060
30 m^3/hour	0.040
40 m^3/hour	0.024
90 m^3/hour	0.013

Chipped forest fuel was transported to the boiler-house by tractor "T – 150" aggregated with a trailer (load volume - 25.3 loose m^3). Transportation time was calculated according to average speed of the tractor (30 km/hour). Forest fuel can be transported by vehicles aggregated with larger trailers, for instance vehicle "MAZ 5516" aggregated with trailer 45 loose m^3 for longer distances (3.10).

Table 3.10. Work expenditure for forest fuel transportation to boiler-house

Machinery and distance	Work expenditure, hour/m^3
Tractor "T – 150" aggregated with trailer load 25,3 loose m^3	
Up to 5 km	0.020
5.1 - 10 km	0.062
10.1 – 15 km	0.103
15.1 – 20 km	0.144
20.1 – 25 km	0.186
25.1 – 30 km	0.227
Lorry "MAZ 5516" aggregated with trailer load 45 loose m^3	
Up to 5 km	0.007
5.1 - 10 km	0.022
10.1 – 15 km	0.035
15.1 – 20 km	0.049
20.1 – 25 km	0.064
25.1 – 30 km	0.077

3.3. CALCULATION OF FOREST FUEL COST

Calculation of forest fuel cost for pre-commercial thinings (2 plots), commercial thinnings (4 plots) and for final cuttings (3 plots) is given in Apendix 1.
Summary of logging cost is given in table 3.11.

Table 3.11. Forest fuel cost

Cutting category (Trial No)	Cost, Lt/m^3
Pre-commercial thinning (R)	43.6
Pre-commercial thinning (M)	51.1
Commercial thinning (1E)	34.8
Commercial thinning (2E)	34.4
Commercial thinning (3E)	33.8
Sanitary cutting (1S)	33.8
Clear-cutting (2P-1)	30.4
Clear-cutting (2P-2)	30.5
Clear-cutting (3P)	29.9

3.4. THE EFFICIENCY OF FOREST FUEL LOGGING

Production cost for traditional industrial assortments decreases with integrated forest fuel handling, table (3.12)

Table 3.12. Differences in direct costs (Lt/solid m^3) for wood produced and extracted to roadside

Cutting category (Trial No)	Traditional technology	Integrated technology		Reduce cost for industrial wood, %/m^3
	Industrial wood incl. fire wood, Lt/m^3	Industrial wood, Lt/m^3	Forest fuel, Lt/m^3	
Commercial thinning (1E)	27	23	15	**15**
Commercial thinning (2E)	28	24	15	**14**
Commercial thinning (3E)	29	27	14	**7**
Sanitary cutting (1S)	26	25	14	**4**
Clear-cutting (2P-1)	18	17	11	**6**
Clear-cutting (2P-2)	19	17	11	**11**
Clear-cutting (3P)	22	20	10	**9**

There were calculated the main parameters, such as work expenditure, work and total costs for every trial. The data are presented in the Appendix 1. Calculation of forest fuel production efficiency is given in table 3.13.

Table 3.13. Economical efficiency of forest fuel production (Lt/ha)

Cutting category (Trial No)	With forest fuel production			Traditional technology			Efficiency of forest fuel production
	Income	Cost	Profit	Income	Cost	Profit	
Pre-commercial thinning (R)	2184	2442	-258	-	319	-319	61
Pre-commercial thinning (M)	2184	2860	-676	-	476	-476	-200
Commercial thinning (1E)	1972	766	1206	1790	699	1091	115
Commercial thinning (2E)	6907	2531	4376	6072	2382	3690	686
Commercial thinning (3E)	7129	2681	4448	6074	1961	4113	335
Sanitary cutting (1S)	7664	2412	5252	7310	2243	5067	185
Clear-cutting (3P)	22640	7426	15214	18810	4978	13832	1382
Clear-cutting (2P-1)	22287	5639	16648	20399	4639	15760	888
Clear-cutting (2P-2)	22162	5200	16962	19992	3882	16110	852

Note: Manual tools (R) and motor-saw aggregated with felling handle (M) used

Most cost ineffective is forest fuel production in pre-commercial thinning areas. The efficiency of forest fuel production was 61 Lt/ha in manually cut areas while negative efficiency was using machinery (-200 Lt/ha). Low experience of workers was the reason for low thinning efficiency.

Clear-cutting trials were most effective. The efficiency of forest fuel production in trial 3P was 1382 Lt/ha, while in other two cases efficiency was lower – 852-888 Lt/ha. Commercial thinnings and sanitary cuttings were less effective. The efficiency of forest fuel production there was 115-686 Lt/ha.

3.5. COST EFFECTING FACTORS

The main factors effecting cost of forest fuel production include: the method of felling, intensity, extraction distance, and actual productivity of the wood chipper and transportation distance to boiler-houses.

Forest fuel production in pre-commercial thinnings is new area for foresters and workers. Workers have no sufficient knowledge about work with new technological requirements. If compare work efficiency then work efficiency increases by 30% over four workdays in forest fuel production when machinery is used while only by - 20% in manual work (Figure 3.1.). Forest fuel production technology is similar to traditional pre-commercial thinnings technology when handle tools are used. It has two additional operations - cross cutting and piling of brushwood. Worker can increase work productivity when tree cutting and stowage operations are carried in rational way.

When forest fuel is produced by machinery good working skilled motor-sawers are required. Better results could be achieved improving working skills. Besides forest fuel production technology contains some additional operations. After tree cutting worker has to take it down properly for release piling. Saw can be placed on the ground or handle depending on the tree size.

Workers psychological attitude towards the work with machinery is also very important. Bigger dissatisfaction was caused by motor-saw aggregated with handle "Apuri" usage. It is possible to say that the work productivity increases only when worker get used to the new technique psychologically. The data mentioned above shows, that real work productivity could be easily brought closer to the normative. That is why for the further calculations of productivity the normative work time was used.

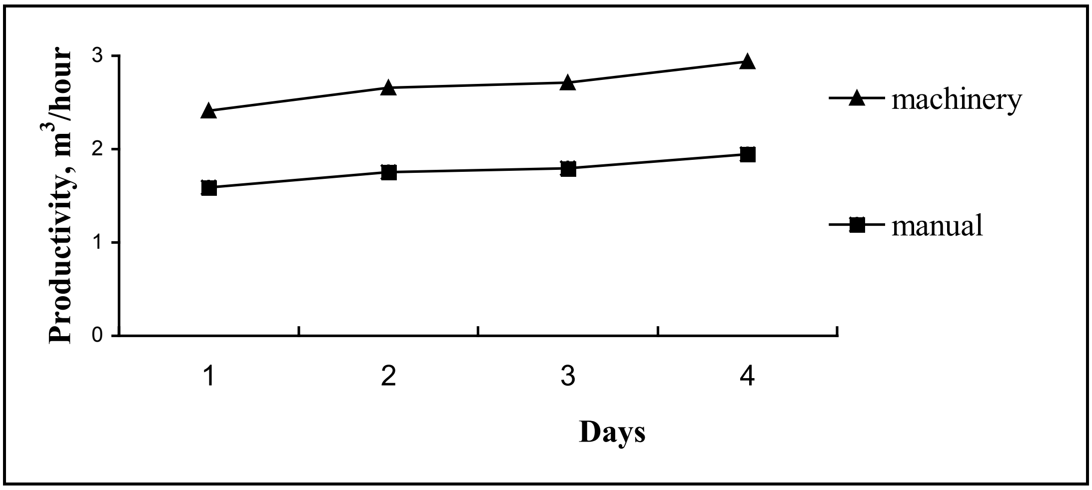


Fig. 3.1. Work productivity dynamics in forest fuel production

Forest fuel logging cost in young stands depends on the intensity of cuttings. The lower is felled volume per 1 ha, the higher is work time expenditure. Besides, cost increases when brushwood height decreases. Figure 3.2 shows how forest fuel logging cost depends on intensity in pre-commercial thinnings. Forest fuel cost could vary up to 40 % depending on cutting intensity

Fig. 3.2. Forest fuel cost due to intensity of cuttings

Piling takes more time in young stands by forest fuel production technology than in commercial or final cuttings because extraction distance to technical corridors is longer and residual trees disturbs the process. Most of the trees are felled near technical corridors in commercial or final cuttings, thus extraction distance is considerably shorter. Costs of forest fuel extraction in young stands is higher, because loading onto the trailer takes more time, due to residual trees.

Forest fuel extraction costs depend on many factors; one of them is type of cuttings. Costs are lowest in final cuttings, and highest in pre-commercial cuttings. Other important factors include: machinery exploitation costs and its productivity and extraction distance. Forest fuel logging cost due to extraction distance is shown in table 3.14.

Table 3.14. Forest fuel cost due to extraction distance

Distance, m	Cost, Lt/ m³
< 200	30.3
201-500	32.2
501-1000	35.2
>1000	39.0

Chipping costs mostly depend on the actual productivity of chipper. When chipper productivity increases from 10 to 50 m^3/hour, the fuel wood cost decreases about 1.5 times (Fig. 3.3).

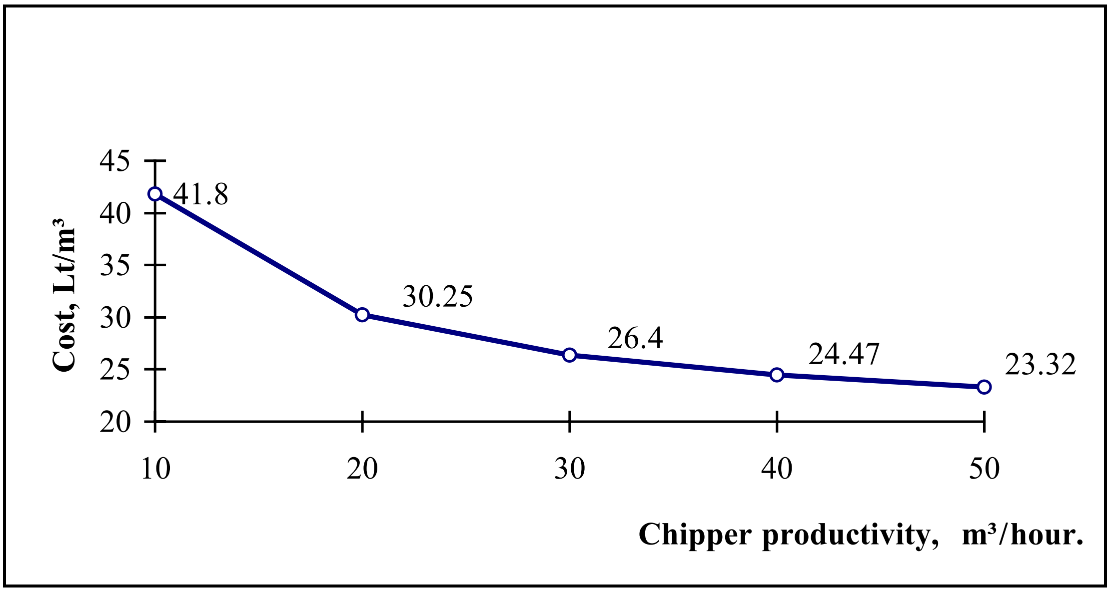


Fig. 3.3. Forest fuel cost due to chipper productivity

Forest fuel cost due to the distance of forest fuel transportation to the boiler-house is shown in figure 3.4. Cost increases from 24.7 Lt/m^3 to 38.5 Lt/m^3 due to increase of transportation distance from 5 km to 30 km.

