Costs and efficiency of timber harvesting by NIAB 5–15 processor mounted on a farm tractor

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Abstract – Nacrtak

The present research deals with costs and economic effectiveness of timber harvesting technology with the use of the NIAB 5–15 processor mounted on a farm tractor, which method is used in Poland. Measurements were conducted in pine, fir and spruce stands, which underwent early and late thinnings. During harvesting, a time study was performed using the continuous reading method. On completion of felling works, the volume of timber harvested was measured.

The efficiency and unit costs of timber harvesting were calculated in the operational working time for the chainsaw operator and processor operator.

In all analysed stands, significantly higher efficiency was observed in late thinnings than in early ones. This resulted in higher economic effectiveness of this technology in the thinnings of older age classes. The approximation of regression functions allowed for the prediction of fixed unit costs and efficiency depending on the average volume of trees being removed. The low share of fixed costs in the costs of exploitation by processor proves that a longer shift only affects to a small degree the economic effectiveness of the analysed technology.

Keywords: *timber harvesting, thinnings, processor, costs, productivity*

1. Introduction – *Uvod*

Considering the fierce competition in the Polish market of forest services, timber harvesting companies can achieve the greatest advantage by using work methods of low unit costs. In Poland, the majority of companies are small, with limited financial capacity (Kocel 2003) and lack of highly efficient and very expensive multi-operational machinery. The degree of harvesting mechanization may be increased by means of machines accessible to middle-size forest service companies thanks to the use of farm tractor-mounted processors (Karlsson 1988, Walczyk 1997). The use of such machines makes the working environment relatively less strenuous (Giefing 1994b), which is another argument for their widespread introduction. However, in the free market economy, one of the basic criteria of assessment of technological processes of timber harvesting is their economic effectiveness. That is why it is necessary to analyse the processor exploitation costs in detail before making a decision to purchase it. At present there are no results of such analyses conducted in Poland (Giefing 1994a), which may constitute an obstacle to the introduction of processors in forest work.

The aim of the present research is to determine the efficiency and timber harvesting costs by the NIAB 5–15 processor mounted on a farm tractor. The scope of the research is limited to early and late thinnings, performed in pine, fir and spruce stands.

2. Research area – *Područje istraživanja*

The present research was located in southern Poland. Measurements were taken on square sample plots with the surface of 0.5 ha each. The longer side of each plot ran along a skid trail. The basic features of the researched stands and the characteristics of the measures taken in them are presented in Table 1.

Table 1 Characteristics of researched stands
Tablica 1. *Značajke istraživanih sastojina*

Stand number *Broj sastojine*	1	2	3	4	5	6	7	8
No. of sample plots *Broj pokusnih ploha*	3	3	3	3	1	2	2	1
Category of utilisation *Vrsta prihoda*	Early thinning *Rana proreda*	Late thinning *Kasna proreda*	Early thinning *Rana proreda*	Late thinning *Kasna proreda*	Early thinning *Rana proreda*		Late thinning *Kasna proreda*	
Species composition, % *Omjer smjese, %*	*Pinus* – 100	*Pinus* – 90 *Betula* – 10	*Abies* – 70 *Fagus* – 30	*Abies* – 70 *Fagus* – 30	*Picea* – 70 *Abies* – 30	*Picea* – 50 *Abies* – 50	*Picea* – 80 *Abies* – 20	*Picea* – 90 *Abies* – 10
Age, years *Dob, godine*	25	45	37	52	35	40	80	60
Stand density index *Obrast*	0.9	0.7	0.9	0.6	0.8	1.1	1.0	1.2
Stand density *Sklop sastojine*	full *potpun*	moderate *djelomičan*	full *potpun*	moderate *djelomičan*	moderate *djelomičan*	full *potpun*	moderate *djelomičan*	moderate *djelomičan*
Stand quality class *Bonitetni razred*	Ia	Ia I	I	I	I	I	I	I
Breast height diameter, cm *Prsni promjer*, cm	*Pinus* – 13	*Pinus* – 22 *Betula* – 29	*Abies* – 13 *Fagus* – 14	*Abies* – 24 *Fagus* – 20	*Picea* – 14 *Abies* – 10	*Picea* – 13 *Abies* – 10	*Picea* – 35 *Abies* – 30	*Picea* – 24 *Abies* – 19
Height, m *Visina*, m	*Pinus* – 12	*Pinus* – 20 *Betula* – 22	*Abies* – 12 *Fagus* – 12	*Abies* – 18 *Fagus* – 17	*Picea* – 14 *Abies* – 10	*Picea* – 16 *Abies* – 13	*Picea* – 30 *Abies* – 23	*Picea* – 23 *Abies* – 18
Growing stock, m^3/ha *Drvna zaliha*, m^3/ha	140	228	164	311	90	320	668	637
Mean cutting tree, m^3 *Srednje sječno stablo*, m^3	0.06	0.32	0.07	0.38	0.09	0.09	0.56	0.47

Table 2 Technical data of the NIAB 5–15 processor
Tablica 2. *Tehnički podaci procesora NIAB 5–15*

Technical parameters – *Tehnički podaci*	Values – *Vrijednosti*
Mass – *Masa*	1030 kg
Length – *Duljina*	2000 mm
Width – *Širina*	2450 mm
Height – *Visina*	2300 mm
Engine power – *Snaga motora*	30 kW
Maximum cutting diameter – *Najveći sječivi promjer*	500 mm
Length of winch cable – *Duljina užeta vitla*	50 m
Cable winch pulling power – *Vučna sila vitla*	25 kN
Working pressure – *Radni tlak*	20 MPa
Pump capacity – *Protok ulja*	60 dm^3/min
Oil tank capacity – *Obujam spremnika ulja*	60 dm^3

3. Used machines and harvesting technology – *Istraživani strojevi i načini pridobivanja drva*

The basic parameters of the NIAB 5–15 processor mounted on a MTZ 100 farm tractor, used in the research, are presented in Table 2.

Harvesting was conducted according to the following schedule. Using the chain saw, the operator felled the trees marked by the staff of the State Forest Administration. The felling was performed in the direction opposite to the skid trail. If a tree remained suspended, the operator cut only the hinge. The processor operator stretched the cable and attached it to the butt end of the tree. Then, he performed winching operating the winch via radio, and sometimes preceded by removing the suspension. At the skid trail, the operator detached the load and performed timber debranching and cross-cutting using the processor (Fig. 1). The timber was cut into 1.25-m

Fig. 1 Timber debranching and cross-cutting

Slika 1. *Kresanje grana i trupljenje*

Fig. 2 Processed timber on the skid trail

Slika 2. *Izrađeno drvo na traktorskoj vlaci*

long pieces (Fig. 2). After the winching and timber processing was completed within the range of the cable, a new working point of the processor was found on the skid trail.

4. Methods of measurements and calculations – *Metode mjerenja i obrade podataka*

A time study of harvesting was performed using data loggers of the PSION type, equipped with appropriate software. The precision of time measurements was 1 s. The time study was conducted separately for the chainsaw operator and for the processor operator. The amount of the fuel used was measured during each tank filling. After the completion of harvesting, the volume of the timber harvested was determined on the basis of log pieces diameters.

It was assumed that the economic effectiveness of the analysed timber harvesting variants, performed during thinnings, would be best characterized by their unit costs, expressed in €/m^3. Considering the methods of cost calculation provided in the literature (Suwała and Rzadkowski 2001, Suwała 1998, Zychowicz 1998), the following equipment harvesting costs (C) were taken into account:

$C = C_a + C_i + C_{fl} + C_r$ [EUR/h] where:

⇒ harvesting costs C [EUR/h]

⇒ amortization $C_a = \dfrac{P}{T \cdot H} \left[\dfrac{\text{EUR}}{\text{h}}\right]$

⇒ interest of capital $C_i = \dfrac{\frac{P}{2} \cdot \frac{p}{100}}{T \cdot H} \left[\dfrac{\text{EUR}}{h}\right]$

⇒ fuel and lubrication cost C_{fl} [EUR/h]

⇒ repair cost $C_r = \dfrac{P \cdot \frac{k}{100}}{T \cdot A} \left[\dfrac{\text{EUR}}{h}\right]$

⇒ machine purchase price P [EUR]

⇒ machine economic life T [years]

⇒ scheduled operating time H [h/year]

⇒ capital interest rate p [%]

⇒ repair cost index n [%]

The calculations disregard the cost of wages for machine operators. According to other authors' work (Jodłowski 2000, Maciak and Skarżyński 1995, Porter 1998), all calculations were performed for the effective work time. This allowed for the elimination of contingency in the assessment of efficiency, caused by e.g. the number of machine failures or the length of breaks during work (Giefing and Gackowski 2001). Both the processor and the tractor under analysis were in their post-amortization period. However, for the sake of the calculations, it was assumed that the machines were new (Tab. 3).