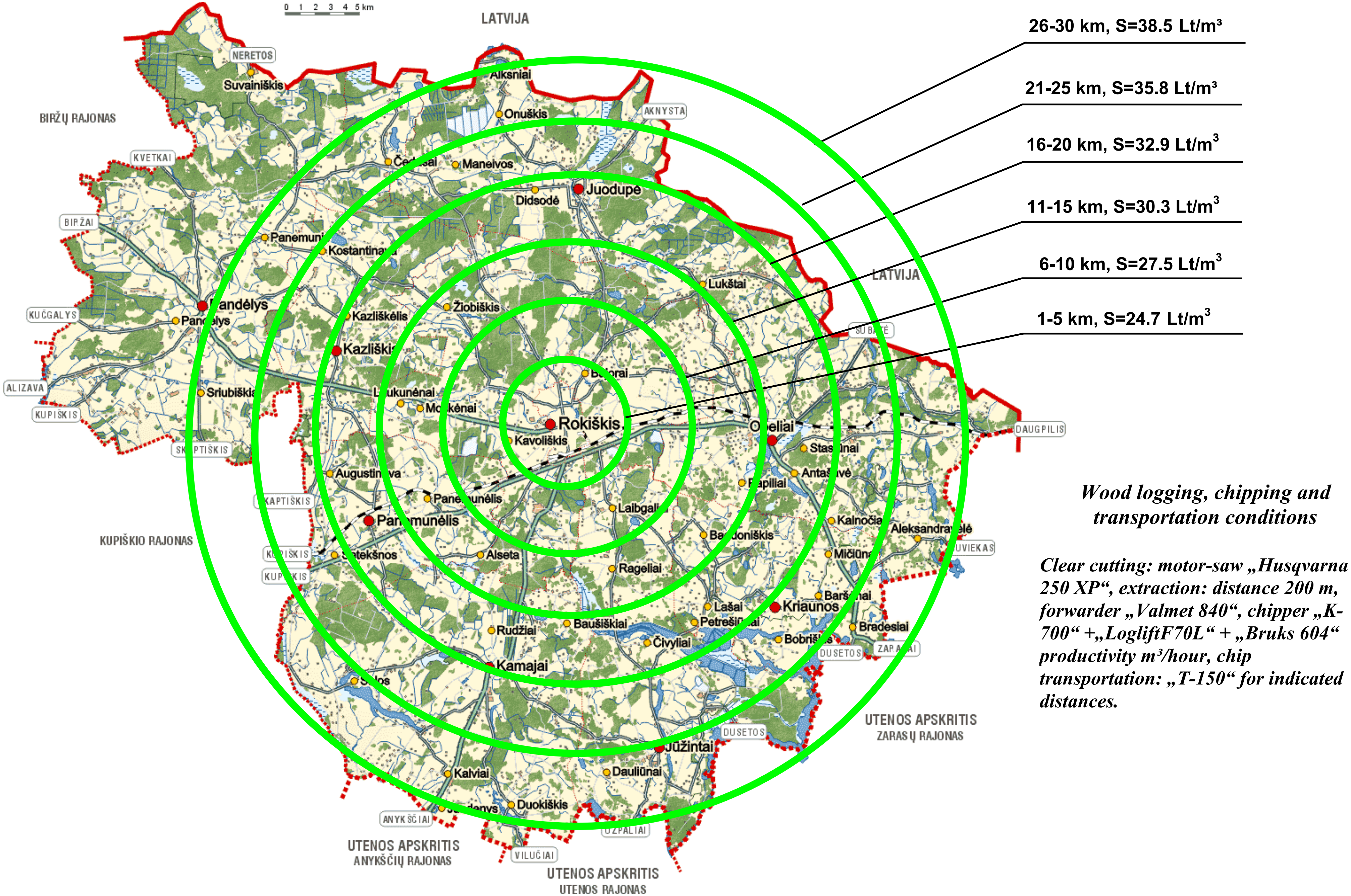


Fig. 3.4. Forest fuel cost (S) due to the chip transportation distance

Forest fuel logging costs depend on used machinery and trailer capacity. Forest fuel cost decreases by 25 % when it is transported 30 km with MAZ 5516 aggregated with 45 loose m^3 trailer, as opposite to transportation by the tractor T-150 aggregated with 25.3 loose m^3trailer. (Figure 3.5).

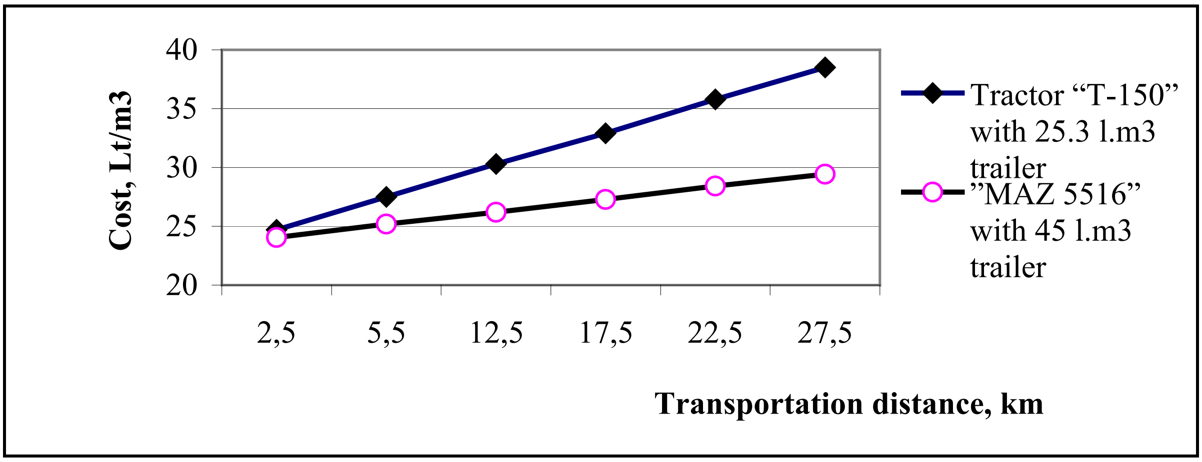


Fig. 3.5. Forest fuel cost due to chip transportation distance

Forest fuel cost structure was analyzed following the logging operations and cost economical elements (figures 3.6., 3.7.). Chipping (38.7%) makes up the biggest part of forest fuel cost in final cuttings according to logging operations. Transportation and extraction make up about 23-24% of the cost. Among the economical elements the biggest part of costs is given to machinery - 77.5% while 17.6% to fuel. Increased machinery usage intensity may reduce machinery costs. The increase of work time per day, workdays per year, and/or machinery productivity, time of useful usage could reduce machinery costs. For example, when tractor "K-700" is used 800 hours per year hourly exploitation costs comprise 131.50 Lt, 111.06 Lt while it is used for 1000 work hours. In the second case hourly costs decrease by 15.54%.

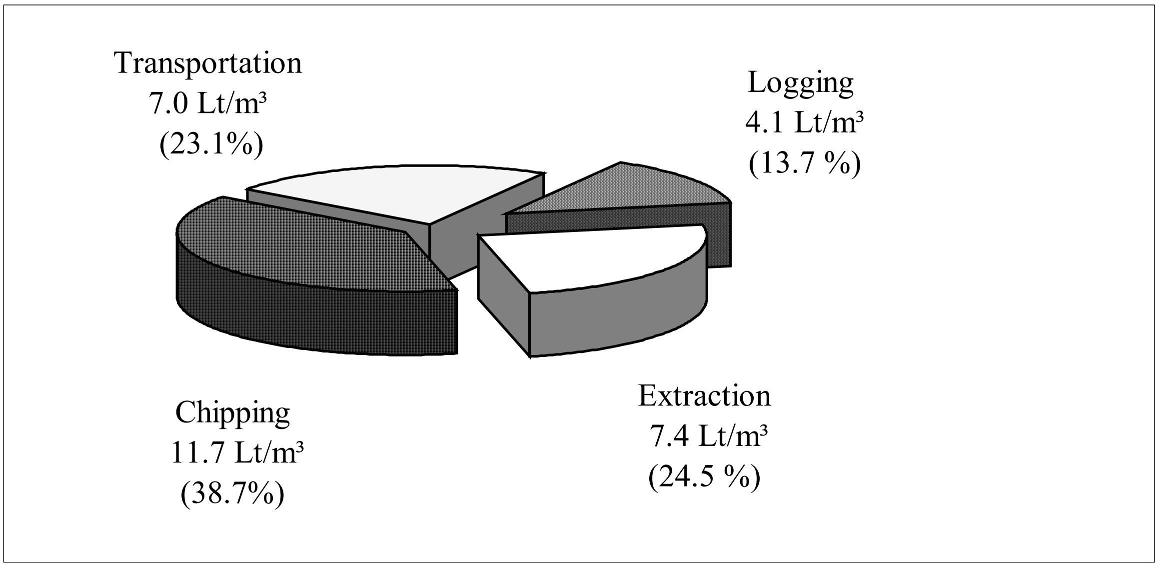


Fig.3.6. Structure of forest fuel producing costs (30,20 Lt/m^3) according to operations

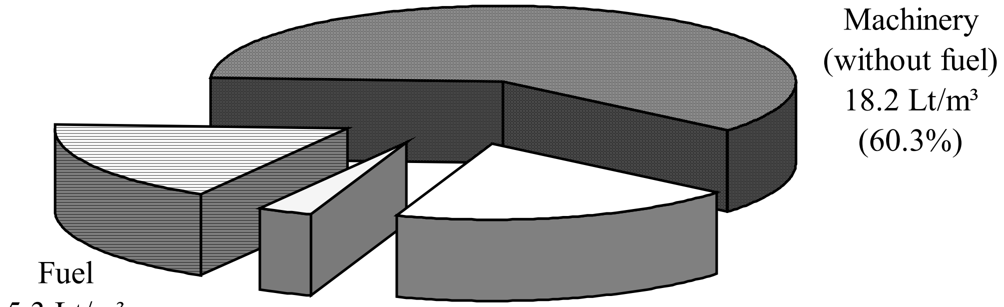


Fig. 3.7. Structure of forest fuel producing costs (30,20 Lt/m^3) due to input elements