The cost of fuel and lubricants (C_{fl}) was determined on the basis of their use in field conditions.

Unit costs c_0 were calculated for each machine separately using the following formula:

$$c_0 = \frac{C}{V_0} \left[\frac{\text{EUR}}{\text{m}^3}\right], \quad \text{where:}$$

⇒ V_0 – productivity in the effective time (m^3/h).

Unit costs for the whole technology were determined by summing the unit costs of felling by chainsaw and the unit costs of winching, debranching and cross-cutting by processor.

Table 3 Assumed cost parameters for machine rate calculation
Tablica 3. *Pretpostavljeni troškovni parametri za kalkulaciju strojnoga rada*

Cost calculation inputs *Ulazni podaci kalkulacije*	Chain saw *Motorna pila*	NIAB 5–15 processor *Procesor NIAB 5–15*	Farm tractor *Poljoprivredni traktor*
Machine purchase price – *Nabavna vrijednost stroja P* [€]	658	21,053	26,316
Machine economic life *T* [years] – *Normalno vrijeme uporabe stroja T* [godine]	2	8	8
Scheduled operating time H [h/year] – *Iskorištenost stroja* H [h/godina]	1800	1800	1800
Capital interest rate – *Kamatna stopa p* [%]	13.2	13.2	13.2
Fuel price – *Cijena goriva* [€/dm^3]	1.11	–	1.03
Oil price – *Cijena maziva* [€/dm^3]	1.8	1.8	–
Repair cost index – *Indeks troškova popravka* n [%]	30	30	10

5. Results and discussion – *Rezultati i rasprava*

On the basis of the above assumptions, the costs of exploitation of each machine used in the analysed technological process were calculated as follows: the chain saw: $C = 2.28$ €/h, the farm tractor (carrier): $C = 6.75$ €/h, the processor: $C = 2.45$ €/h, which means that the costs of exploitation of the processor with the tractor equal 9.20 €/h. A detailed cost structure related to each machine is presented in Table 4.

The cost structure of the processor is dominated by fixed costs because it is not fuelled but driven by tractor. The fixed costs constitute over 60% of the total cost. This percentage is less than 40% for the whole assembly because the tractor, whose exploitation costs dominate in the assembly, has a share of 29% in fixed costs. The conclusion is that by prolonging the working period of the whole assembly, the costs of its exploitation will not be considerably reduced. For example, work during 1.5 shifts (12 hours/day) will reduce the costs of exploitation by 15%, i.e. bring them down to 7.82 €/h.

Effectiveness on each work-stand, calculated on the basis of the field time study, is presented in Figures 3 and 4.

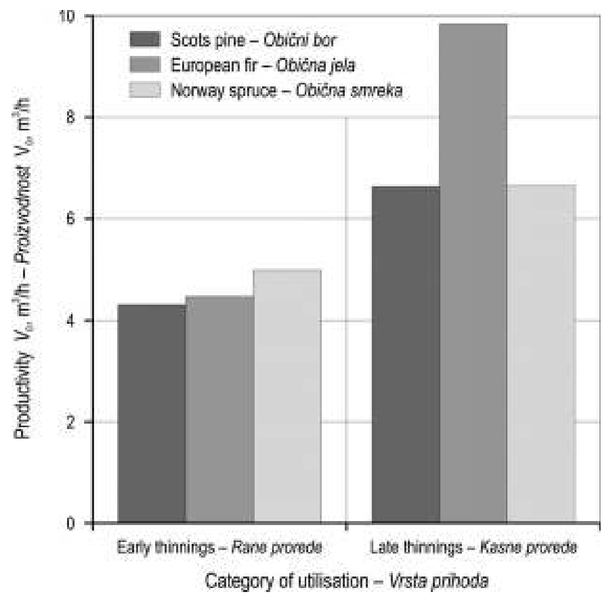

Fig. 3 Productivity of the chainsaw operator in effective time
Slika 3. *Proizvodnost radnika s motornom pilom u efektivnom vremenu*

In the analysed technology, the chainsaw operator's work consists exclusively of tree felling; that is why the effectiveness of his job was very high. In

Table 4 Cost structure per hour of machine
Tablica 4. *Struktura troškova po satu rada stroja*

Cost item *Sastavnice troška*	Chain saw *Motorna pila*	NIAB 5–15 processor *NIAB 5–15 procesor*	Farm tractor *Poljoprivredni traktor*	Harvesting system *Sustav pridobivanja drva*
Amortization – *Amortizacija* [€/h]	0.18	1.46	1.83	3.29
Cost of interest – *Trošak kamata* [€/h]	0.01	0.10	0.12	0.22
Fixed costs – *Fiksni troškovi* [€/h]	0.19	1.56	1.95	3.51
Fuel and lubrication – *Gorivo i mazivo* [€/h]	2.03	0.46	4.62	5.08
Repairs – *Popravci* [€/h]	0.05	0.44	0.18	0.62
Variable costs – *Varijabilni troškovi* [€/h]	2.08	0.90	4.80	5.70

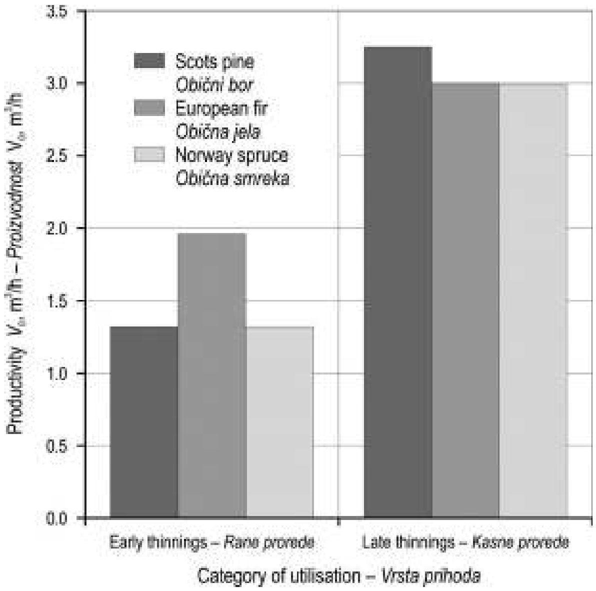

Fig. 4 Productivity of the processor in effective time

Slika 4. *Proizvodnost procesora u efektivnom vremenu*

early thinnings, the effectiveness of felling was not very differentiated and remained in the range from 4.3 to 5.0 m^3/h (Fig. 3). In late thinnings, the effectiveness was higher than in the early ones, which was related to a greater volume of a single tree. The effectiveness of the processor was more differentiated in early thinnings (Fig. 4). The highest effectiveness, i.e. almost 2 m^3/h, was observed in fir forest while in spruce and pine forests it was by about 0.7 m^3/h lower. In late thinnings the effectiveness of the processor was very balanced and amounted to about 3 m^3/h. The results obtained are close to the ones observed in Germany and Sweden, where, depending on the stand composition and age, the effectiveness was between 1.5 and 3.8 m^3/h (Giefing 1994a, Marntell and Marntell 1988, Walczyk 1997).

Calculated on the basis of exploitation costs per hour and the effectiveness obtained, the unit costs of tree felling by chain saw are presented in Figure 5.

Low costs of the chain saw harvesting (Tab. 4) and its high effectiveness, connected with the use of this equipment for only one technological operation (i.e. felling), resulted in very low unit costs. In early thinnings, they amounted to 0.48 €/m^3 on average and in late thinnings to 0.28 €/m^3.

The work of the assembly with the processor constitutes the chief item in the analysed technology costs (Fig. 6).

The application of the processor in late thinnings resulted in the costs of 2.53 €/m^3 in the operational time; and in early thinnings the costs were almost twice higher: 4.74 €/m^3. A larger differentiation of unit costs, obtained in early thinnings carried out in stands composed of different species, results from a higher effectiveness of the processor in fir stands.