3.6. Conclusions

1. Work expenditure for forest fuel producing comprised 2-3 hours per solid m^3 in thinnings, 0.6-0.8 in commercial thinnings and 0.6-0.7 hours per solid m^3 in final clear cuttings.
2. Forest fuel costs in pre-commercial thinning reduced by the costs of traditional pre-commercial thinning were 38-43 Lt/solid m^3. Total forest fuel costs in commercial thinnings are 34-35 Lt/solid m^3, while 30 Lt/solid m^3in clear cutting.
3. Forest fuel production in pre-commercial thinning by using hand tools decreased losses by 61 Lt/ha. The use of mechanism in pre-commercial thinning is not profitable due to low skillness of workers. Forest fuel production is more profitable if to compare with the traditional technology in commercial and final cuttings. It gives additionally 115-686 Lt/ha in commercial thinnings, 852-1382 Lt/m^3 in final cutting. Forest fuel concentration in cutting areas has the biggest influence on profitability.
4. Influence of various factors on the forest fuel cost:

- The increase of cutting intensity decreases the cost of forest fuel in pre-commercial thinnings. The increase of cut volume from 35 to 260 loose m^3/ha decreases the forest fuel cost from 48 to 43 Lt/ha by using motor-saw with felling handle in stands higher than 4 m.
- Cost of forest fuel increases when extraction distance increasing. Forest fuel cost increases from 30 to 35 Lt/solid m^3 in clear cuttings when extraction distance increases from 200 m to 1000 m.
- Forest fuel cost decreases while chipper productivity increasing. If chipper produces 20 solid m^3/hour, then forest fuel cost is 30 Lt/ m^3. Forest fuel cost decreases down to 25 Lt/ m^3, while productivity increases up to 40 solid m^3/hour.

5. Forest fuel cost increases while transportation distance increasing. Forest fuel cost increases from 25 to 39 Lt/m^3, when distance increase from 5 to 30 km by using “T-150” with 25 loose m^3 trailer. The increase of cost would be lower - from 24 to 29 Lt/ m^3 by using “MAZ 5516” (45 loose m^3).
6. The biggest part of forest fuel cost in clear cutting makes up chipping (39%), extraction and transportation - 24%. Machinery takes 78% of the cost, including 18% of fuel cost.

4. STUDIES OF WOOD ASH UTILIZATION (K.Armolaitis, A.Raguotis, J.Zenkovaite)

4.1. METHODICS

Wood ash fertilisation demonstrative objects were established (2001 10 25) in site No 13 (area 10.1 ha) of block No 54 in Selyne forest district of Rokiskis Forest Enterprise. There grows 90-year-old Scots pine stand with Norway spruce in the second storey.

Soil of the stand with established demonstrative fertilisation objects is Haplic Luvisol; forest type – *Pinetum oxalidosum*.

Ash from Rokiskis town heating plant was applied as a fertiliser, the quality of which in most cases corresponds the criteria accepted in Sweden (Table 4.1). Prior to the studies ash 2 months was kept in an open area and spreaded by 20-40 cm thick layer, thus, under the rain influence became hardened (stabilised). Fertilisation was conducted manually: 2.5 t ha^{-1} (amount recommended in Sweden) and 5.0 t ha^{-1}. Unfertilised part of the stand was considered to be the control.

Studying the influence of ash applied in demonstrative objects on forest soil and vegetation after 6 months since ash application it was evaluated in May 2002.

4.1.1. Forest soil chemical properties

The combined samples of forest litter and mineral soil (0-5; 5-10 and 10-20 cm depths) were taken from 20 places systematically. In laboratories of Lithuanian Forest Research Institute and the Centre of Agrochemical Studies of Lithuanian Agricultural Institute were evaluated the following parameters: pH_{CaCl2} and pH_{KCl} – by potentiometer; org. C – with Heraeus apparatus; total P – colorimetrically with molybdate; total K – with flame photometer; total Ca – with atomic absorption spectrometer; total Mg – with atomic absorption spectrometer; total content of heavy metals (Cr, Cd, Pb, Ni, Cu, Zn, Mn and Fe) – ISO/DIS 11047-93, with atomic absorption spectrometer Analist 800 (totally 96 chemical analyses were done).

Table 4.1. Chemical composition of wood ash from Rokiskis town heating plant

Chemical parameter	Content	Recommended minimal and maximal contents of complex ash substances (Skogsstyrelsen, 2001)
$C_{org.}$, %	1.32	10-15 (maximally)
Total P, g kg^{-1}	7.2	10 (minimal)
Total K, g kg^{-1}	24.6	30 (minimal)
Total Ca, g kg^{-1}	255	125 (minimal)
Total Mg, g kg^{-1}	34.4	20 (maximal)
Boron, mg kg^{-1}	225	500 (maximal)
Vanadium, mg kg^{-1}	109	70 (maximal)
Chromium, mg kg^{-1}	44	100 (maximal)
Cadmium, mg kg^{-1}	9.6	30 (maximal)
Lead, mg kg^{-1}	40	300 (maximal)
Copper, mg kg^{-1}	80	400 (maximal)
Zinc, mg kg^{-1}	820	1000-7000
Mercury, mg kg^{-1}	0.015	3 (maximal)
Arsenic, mg kg^{-1}	0.65	30 (maximal)
^{137}Cesium, Bq kg^{-1}	<5.0	5 (maximal)
Benzo(a)pyrene, μg kg^{-1}	0.0	2 (maximal)

4.1.2. Forest soil microflora and bioactivity

The microflora of forest litter and upper mineral soil layer (0-10 cm) was studied by sowing to a various degree diluted soil suspensions on nutrient medium for assessing different groups of microorganisms. The studies of microorganisms were conducted with three replications (totally 162 analyses were done).

Some indices of soil biological activity were evaluated in the forest. The intensity of CO_2 depletion from forest litter with 5 replications was defined by the absorption method (Shtatnov, 1952), and the intensity of cellulose decomposition with 5 replications was determined by methodics accepted in Finland and provided in the program of Integrated monitoring (UN/ECE, 1993). The activity of soil ferments (catalase and saccharase) was assessed in the laboratory with 3 replications according to the methodics described by S.Klupt (1962). Totally 36 analyses were done.

4.1.3. Diversity of soil ground vegetation

Diversity of soil ground vegetation has been described as species composition and coverage of mosses, lichen and grasses. It was assessed by means of inventory in 12.56 m^2 (radius 2 m) circular plots with 3 replications (totally 9 observation plots).

4.2. STUDIES OF ASH UTILISATION

4.2.1. Changes in soil chemical properties

Forest soil due to wood ash application may become more alkaline and enriched by org. C and all macronutrients (P, K, Ca and Mg), except nitrogen. Further, ash is contaminated by heavy metals. Therefore, data on saturation of Haplic Luvisols with both above mentioned groups of elements are analysed separately.

Theoretically calculated, that the greatest contents of Ca (in 2.5 t ha^{-1} of ash – 63.8 g m^{-2} and in 5.0 t ha^{-1} – 127.6 g m^{-2}) were spreaded together with ash in demonstrative objects, while the contents of org. C and other macronutrients were from 7-10 (Mg, K) to 20-35 times (org. C and P) less.

Although great amounts of Ca were applied, the reaction (pH_{CaCl2} and pH_{KCl}) of forest litter and upper 20 cm deep mineral soil layer has not changed essentially 6 months after ash application (Table 4.2). The content of org. C, Ca, Mg, P and K in forest litter and upper mineral soil layer had not changed as well.

It was found, that among heavy metals the greatest amounts of Zn were spreaded (205-410 mg^{-2}), while the amounts of Pb and Cr were 20 times, Cu – 10 times, and Cd even 85 times less. Although, the contents of Zn were greatest in ash, Zn content in forest litter and upper 20 cm thick mineral soil layer did not changed essentially 6 months after ash application (Table 4.3). Concerning heavy metals (Cr, Cd, Pb, Ni, Cu, Mn and Fe) in forest litter and upper 5 cm deep mineral soil layer fertilised by ash an insignificant increment of Pb (on an average increased by 14-35% and 39-41%, respectively) was ascertained, while Zn concentrations only increased (14-32%) in the forest litter. Besides, only in the object where 2.5 t ha^{-1} of ash were applied, the amount of Cr increased by about 30% in forest litter. Even these concentrations are from 4-7 times (Cu, Cr) to 11-13 times (Pb, Cd and Zn) lower than critical concentrations in forest litter accepted in Sweden (Tyler, 1992).

Table 4.2. Acidity and nutrients saturation of Haplic Luvisol in demonstrative objects fertilised by wood ash (2002, 6 months after ash application)

Amount of applied ash	Sampling depths							
	O (forest liter)	0-5 cm	5-10 cm	10-20 cm	O (forest liter)	0-5 cm	5-10 cm	10-20 cm
	pH_{CaCl2}				pH_{KCl}			
0.0 t ha^{-1} (control)	3.24	3.51	3.97	4.25	3.04	3.51	3.87	4.09
2.5 t ha^{-1}	3.16	3.58	4.11	4.26	3.02	3.39	3.87	4.07
5.0 t ha^{-1}	3.36	3.56	4.13	4.27	3.07	3.47	3.86	4.06
	Total Ca, mg kg^{-1}				Total Mg, mg kg^{-1}			
0.0 t ha^{-1} (control)	2575	138	102	110	449	378	524	598
2.5 t ha^{-1}	1975	140	126	112	454	404	466	544
5.0 t ha^{-1}	2700	150	110	126	491	487	527	619
	Total P, mg kg^{-1}				Total K, mg kg^{-1}			
0.0 t ha^{-1} (control)	1050	470	400	520	1650	1320	1080	1080
2.5 t ha^{-1}	760	420	380	400	1350	1100	1080	1100
5.0 t ha^{-1}	960	400	400	400	1700	1200	1080	1250
	Org. C, %							
0.0 t ha^{-1} (control)	40.51	1.72	0.97	0.59				
2.5 t ha^{-1}	32.55	1.66	0.84	0.72				
5.0 t ha^{-1}	34.50	1.75	0.98	0.64				

Table 4.3. Total contents (mg kg^{-1}) of heavy metals in Haplic Luvisols of demonstrative objects fertilised with wood ash (6 months after ash application)*