Summary unit costs in the operational time for the whole technology are as follows: felling, winching, debranching and cross-cutting (Fig. 7) do not exceed 6.44 €/m^3 in younger stands (early thinnings) and

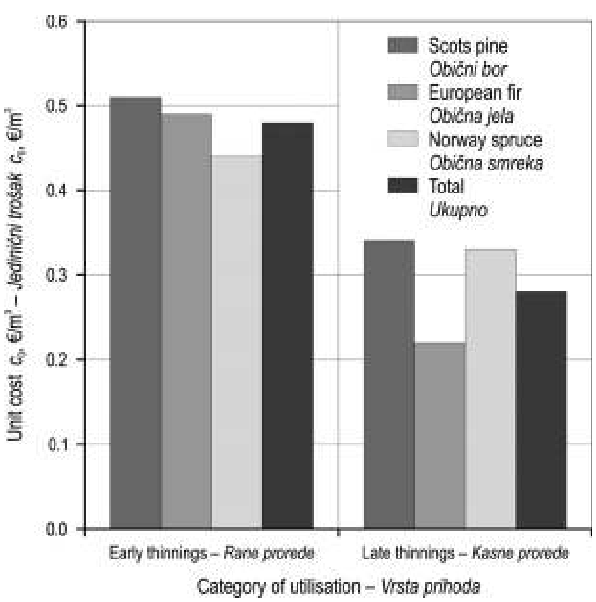

Fig. 5 Unit costs of tree felling (chainsaw operator) in effective time

Slika 5. *Jedinični troškovi sječe stabala (radnik s motornom pilom) u efektivnom vremenu*

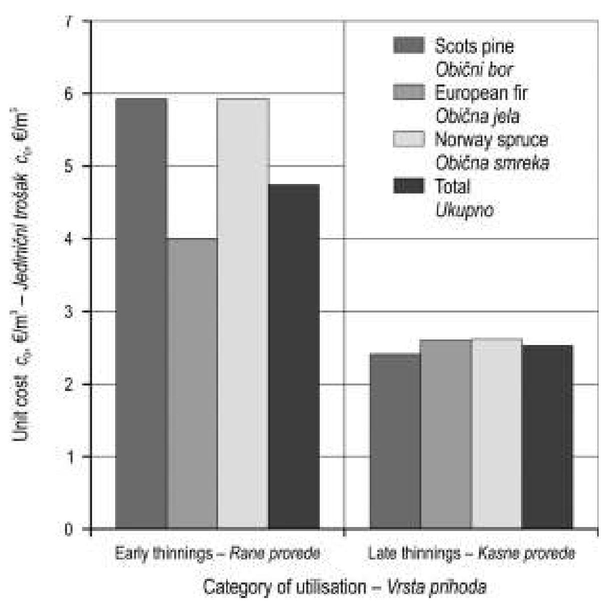

Fig. 6 Unit costs of work of the processor NIAB 5-15 in effective time

Slika 6. *Jedinični troškovi rada procesora NIAB 5-15 u efektivnom vremenu*

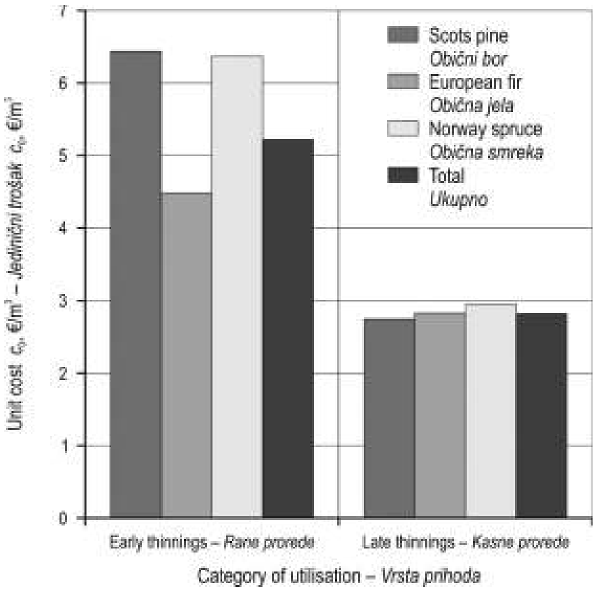

Fig. 7 Unit costs of analysed technology (chainsaw operator + processor NIAB 5–15) in effective time

Slika 7. *Jedinični troškovi istraživane tehnologije (radnik s motornom pilom + procesor NIAB 5–15) u efektivnom vremenu*

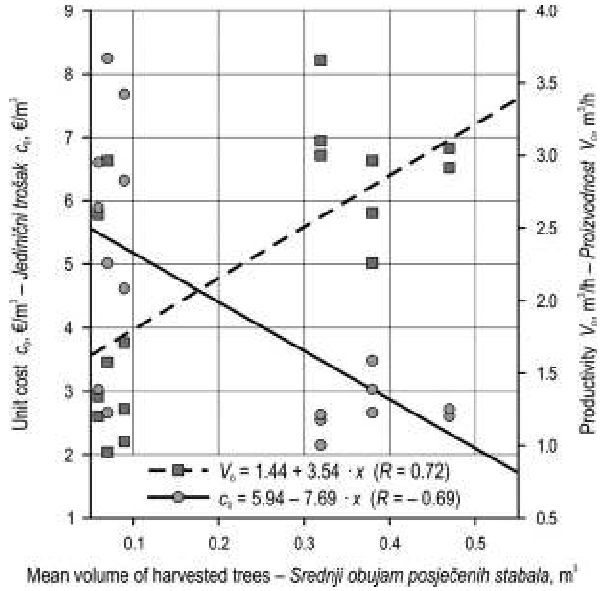

Fig. 8 Unit costs and productivity in effective time vs. the mean tree volume

Slika 8. *Ovisnost jediničnoga troška i proizvodnosti u efektivnom vremenu o srednjem obujmu stabla*

2.95 €/m³ in older stands (late thinnings). The lack of processors mounted on farm tractors in the Polish market of forest services (Kocel 2003) and, hence, the lack of economic analyses of such equipment makes it impossible to directly compare the results obtained in the present research with those by other authors. Comparisons with the economic effectiveness of harvesting of such equipment achieved abroad are not reliable due to considerable differences in the general economic situation, which affects the level of unit costs. For example, according to Giefing (1994a) the unit costs of timber harvesting in Germany, in conditions very similar to stand No. 1 (Tab. 1), amounted to 23 DM/m³.

A simulation of total unit costs, obtained for the whole shift, was performed for the analysed technology. It was assumed that the monthly costs per person for the chainsaw operator and the driver-operator (gross wages with surcharge) are 6.58 €. In accordance with the results, the coefficient of the shift utilisation was established on the level of 0.75. For such conditions, the average total unit costs are: 10.67 €/m³ in early thinnings and 7.49 €/m³ in late thinnings.

The present research results concerning the exploitation and effectiveness of the processor indicate the existence of direct relations between them and the average volume of harvested trees. These relations are presented in Figure 8. The regression equations shown there turned out to be statistically significant. In the case of effectiveness, the significance level, calculated by means of the t-Student test, was 0.00 (t = 4.11) and in the case of unit costs 0.00 (t = –3.78). The strength of the relation between the average volume of harvested trees and effectiveness V_o, measured by the value of the Pearson coefficient of linear correlation R, amounted to 0.72. In the case of unit costs c_o, the correlation coefficient was –0.69. The straight lines of regression (Fig. 8) allow for predicting the value of unit costs and effectiveness depending on the average volume of harvested trees exclusively based on the range of the volume of analysed trees. This is due to two facts: firstly, the processor can debranch trees whose maximum diameter is 50 cm; secondly, using the processor to harvest trees with small mass, e.g. in late thinnings, would require additional research to be performed in such conditions because manual bunching of logs would have to be considered as well as a lot of work for harvesting of timber of low market value.

6. Conclusions – *Zaključci*

On the basis of research results, the following conclusions should be pointed out:

⇒ Hourly costs of harvesting of the processor assembly amounted to about 9.2 €.

⇒ Different values of effectiveness obtained in early and late thinnings resulted in different levels of unit costs in these groups of stands.

⇒ The costs of harvesting of the tractor are the dominant item in the costs of harvesting of the processor-tractor assembly.

⇒ Due to a small share of fixed costs in the costs of harvesting of the harvesting system, prolonging the shift length from 8 to 12 h lowered the unit costs only by 15%.

⇒ Considering the relations between the average volume of processed trees and effectiveness (and, hence, unit costs), as shown in the present research, it is more profitable to use the processor in late thinnings.

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Sažetak

Djelotvornost pridobivanja drva procesorom NIAB 5–15 postavljenim na poljoprivrednom traktoru

Rad prikazuje istraživanje djelotvornosti pridobivanja drva procesorom NIAB 5–15 postavljenim na poljoprivrednom traktoru. U Poljskoj postoji velik broj poduzeća koja se bave šumskim radovima. Većinom su to mala poduzeća ograničenih financijskih mogućnosti te s nedostatkom visokoučinkovitih, ali vrlo skupih šumskih strojeva. Povećanje stupnja mehaniziranosti sječe i izrade stabala omogućeno je primjenom procesora postavljenoga na poljoprivrednom traktoru. Na slobodnom tržištu jedan je od osnovnih kriterija primjene određenoga postupka pridobivanja drva ekonomska isplativost. Stoga je potrebno detaljno analizirati troškove sustava rada, što je ujedno i cilj ovoga istraživanja.