Amount of applied ash	Sampling depths							
	O (forest litter)	0-5 cm	5-10 cm	10-20 cm	O (forest litter)	0-5 cm	5-10 cm	10-20 cm
	Chromium (Cr)				Cadmium (Cd)			
0.0 t ha^{-1} (control)	4.8	4.0	3.6	4.0	0.5	0.2	0.2	0.2
2.5 t ha^{-1}	6.3	3.2	2.8	3.6	0.3	0.2	0.2	0.2
5.0 t ha^{-1}	4.0	3.6	3.6	4.1	0.5	0.2	0.2	0.2
	Lead (Pb)				Nickel (Ni)			
0.0 t ha^{-1} (control)	33.5	8.2	7.6	7.2	5.5	2.6	3.4	4.6
2.5 t ha^{-1}	38.3	11.4	7.6	6.0	6.0	3.2	3.6	4.6
5.0 t ha^{-1}	45.3	11.6	9.6	6.0	5.0	2.8	3.6	4.6
	Cooper (Cu)				Zinc (Zn)			
0.0 t ha^{-1} (control)	5.3	1.8	2.0	2.2	38.8	27.2	13.8	13.8
2.5 t ha^{-1}	4.5	1.4	1.6	2.0	25.8	11.0	11.2	12.6
5,0 t ha^{-1}	3.5	1.8	2.2	2.8	26.0	12.0	12.0	12.6
	Manganese (Mn)				Iron (Fe)			
0.0 t ha^{-1} (control)	500	104	176	130	2750	4500	5900	6200
2.5 t ha^{-1}	270	98	176	130	3625	4600	4700	5600
5.0 t ha^{-1}	263	80	158	100	3125	5250	5700	5900

* Critical concentrations of heavy metals in forest litter accepted in Sweden:
Cr – 30 mg kg^{-1}; Cd – 3.5 mg kg^{-1}; Pb – 500 mg kg^{-1}; Cu – 20 mg kg^{-1};
Zn – 300 mg kg^{-1} (Tyler, 1992)

4.2.2. Soil biological properties

The number of microorganisms and their activity in soil show ecological stability of soils. Forest wood ash fertilisation experiments had revealed, that wood ash impact on soil microflora is rather insignificant 6 months after ash application. An observable increase in the number of ammonifiers occurs only in forest litter then 5 t ha^{-1} of wood ash were applied (Table 4.4). The number of ammonifiers increased by 25%.

Table 4.4. Influence of wood ash on the number of soil ammonifying microorganisms

Amount of applied ash, t ha^{-1}	Total number of microorganisms	Bacteria	Actinomycetes	Micromycetes	Bacteria	Actinomycetes	Micromycetes
	thou. g^{-1} of dry matter				%		
Forest litter							
0.0 (control)	6256	4982	1034	240	79.6	16.5	3.9
2.5	6085	4740	1053	292	77.9	17.3	4.8
5.0	7823	6573	967	283	84.0	12.4	3.6
Upper mineral soil layer							
0.0 (control)	385	317	29	39	82.3	7.6	10.1
2.5	346	247	58	41	71.4	16.8	11.8
5.0	446	386	29	31	86.6	6.5	6.9

More favourable reaction to ash is characterised by oligonitrophilous microorganisms. The number of these microorganisms under 5.0 t ha^{-1} of ash in forest litter increased even by 120%, while in mineral soil by 70%. Other groups of microorganisms in forest litter and mineral soils are rather scarce, though their role in forest ecosystems is very important (Table 4.5). The number of nitrifying bacteria in forest litter has reached almost 2 thou. cells per 1 g of DW only then 5.0 t ha^{-1} of wood ash were applied. The number of denitrifiers in forest litters is considerably greater. However, the impact of ash on the activity of denitrifiers was not determined. The number of denitrifiers in forest litter and mineral soils remained unchanged 6 months after ash application, while the application of 2.5 t ha^{-1} of wood ash effected even the decrease. Positive reaction of atmospheric nitrogen anaerobic accumulator *Clostridium pasteurianum* to wood ash application was observed. The number of mentioned bacteria in forest litter increased even by 4 times while 5.0 t ha^{-1} of wood as was applied.

Table 4.5. Wood ash influence on microorganisms in forest litter and mineral soil

Amount of applied ash, t ha^{-1}	Nitrifying bacteria	Denitrifiers	*Clostridium pasteurianum*
Forest litter, thou. g^{-1} DW			
0.0 (control)	0.09	99	8
2.5	0.0	40	9
5.0	1.88	102	36
Upper mineral soil layer, thou. g^{-1} DW			
0.0 (control)	0.01	1	1
2.5	0.01	1	1
5.0	0.01	1	3

Soil biological activity reflects the activity of microorganisms. One of the important soil biological activity parameter is CO_2 depletion intensity from the soil. The depletion of CO_2 differed in all objects quite insignificantly and was about 1 kg ha^{-1} per hour (Table 4.6). The intensity of cellulose decomposition showed no differences between variants as well. While the application of 5.0 t ha^{-1} of wood ash influenced the decrease of saccharase activity in the forest litter. It decreased twice in compare with control. No ash impact on the ferment activity was ascertained in the mineral soil.

Table 4.6. Wood ash influence on soil bioactivity

Amount of applied ash, t ha^{-1}	CO_2 depletion intensity, kg ha^{-1} per hour	Cellulose decomposition over 1.5 month, %	Catalase activity, O_2 ml g^{-1} per 5 min.	Saccharase activity, sugar mg g^{-1} per 24 h
Forest litter				
0.0 (control)	0.98	-	40.9	198.3
2.5	0.96	-	35.9	108.5
5.0	1.02	-	30.7	89.4
Upper mineral soil horizon				
0.0 (control)	-	11.2	3.0	9.4
2.5	-	13.0	3.8	11.0
5.0	-	8.6	3.7	9.4

4.2.3. Response of ground vegetation

Mean total coverage of all plants (except bushes and trees) in the control and fertilised by wood ash demonstrative objects is 80-89%. Among semi-bushes the coverage by bilberries comprises 7-14%, by grasses 6-18% and mosses 57-70% (Table 4.7). Among mosses *Hylocomium splendens* and *Pleurozium schreberi* prevailed.

Table 4.7. Coverage of ground vegetation and number of species in demonstrative objects fertilised by wood ash (2002)

Amount of applied ash, t ha^{-1}	Coverage, %				Number of species			
	all species	semi-bushes	grasses	mosses	total	semi-bushes	grasses	mosses
0 (control)	88.5±8.95	13.3±0.88	17.9±4.85	57.3±3.23	13	1	8	4
2.5	79.8±7.04	9.8±1.30	12.5±2.94	57.5±2.80	16	1	13	2
5.0	84.7±5.91	7.9±0.59	6.9±2.30	69.9±3.02	8	1	5	2

Obtained results showed, that application of 5.0 t ha^{-1} of wood ash had caused no negative effect on the cover of mosses 6 months after ash application.

Coverage by red bilberries decreased by increase of wood ash dosage. In the same way was changing the coverage by grasses. It decreased from 17.9% in the control variant to 6.9% then 5.0 t ha^{-1} of ash were applied.

Summarised study results could state, that soil in established demonstrative objects fertilised by wood ash is covered by dense (80-85% coverage) ground vegetation, where coverage by mosses comprises 58-70%. No negative effect on ground vegetation species composition and abundance of individual species was ascertained 6 months after ash application. However, the first signs of withering of mosses favoured by acid environment – whitening and turning grey – have been observed.

4.3. CONCLUTIONS

1. Six months after the spreading of 2.5 and 5.0 tones per ha hardened ash in Haplic Luvisols no changes of organic carbon and macronutrients, such as Ca, Mg, P, K were found. Insignificant increases of some heavy metal content (Pb, Fe and Cr) in forest litter were ascertained.

2. Positive effect on litter microflora was detected while spreading 5.0 t ha^{-1} of wood ash. The number of ammonifying bacteria increased by 25%, bacilas - 100%, oligotrophic microorganisms – by 120%. An increased role of nitrificators, *Clostridium pasteurianum* and cellulose-decomposing bacteria was ascertained. The influence on microorganisms in mineral soil was not detected.

3. Ground vegetation species composition did not changed 6 months after spreading ash. First signs of mosses drying were observed - they became white or grey.

4. Currently it is worthwhile to use forest fuel ash for spreading (Skogsstyrelsen, 2001). It could not cause any negative effect, because Lithuanian forest soils are more buffer if to compare with Swedish.

5. Along with continuous studies Lithuanian recommendation for wood ash application, as a compensatory fertiliser in the forest should be developed.

References

1. Klupt S.E., 1962. Enzymes. Broad practical assistant in microbiology. Edition by Seluber G.L. Moscow, “Vishaja shkola”, 143-164 p. (in Russian).
2. Shtatnov V.I., 1952. Methodology in assessing biological activity of soils. VASXNIL, constitutions, 6 th edition (in Russian).
3. Skogsstyrelsen, 2001. Swedish recommendations for the extraction of forest fuel and compensatory fertilising in Sweden. National Board of Forestry.
4. Tyler G., 1992. Critical Concentrations of Heavy Metals in the Mor Horizon of Swedish Soils. Swedish Environmental Protection Agency, Report 4078. – 38 p.
5. UN/ECE, 1993. Manual for integrated monitoring. Programme phase 1993-1996. Environmental Report 5. National Board of Waters and the Environment. Helsinki. – 126 p.

Appendix 1

Monetary expenditures of forest fuel production in the research plots

Pre-commercial thinnings. **Plots 1-2.** During forest fuel logging young spruce stands were thinned by using the sabre, brush was cut and piled up near technical corridors. Extraction was carried out by the tractor "MTZ – 82" aggregated with the trailer "Weimer WE-8" up to 200 m. Chipper "BRUKS-604 CT" aggregated with the tractor "K-700" was used for chipping. Chipped wood was transported for 15 km by the tractor " T-150" aggregated with the 25.3 m^3 trailer. Thinning intensity - 56m^3/ha. In the traditional method pre-commercial thinning was done by using the sabre and then brushwood was spread in the cutting area. The cost calculation is shown in table 1.