Istraživanje je ograničeno na rane i kasne prorede borovih, jelovih i smrekovih sastojina. Mjerenja su provedena na pokusnim plohama veličine 0,5 ha uz traktorsku vlaku. Osnovne značajke istraživanih sastojina prikazane su u tablici 1, a tehnički podaci o ispitivanom procesoru u tablici 2.

Postupak pridobivanja drva podrazumijeva usmjerenu sječu doznačenih stabala motornom pilom okomito prema smjeru šumske vlake, vezanje tovara i privitlavanje vitlom, kresanje grana i trupljenje debla procesorom. Drvni su se sortimenti izrađivali u duljinama od 1,25 m.

Studij rada i vremena proveden je protočnom metodom zasebno za radnika s motornom pilom i radnika na procesoru. Izrađenim drvnim sortimentima određen je obujam na osnovi mjerenja srednjega promjera. Također je mjerena potrošnja goriva i maziva motorne pile i traktora.

Troškovi su izračunati na osnovi efektivnoga vremena rada. Za potrebe istraživanja pretpostavljeno je da su strojevi novi te da su u izračunu uzete vrijednosti prikazane u tablici 3.

Satni trošak pojedinoga stroja pri ispitivanom postupku iznosi: motorna pila 2,28 EUR/h, poljoprivredni traktor 6,75 EUR/h, procesor 2,45 EUR/h, što daje ukupni trošak od 9,20 EUR/h. Detaljna je struktura troškova prikazana u tablici 4. U strukturi troškova procesora prevladavaju fiksni troškovi (preko 60 %), jer procesor ne troši gorivo već ga pogoni traktor. Za cijeli sustav pridobivanja drva fiksni troškovi iznose manje od 40 % jer traktor, čiji su troškovi najveći, ima samo 29 % fiksnih troškova. Zaključak je da produljenje radnoga vremena neće bitno utjecati na smanjenje troškova (npr. radnim danom od 12 sati mogu se smanjiti troškovi za samo 15 %).

Proizvodnost radnika s motornom pilom i radnika na procesoru izračunata je na osnovi provedenoga studija rada i vremena. Radnik s motornom pilom radi isključivo na sječi stabala te je stoga njegova proizvodnost velika i kreće se od 4,3 m^3/h do 5 m^3/h u ranim proredama. U kasnim proredama proizvodnost radnika s motornom pilom još je veća zbog većega obujma stabala (slika 3). Proizvodnost radnika na procesoru razlikuje se kod ranih proreda ovisno o vrsti drveća, a u kasnim proredama iznosi približno 3 m^3/h u uvjetima rada obuhvaćenim istraživanjem (slika 4).

Jedinični su troškovi izračunati na osnovi satnoga troška rada pojedinoga sredstva i ostvarene proizvodnosti. Rad motornom pilom ostvario je male jedinične troškove (0,48 EUR/m^3 u ranim proredama, odnosno 0,28 EUR/m^3 u kasnim proredama) zbog niskoga satnoga troška i velike prizvodnosti (slika 5). Najveći su jedinični troškovi zabilježeni u radu na procesoru – 4,74 EUR/m^3 u ranim proredama i 2,53 EUR/m^3 u kasnim proredama (slika 6). Ukupni jedinični troškovi sustava pridobivanja drva ne iznose više od 6,44 EUR/m^3 u ranim proredama, odnosno 2,95 EUR/m^3 u kasnim proredama (slika 7).

Provedeno je istraživanje pokazalo ovisnost proizvodnosti procesora te jediničnih troškova o obujmu posječenoga stabla. Stoga je provedena regresijska analiza navedenih parova podataka te se statičkim ispitivanjem utvrdila značajna povezanost podataka. Rezultati regresijske analize omogućuju predviđanje vrijednosti jediničnih troškova i proizvodnosti rada procesora ovisno o srednjem obujmu posječenoga stabla. Na osnovi promatranih odnosa zaključuje se da je veća isplativosti rada procesora u kasnim proredama.

Ključne riječi: *pridobivanje drva, prorede, procesor, troškovi, proizvodnost*

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Received (*Primljeno*): December 19, 2006
Accepted (*Prihvaćeno*): November 19, 2007