Table 1. Cost calculation in pre-commercial thinnings (when hand tools were used)

Work	Pre-commercial thinning with forest fuel production			Traditional technology		
	Work expenditures, hour/m³	Work cost, Lt/hour	Total cost, Lt/m³	Work expenditures, hour/m³	Work cost, Lt/hour	Total cost, Lt/m³
Brush cutting and piling	2.760	5.18	14.30	1.100	5.18	5.70
Extraction	0.205	50.75	10.40			
At roadside	**2.97**		**24.70**			
Chipping	0.06	192.54	11.55			
Transportation	0.103	66.46	6.85			
Material cost			0.51			
Total cost 1 m³	**3.13**		**43.61**	**1.100**		**5.70**

Plot 1-2. Producing forest fuel young spruce stands were thinned by using the **motor-saw "Jonsered 2150 Turbo" and felling handle "Apuri".** Cut brushwood was piled near technical corridors. Extraction was carried out by the tractor "MTZ – 82" aggregated with the trailer "Weimer WE-8" up to 200 m. Chipper "BRUKS-604 CT" aggregated with the tractor "K-700" was used for chipping. Chipped wood was transported for 15 km by the tractor " T-150" aggregated with the 25.3 m^3 trailer. Thinning intensity - 56m^3/ha. In the traditional pre-commercial thinnings brushwood was cut by using the brush-cutter "Husquarna 250R" and then spread in the cutting area. Cost calculation is shown in the table 2.

Table 2. Cost calculation in pre-commercial thinnings when motor–manual tools were used

Work	Pre-commercial thinning with forest fuel production			Traditional technology		
	Work expenditures, hour/m³	Work cost, Lt/hour	Total cost, Lt/m³	Work expenditures, hour/m³	Work cost, Lt/hour	Total cost, Lt/m³
Bush cutting and piling	1.70	12.80	21.76	0.740	11.48	8.50
Extraction	0.205	50.75	10.40			
At roadside	**1.91**		**32.16**			
Chipping	0.06	192.54	11.55			
Transportation	0.103	66.46	6.85			
Material cost			0.51			
Total cost 1 m³	**2.07**		**51.07**	**0,740**		**8.50**

Commercial cuttings. Plot 1E. Commercial thinning was carried out in Kamajai forest district plot No. 16 in the block No. 136. Plot area is 0.18 ha, average stem volume is 0.378 m^3. 0.4 m^3 of large industrial assortments, 4.2 m^3 of small industrial assortments and 0.9 m^3 of forest fuel were produced by integrated with forest fuel technology in this plot. 0.4 m^3 of large industrial assortments, 4.2 m^3 of small industrial assortments and 0.1 m^3 of firewood were produced by traditional technology. *Technology.* Producing forest fuel motor-saw " Husqvarna 254X" was used, 2 people team worked. Firewood was prepared only from the butt part of stems. Forest fuel (top and branches) was piled near technical corridors. Industrial assortments and firewood were piled near technical corridors by the traditional technology. Extraction was done by the forwarder "Valmet 840Y" for 250 m. Chipper "BRUKS-604 CT" aggregated with the tractor "K-700" was used for chipping. Chipped wood was transported for 15 km by the tractor "T-150" aggregated with a trailer. Cost calculation is shown in the table 3.

Table 3. Cost calculation in commercial thinning trial 1E

Work	With forest fuel production			Traditional technology		
	Work expenditures, hour/m³	Work cost, Lt/hour	Total cost, Lt/m³	Work expenditures, hour/m³	Work cost, Lt/hour	Total cost, Lt/m³
Trad. assortment						
production	0.976	10.77	10.51	1.557	9.05	14.09
extraction	0.157	72.92	11.45	0.157	72.92	11.45
Material cost			1.24			1.24
Total at roadside	**1.133**		**23.20**	**1.714**		**26.78**
Forest fuel						
cross-cutting	0.017	12.35	0.21			
piling	0.45	6.04	2.72			
Total in cutting area	***0.47***		***2.93***			
extraction	0.172	72.92	12.54			
Total at roadside	***0.64***		***15.47***			
chipping	0.06	192.54	11.55			
transportation	0.103	66.46	6.85			
materials			0.95			
Total forest fuel cost			**34.82**			

Plot 2E. Commercial thinning was carried out in Kamajai forest district plot No.16 in the block No. 136. Plot area is 0.07 ha, average stem volume is 0.345 m^3. 1.3 m^3 of large industrial assortments, 4.0 m^3 of small industrial assortment and 1.5 m^3 of forest fuel were produced by integrated with forest fuel technology in the plot. 1.3 m^3 of large industrial assortments, 4.0 m^3 of small industrial assortments and 0.1 m^3 of firewood were produced by traditional technology. *Technology.* Producing forest fuel motor-saw " Husqvarna 254X" was used, 2 people team worked. Firewood was prepared only from the butt part of stems. Forest fuel (top and branches) was piled near technical corridors. Industrial assortments and firewood were piled near technical corridors by the traditional technology. Extraction was done by the forwarder "Valmet 840Y" for 250 m. Chipper "BRUKS-604 CT" aggregated with the tractor "K-700" was used for chipping. Chipped wood was transported for 15 km by the tractor "T-150" aggregated with a trailer. Cost calculation is shown in the table 4.

Table 4. Cost calculation in commercial thinning trial 2E

Work	With forest fuel production			Traditional technology		
	Work expenditures, hour/m³	Work cost, Lt/hour	Total cost, Lt/m³	Work expenditures, hour/m³	Work cost, Lt/hour	Total cost, Lt/m³
Trad. assortment						
production	1.012		11.03	1.641		15.16
extraction	0.157	72.92	11.45	0.157	72.92	11.45
Material cost			1.24			1.24
Total at roadside	**1.169**		**23.72**	**1.798**		**27.85**
Forest fuel						
cross-cutting	0.017	12.35	0.21			
piling	0.38	6.04	2.30			
Total in cutting area	***0.40***		***2.51***			
extraction	0.172	72.92	12.54			
Total at roadside	***0.6***		***15.05***			
chipping	0.06	192.54	11.55			
transportation	0.103	66.46	6.85			
materials			0.95			
Total forest fuel cost			**34.40**			

Plot 3E. Commercial thinning was carried out in Selynes forest district No. 18 in the block No. 58. Plot area is 0.49 ha, average stem volume is 0.251 m^3. 14.7 m^3 of large industrial assortments, 15.6 m^3 of small industrial assortments and 15 m^3 of forest fuel were produced by integrated with forest fuel technology in the plot. 14.7 m^3 of large industrial assortments, 15.6 m^3 of small industrial assortments and 3.1 m^3 of firewood were produced by traditional technology. *Technology* Producing forest fuel motor-saw " Husqvarna 254X" was used, 2 people team worked. Firewood was prepared only from the butt part of stems. Forest fuel (top and branches) was piled near technical corridors. Industrial assortments and firewood were piled near technical corridors by the traditional technology. Extraction was done by the forwarder "Valmet 840Y" for 250 m. Chipper "BRUKS-604 CT" aggregated with the tractor "K-700" was used for chipping. Chipped wood was transported for 15 km by the tractor "T-150" aggregated with a trailer. Cost calculation is shown in the table 5.

Table 5. Cost calculation in commercial thinning trial 3E

Work	With forest fuel production			Traditional technology		
	Work expenditures, hour/m³	Work cost, Lt/hour	Total cost, Lt/m³	Work expenditures, hour/m³	Work cost, Lt/hour	Total cost, Lt/m³
Trad. assortment						
production	1.206	11.56	13.94	1.489	10.82	16.10
extraction	0.157	72.92	11.45	0.157	72.92	11.45
Material cost			1.24			1.24
Total at roadside	**1.169**		**26.63**	**1.646**		**28.79**
Forest fuel						
cross-cutting	0.017	12.35	0.21			
piling	0.309	6.04	1.87			
Total in cutting area	***0.326***		***2.08***			
extraction	0.172	72.92	12.40			
Total at roadside	***0.498***		***14.48***			
chipping	0.06	192.54	11.55			
transportation	0.103	66.46	6.85			
materials			0.95			
Total forest fuel cost			**33.83**			

Plot 1S. Sanitary cutting was carried out in Selynes forest district plot No.16 in the block No.136. Plot area is 0,34 ha, average stem volume is 0.374 m^3. 10.8 m^3 of large industrial assortments, 16.2 m^3 of small industrial assortments and 4.2 m^3 of forest fuel were produced by integrated with forest fuel technology in the plot. 10.8 m^3 of large industrial assortments, 16.2 m^3 of small industrial assortments and 2.0 m^3 of firewood were produced by traditional technology. *Technology.* Producing forest fuel motor-saw " Husqvarna 254X" was used, 2 people team worked. Firewood was prepared only from the butt part of stems. Forest fuel (top and branches) was piled near technical corridors. Industrial assortments and firewood were piled near technical corridors by the traditional technology. Extraction was done by the forwarder "Valmet 840Y" for 250 m. Chipper "BRUKS-604 CT" aggregated with the tractor "K-700" was used for chipping. Chipped wood was transported for 15 km by the tractor "T-150" aggregated with a trailer. Cost calculation is shown in the table 6.

Table 6. Cost calculation in sanitary cutting trial 1S

Work	With forest fuel production			Traditional technology		
	Work expenditures, hour/m³	Work cost, Lt/hour	Total cost, Lt/m³	Work expenditures, hour/m³	Work cost, Lt/hour	Total cost, Lt/m³
Trad. assortment						
production	1.131		12.43	1.234		12.97
extraction	0.157	72.70	11.41	0.157	72.7	11.41
Material cost			1.24			1.24
Total at roadside	**1.288**		**25.08**	**1.275**		**25.62**
Forest fuel						
cross-cutting	0.017	12.30	0.21			
piling	0.294	6.04	1.78			
Total in cutting area	***0.311***		***1.99***			
extraction	0.172	72.70	12.50			
Total at roadside	***0.483***		***14.49***			
chipping	0.06	192.54	11.55			
transportation	0.103	66.46	6.85			
materials			0.95			
Total forest fuel cost			**33.84**			

<u>In the final cuttings.</u> Plot 3P. Final clear-cutting was carried out in Selynes forest district .the plots No. 12,13 in the block No. 62. Plot area is 0.22 ha, average stem volume is 0.252 m^3. 17.7 m^3 of large industrial assortments, 26.8m^3 of small industrial assortments and 24.7 m^3 of forest fuel were produced by integrated with forest fuel technology in the plot. 17.7 m^3 of large industrial assortments, 26.8 m^3 of small industrial assortments and 5.5 m^3 of firewood were produced by traditional technology. *Technology.* During forest fuel logging the motor-saw " Husqvarna 254X" was used, 2 people team was worked. Firewood was prepared only from the butt part of the stem. Forest fuel (top and branches and understorey brushwood) was piled up near technical corridors. Industrial assortments and firewood were piled near technical corridors by traditional technology. Forest fuel and industrial assortments were extracted by the forwarder"Valmet 840Y" for 200 m. Chipper "BRUKS-604 CT" aggregated with the tractor "K-700"was used for chipping. Chipped wood was transported by the tractor "T-150" aggregated with trailer of 25.3 m^3. Cost calculation is shown in the table 7.

Table 7. Cost calculation in clear-cutting trial 3P

Work	With forest fuel production			Traditional technology		
	Work expenditures, hour/m³	Work cost, Lt/hour	Total cost, Lt/m³	Work expenditures, hour/m³	Work cost, Lt/hour	Total cost, Lt/m³
Trad. assortment						
production	0.977	11.18	10.92	1.242	10.26	12.74
extraction	0.109	72.92	7.95	0.109	72.92	7.95
Material cost			1.24			1.24
Total at roadside			**20.11**	**1.351**		**21.93**
Forest fuel						
cross-cutting	0.102	12.35	1.26			
piling	0.274	6.04	1.65			
Total in cutting area	***0.376***		***2.91***			
extraction	0.104	72.92	7.58			
Total at roadside	***0.480***		***10.49***			
chipping	0.06	192.54	11.55			
transportation	0.104	66.46	6.91			
materials			0.95			
Total forest fuel cost			**29.90**			

Plot 2P-1. Final clear-cutting was carried out in Selynes forest district plots No. 7,11 in the block No. 62. Plot area is 0.19 ha, average stem volume is 0.327 m^3. 14.3 m^3 of large industrial assortments, 30.4 m^3 of small industrial assortments and 11 m^3 of forest fuel were produced by integrated with forest fuel technology in the plot. 14.3 m^3 of large industrial assortments, 30.4 m^3 of small industrial assortments and 3,2 m^3 of firewood were produced by traditional technology. *Technology.* During forest fuel logging the motor-saw " Husqvarna 254X" was used, 2 people team was worked. Firewood was prepared only from the butt part of the stem. Forest fuel (top and branches and understorey brushwood) was piled up near technical corridors. Industrial assortments and firewood were piled near technical corridors by traditional technology. Forest fuel and industrial assortments were extracted by the forwarder "Valmet 840Y" for 200 m. Chipper "BRUKS-604 CT" aggregated with the tractor "K-700"was used for chipping. Chipped wood was transported by the tractor "T-150" aggregated with trailer of 25.3 m^3. Cost calculation is shown in the table 8.

Table 8. Cost calculation in clear-cutting trial 2P-1

Work	With forest fuel production			Traditional technology		
	Work expenditures, hour/m³	Work cost, Lt/hour	Total cost, Lt/m³	Work expenditures, hour/m³	Work cost, Lt/hour	Total cost, Lt/m³
Trad. assortment						
production	0.774	9.44	7.31	0.932	9.91	9.24
extraction	0.109	72.92	7.95	0.109	72.92	7.95
Material cost			1.24			1.24
Total at roadside			**16.50**	**1.041**		**18.43**
Forest fuel						
cross-cutting	0.107	12.35	1.32			
piling	0.348	6.04	2.10			
Total in cutting area	***0.455***		***3.42***			
extraction	0.104	72.92	7.58			
Total at roadside	***0.559***		***11.00***			
chipping	0.060	192.54	11.55			
transportation	0.103	66.46	6.85			
materials			0.95			
Total forest fuel cost			**30.35**			

Plot 2P-2. The final cutting was carried out in Selynes forest district plots No. 7,11 in the block No. 62. Plot area is 0.17 ha, average stem volume is 0.489 m^3. 19.3 m^3 of large industrial assortments, 13.4 m^3 of small industrial assortments and 10.3 m^3 of forest fuel were produced by integrated with forest fuel technology in the plot. 19.3 m^3 of large industrial assortments, 13.4 m^3 of small industrial assortments and 1.5 m^3 of firewood were produced by traditional technology. *Technology.* During forest fuel logging the motor-saw " Husqvarna 254X" was used, 2 people team was worked. Firewood was prepared only from the butt part of the stem. Forest fuel (top and branches and understorey brushwood) was piled up near technical corridors. Industrial assortments and firewood were piled near technical corridors by traditional technology. Forest fuel and industrial assortments were extracted by the forwarder "Valmet 840Y" for 200 m. Chipper "BRUKS-604 CT" aggregated with the tractor "K-700"was used for chipping. Chipped wood was transported by the tractor "T-150" aggregated with trailer of 25.3 m^3. Cost calculation is shown in the table 9.

Table 9. Cost calculation in clear-cutting trial 2P-2

Work	With forest fuel production			Traditional technology		
	Work expenditures, hour/m³	Work cost, Lt/hour	Total cost, Lt/m³	Work expenditures, hour/m³	Work cost, Lt/hour	Total cost, Lt/m³
Trad. assortment						
production	0.863	9.54	8.23	1.071	9.47	10.14
extraction	0.109	72.92	7.95	0.109	72.92	7.95
Material cost			1.24			1.24
Total at roadside			**17.42**			**19.33**
Forest fuel						
cross-cutting	0.121	12.35	1.49			
piling	0.350	6.04	2.11			
Total in cutting area	***0.471***		***3.60***			
extraction	0.104	72.92	7.58			
Total at roadside	***0.575***		***11.18***			
chipping	0.060	192.54	11.55			
transportation	0.103	66.46	6.85			
materials			0.95			
Total forest fuel cost			**30.53**			

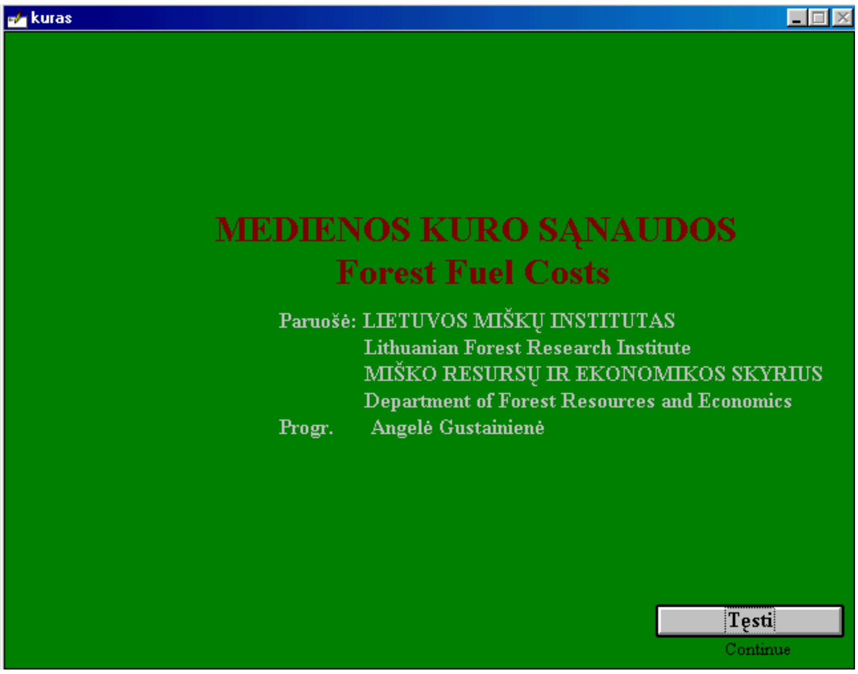
Appendix 2

Description of the computer software SANAUDOS for calculation forest fuel direct costs

Scheme of the computer software SĄNAUDOS for calculation forest fuel direct costs in pre-commercial thinning, commercial thinning and clear-cutting

- **BEGINNING [Screen 0.1]**
- **FOREST FUEL COSTS IN PRE-COMMERCIAL THINNING [Screen 1, 1*]**
  - RAW-MATERIAL COSTS [SCREEN 1.1. (FELLING METHOD, LABOUR COST, LENGTH OF BRUSHWOOD, STAND
  - EXTRACTION COSTS [SCREEN 1.2. (LABOUR COST, DISTANCE, MACHINERY, MACHINERY PARAMETERS)]
  - CHIPPING COSTS [SCREEN 1.2. (LABOUR COST, PRODUCTIVITY, MACHINERY, MACHINERY
  - TRANSPORTATION COST [SCREEN 1.1.4. (LABOUR COST, DISTANCE, MACHINERY, MACHINERY'S PARAMETERS)]
- **FOREST FUEL COSTS IN CLEAR-CUTTING [Screen 2, 2*]**
  - RAW-MATERIAL COSTS [SCREEN 2.1. (LABOUR COST, STAND, FOREST FUEL VOLUME IN HA, OVERAGE VOLUME
  - EXTRACTION COSTS [SCREEN 2.2. (LABOUR COST, DISTANCE, MACHINERY, MACHINERY'S PARAMETERS)]
  - CHIPPING COSTS [SCREEN 2.3. (LABOUR COST, PRODUCTIVITY, MACHINERY, MACHINERY'S
  - TRANSPORTATION COST [SCREEN 2.4. (LABOUR COST, DISTANCE, MACHINERY, MACHINERY'S PARAMETERS)]
- **FOREST FUEL COSTS IN COMMERCIAL THINNING [Screen 3, 3*]**
  - RAW-MATERIAL COSTS [SCREEN 3.1. (LABOUR COST, STAND, FOREST FUEL VOLUME IN HA, OVERAGE VOLUME
  - EXTRACTION COSTS [SCREEN 3.2. (LABOUR COST, DISTANCE, MACHINERY, MACHINERY'S PARAMETERS)]
  - CHIPPING COSTS [SCREEN 3.3. (LABOUR COST, PRODUCTIVITY, MACHINERY, MACHINERY'S
  - TRANSPORTATION COST [SCREEN 3.4. (LABOUR COST, DISTANCE, MACHINERY, MACHINERY'S PARAMETERS)]
- **NORMATIVES [Screen 4]**
- **RESULTS [Screen 5]**
- **END**

Screen 0. **Introduction**



Screen 0.1. **Beginning**

1. Pre-commercial thinning
2. Clear cutting
3. Commercial thinning
4. Normatives
5. Results
6. Finish

Screen1. **Forest fuel costs in pre-commercial thinning**

Screen 1.1. **Raw-material costs in pre-commercial thinning**

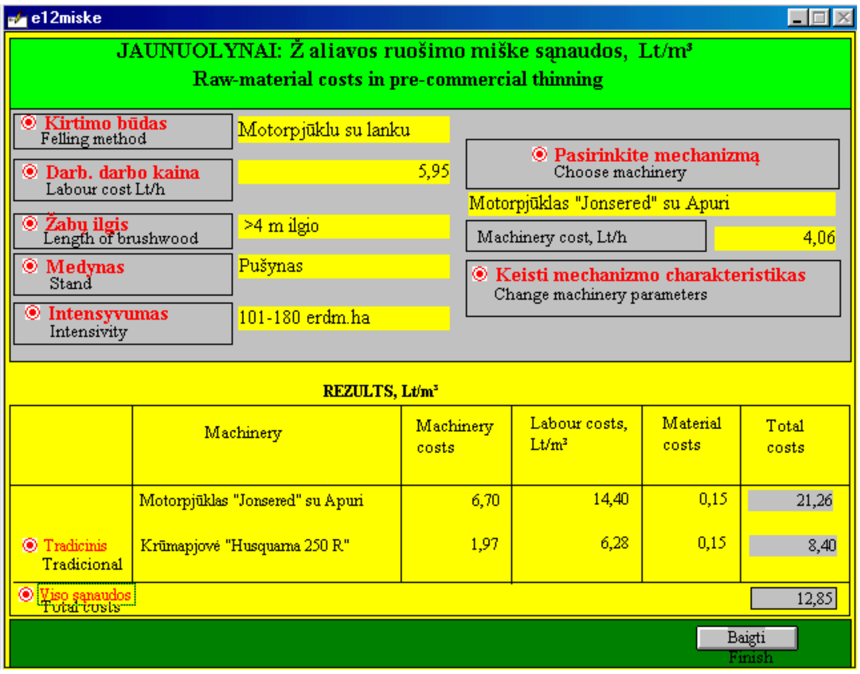
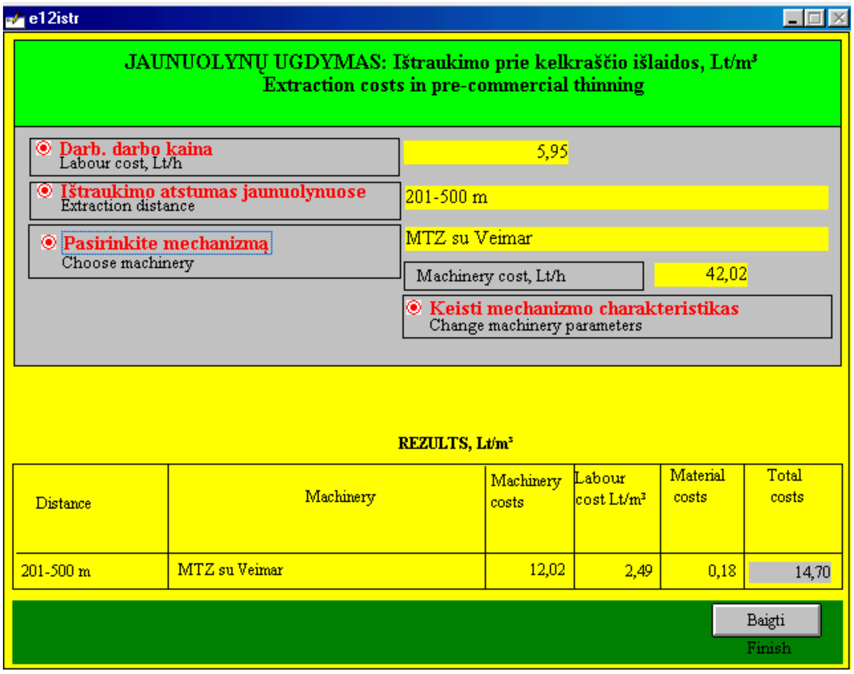
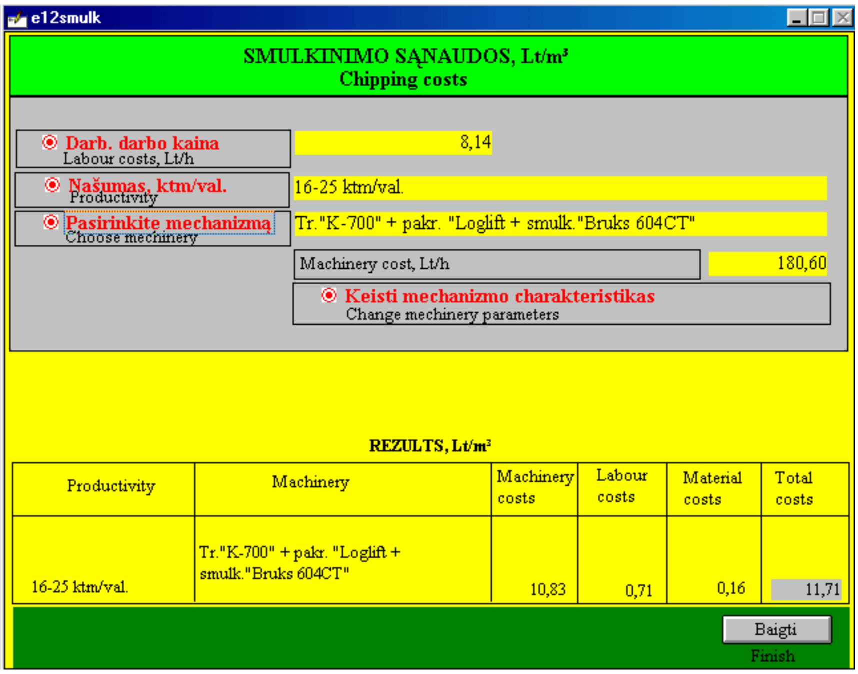


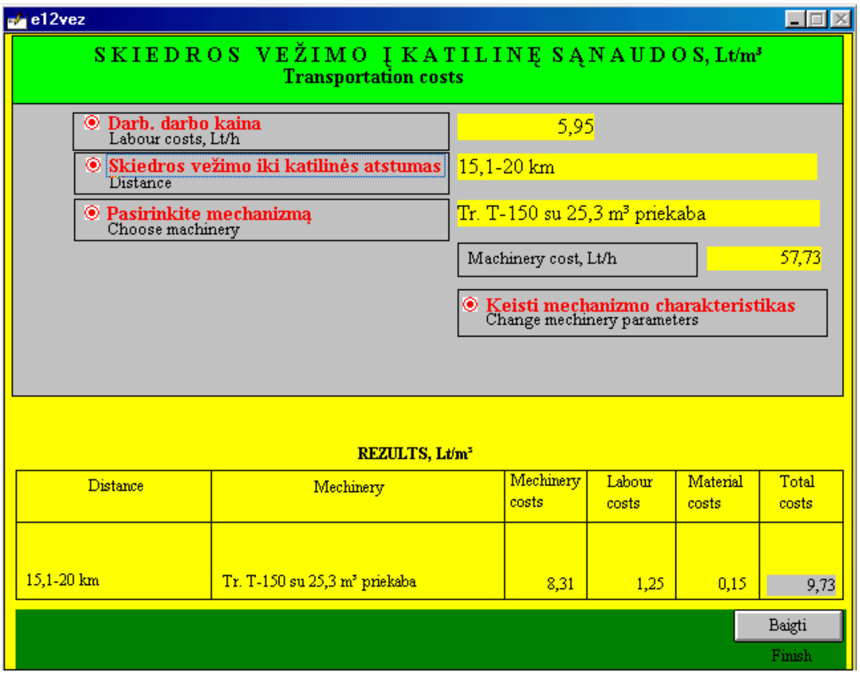
Figure 1.2. **Extraction costs in pre-commercial thinning**



Screen 1.3. **Chipping costs**



Screen 1.4. **Transportation costs**



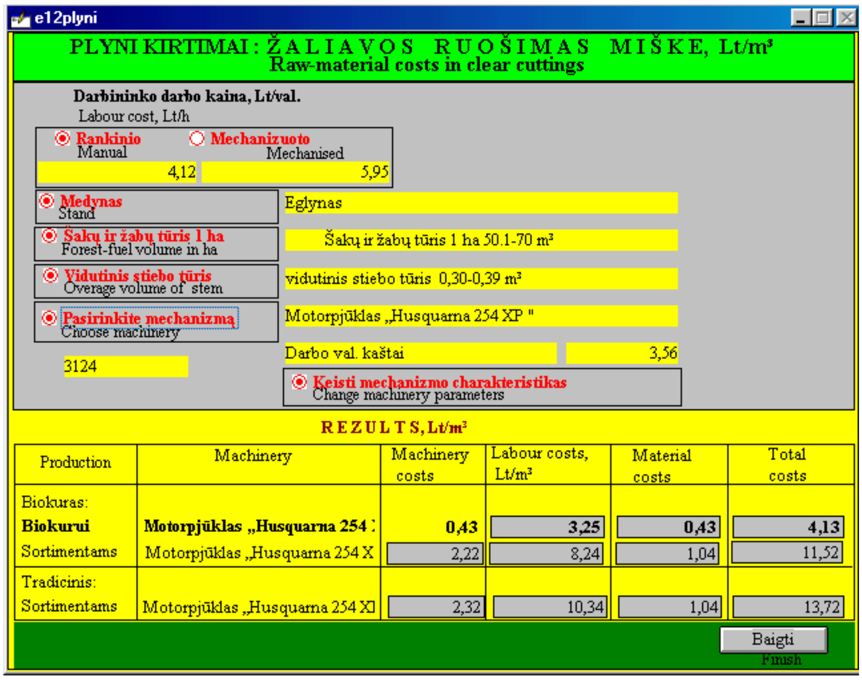
Screen1*. **Forest fuel costs in pre-commercial thinning** (after calculation)

	Atstumas Distance	Našumas Productivity	Mechanizmas Pavadinimas Machinery	Sanaudos Cost	Darb. san. Labour cost	Medž. san. Material cost	Iš viso sanaudų Total cost
Ruošimas miške Raw-material			Motorpjūklas "Jonsered" su Apuri	6,70	14,40	0,15	21,26
Ištraukimas Extraction	201-500 m		MTZ su Veimar	12,02	2,49	0,18	14,70
Smulkinimas Chipping		16-25 ktm/val.	Tr."K-700" + pakr. "Loglift + smulk."Bruks	10,83	0,71	0,16	11,71
Vežimas į katilinę Transportation	15,1-20 km		Tr. T-150 su 25,3 m³ priekaba	8,31	1,25	0,15	9,73
Iš viso sąnaudų Total cost							57,40

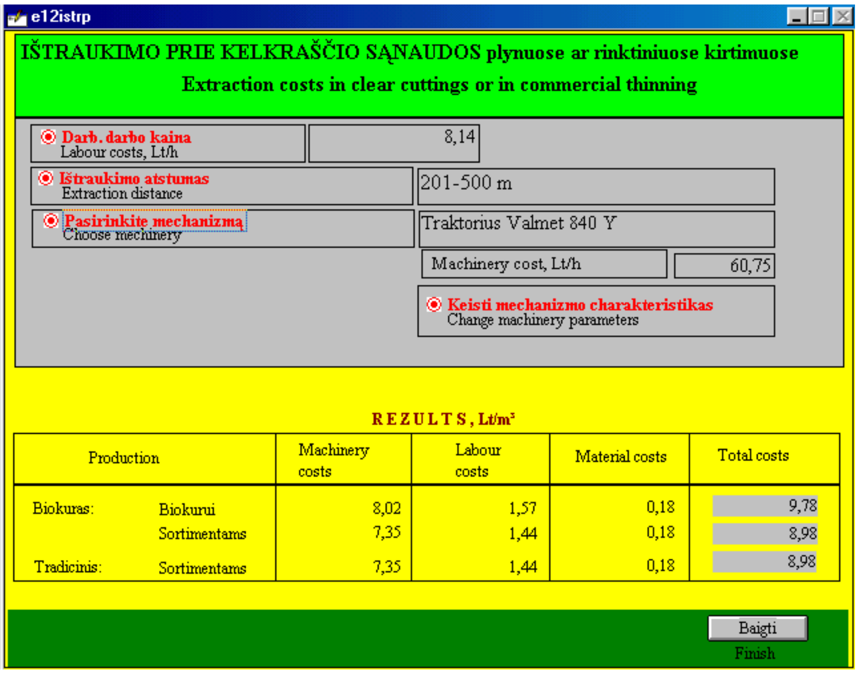
Screen 2. **Forest fuel costs in clear cutting**

Darbai Operations	Atstumas Distance	Našumas Productivity	Mechanizmas Machinery pavadinimas	sąnaudos costs	Darb. san. Labour costs	Medž. san. Material costs	Viso sąnaudų Total costs
Ruošimas miške Raw-material							
Ištraukimas Extraction							
Smulkinimas Chipping							
Vežimas į katilinę Transportation							
Viso sąnaudų Total costs							

Screen 2.1. **Raw-material costs in clear cutting**



Screen 2.2. **Extraction costs**

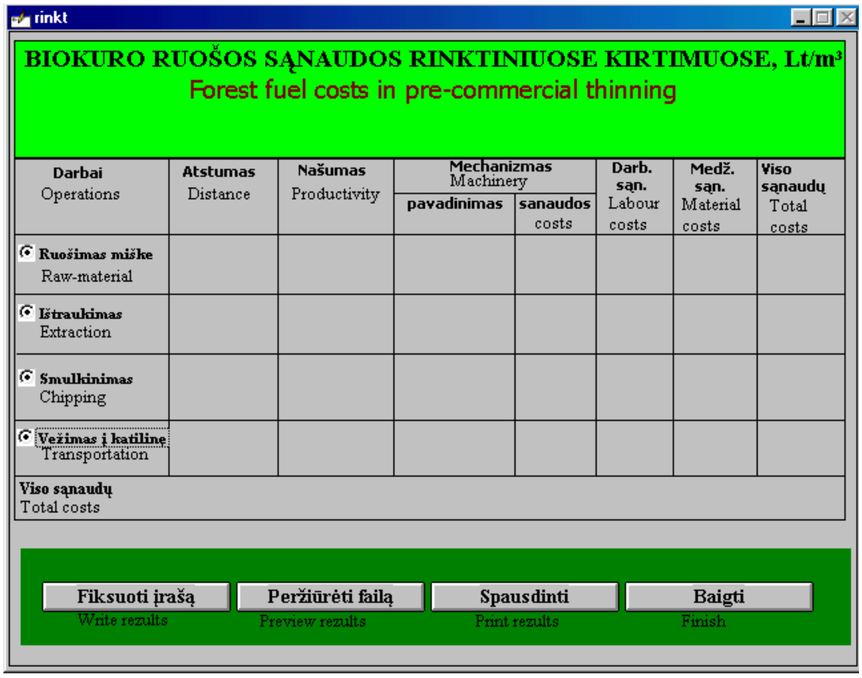


Calculation of chipping and transportation costs in clear-cutting is similar to of chipping and transportation costs calculation in pre-commercial thinning (Screen 1.3-1.4)

Screen 2. **Forest fuel costs in clear cutting** (after calculation)

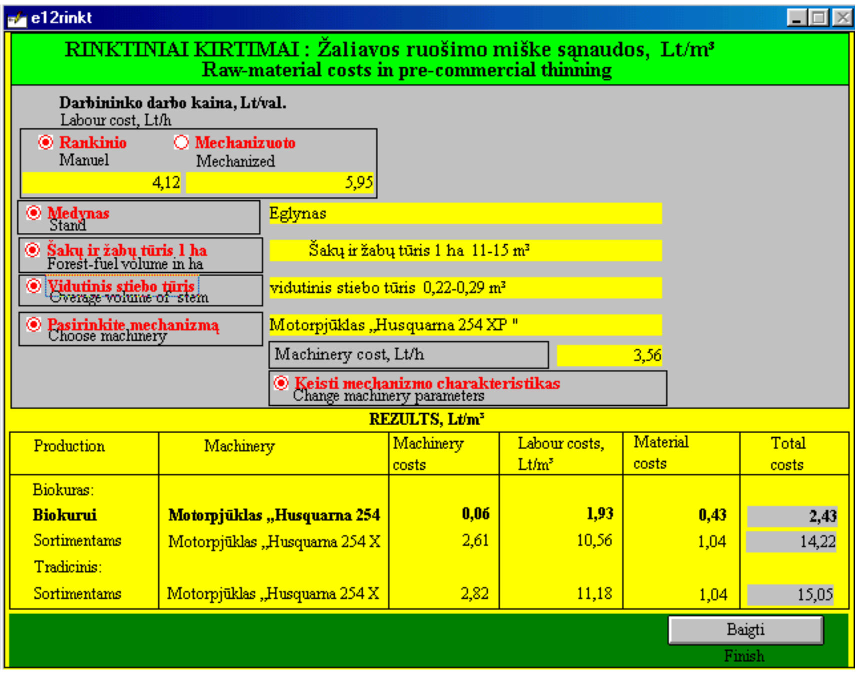
Darbai Operations	Atstumas Distance	Našumas Productivity	Mechanizmas Machinery pavadinimas	sąnaudos costs	Darb. sąn. Labour costs	Medž. sąn. Material costs	Viso sąnaudų Total costs
Ruošimas miške Raw-material			Motorpjūklas „Husquarna 254 XP"	0,43	3,25	0,43	4,13
Ištraukimas Extraction	201-500 m		Traktorius Valmet 840 Y	8,02	1,57	0,18	9,78
Smulkinimas Chipping		16-25 ktm/val.	Tr."K-700" + pakr. "Loglift + smulk."Bruks	10,83	0,71	0,16	11,71
Vežimas į katilinę Transportation	15,1-20 km		Tr. T-150 su 25,3 m³ priekaba	8,31	1,25	0,15	9,73
Viso sąnaudų Total costs							35,35

Screen 3. **Forest fuel costs in commercial cutting**



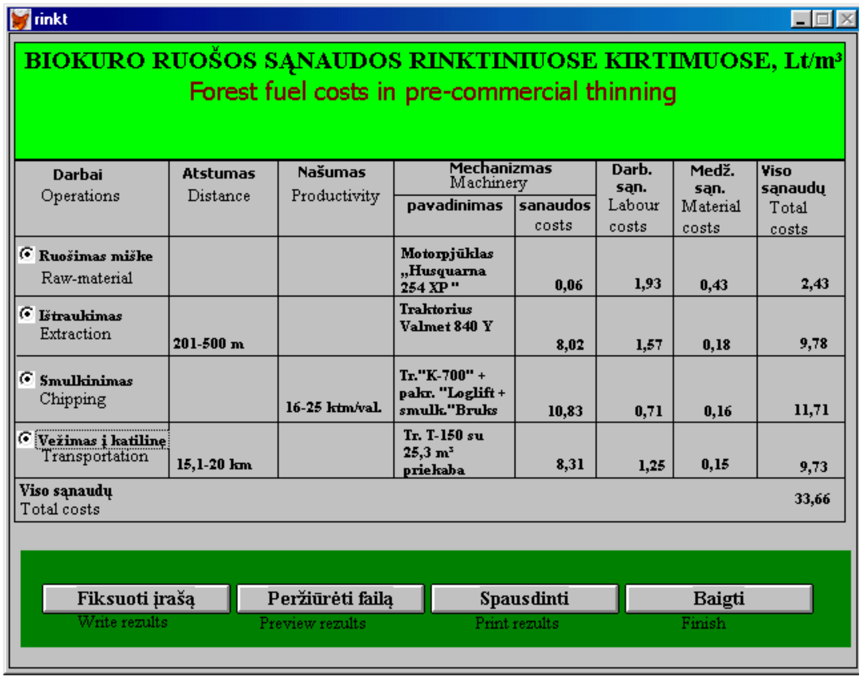
Darbai Operations	Atstumas Distance	Našumas Productivity	Mechanizmas Machinery pavadinimas	sąnaudos costs	Darb. sąn. Labour costs	Medž. sąn. Material costs	Viso sąnaudų Total costs
Ruošimas miške Raw-material							
Ištraukimas Extraction							
Smulkinimas Chipping							
Vežimas į katilinę Transportation							
Viso sąnaudų Total costs							

Screen 3.1. Raw-material costs in commercial cutting

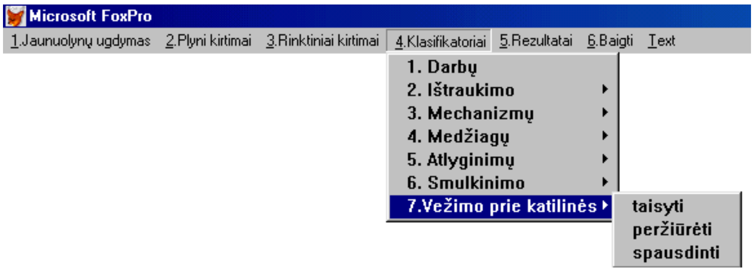


Calculation of chipping and transportation costs in commercial thinning is similar to of chipping and transportation costs calculation in pre-commercial thinning (Screen 1.3-1.4)

Screen 3*. **Forest fuel costs in commercial cutting** (after calculation)

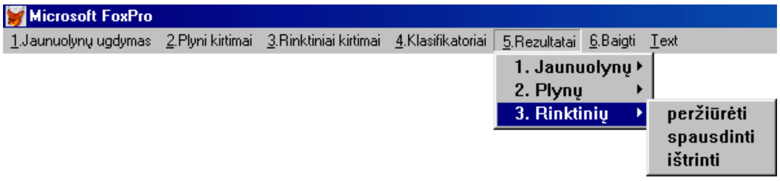


Screen 4. **Normatives**



1. Preparation of raw-material (correction, preview, print);
2. Extraction (correction, preview, print);
3. Machinery (correction, preview, print);
4. Materials (correction, preview, print);
5. Wages (correction, preview, print);
6. Chipping (correction, preview, print);
7. Transportation (correction, preview, print).

Screen 5. **Results**



1. Pre-commercial thinning costs (preview, print, delete);
2. Clear cutting costs (preview, print, delete);
3. Commercial cutting costs (preview, print, delete).