Efficiency of John Deere 1470D ECOIII Harvester in Poplar Plantations

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Abstract – Nacrtak

This article presents the results of researching John Deere 1470 D ECO III harvester in clear cuttings of Populus×euramericana 'I-214' poplar trees in lowland regions. Four different methods of the harvester work were analyzed from the aspect of its movement direction and the number of trees that were cut from one standing point. Apart from that, the effect of forks on the harvester productivity was analyzed. A study of work and time was carried out in the research. Duration of the working operations was measured on the chronometer, by the time flowing method. The method of work had the most significant effect on the moving and the positioning time of the harvester, while the stem forking greatly affected the stem processing time. The differences in the time length of various felling operation phases affected the productivity that the harvester achieved in different methods of work. The average productivity ranges from 30.3 to 34.7 m^3/h, depending on the method of work. The harvester achieves the highest productivity when it moves backwards between two rows and cuts a stem in the row to the right and then in the row to the left, observed from the moving direction, while on its way back, it drives forward between the rows and cuts a stem from the row on the left first and then from the row on the right, observed from the moving direction. When this method is applied, the harvester productivity amounts to 34.7 m^3/h. Its productivity is significantly affected by stem dimensions, i.e. the increasing volume of timber wood decreases the time needed for the processing of one unit product.

Keywords: harvester, poplar plantations, tree characteristics, method of work, productivity, costs

1. Introduction – *Uvod*

Poplar is a tree species that covers 1.9% of the total forest area in Serbia. It grows both in natural stands and on artificially established plantations in lowland areas.

According to their production goal, the most common plantations are long rotation plantations from 20 to 25 years of age, intended for the production of saw logs for mechanical wood processing. Plantations with combined production goals, which are thinned between the age of 8 and 12, are significantly less frequent.

The processes of felling and processing assortments in long rotation plantations are characterized by larger trees, thicker branches and bigger forks in comparison with the processes of felling and processing logs in short rotation plantations. One of the aims of this research is to determine the effects of these characteristics of poplar trees from long rotation plantations on the harvester productivity.

Up until 2008 chain saws were solely used in the felling and processing operations in mature poplar plantations in Serbia, with the application of the group selection system. Since 2008, apart from chain saws, John Deere 1470 D ECO III harvester has been used for the purposes of felling and processing logs in mature poplar plantations.

The harvester has been introduced in the regular cutting operations of poplar trees in order to achieve better mechanization of felling and processing operations, to reduce the number of workers with occupational diseases, to overcome labor shortage and to achieve better production outputs.

Daily production outputs of the workers who are employed in felling and processing logs with a chainsaw in poplar plantations mature for felling are high, i.e. unit costs of felling and processing are considerably lower than the costs of cutting and processing the logs in the final felling of hard broadleaves.

Processing logs into long cellulose wood and cordwood in poplar plantations mature for felling on the territory of Serbia has become a regular practice, and it has a considerable positive effect on the achieved outputs.

In such working conditions, the use of the harvester is profitable only when high outputs are produced.

The efficiency of the harvester in felling and processing operations depends on a great number of factors, the most important being terrain conditions and stem characteristics.

Site slope significantly affects the productivity of the harvester and it is often a limiting factor in its use. With the development of a driving system that enables harvesters to operate on steep slopes, the effect of this factor is considerably smaller, which has been proved by the results of recent researches (Stampfer 1999, Stampfer and Steinmüeller 2001).

The work of the harvester in different working conditions has been studied by a great number of authors (Brunberg 1991, Tufs and Brinker 1993, Kellogg and Bettinger 1994, Tufts 1997, Stampfer 1999, Glöde 1999, Stampfer and Steinmüeller 2001, Krpan et al. 2001, Krpan and Poršinsky 2002, Eliasson 1998, Wester and Eliasson 2003, Kärhä et al. 2004, Nurminen et al. 2006). The results of these researches show that the harvester productivity is highly variable and it depends on a great number of factors. However, all the researchers stress the stem volume as the most significant factor. The productivity of the harvester increases with the growth of stem volume.

The productivity of the harvester also varies with the felling intensity or the number of stems intended for clear-cutting (Eliasson et al. 1999).

Apart from that, skilled and experienced operators can increase the productivity of the harvester to a great extent (Sirén 1998).

The use of the harvester in regular poplar fellings is seemingly a simple solution, since here we deal with clear-cuttings on flat terrains, a homogeneous stand from the aspect of tree dimensions and arrangement and lower wood hardness. However, even in such conditions there are a number of factors that affect the productivity of the machine.

Poplar plantations are characterized by low bearing capacity of the terrain and large stems with distinctive external characteristics (excessive branching, sweep, forks and others).

The effect of stem characteristics on the harvester productivity is more significant in cutting and processing broadleaved tree species due to a higher rate of branching in the crown region, sweep of the lower or the most valuable part of the stem and the incidence of forking.

Sweep of the lower or the most valuable part of the stem is particularly characteristic of the plantations that are exposed to flood waters. This part of the stem is the most valuable and according to the previous research, the assortments that are in qualitative marking for cross-cutting obtained from this part of the stem are logs for sliced and peeled veneer (Danilović 2006).

Damage arising from processing curved tree stems leads to more intensive drying of peripheral parts of the assortments, which has a negative effect on the quality of peeling in the mechanical wood processing.

Trees that are regularly felled often form forks, which can affect the time required for processing a unit product. The frequency of forking, as well as the height at which the forks appear, depend on the measures taken to correct the tops of young plants or prune thicker branches off young poplar standing trees.

In the early years of plantation development, it is necessary to form the top of the trees by removing thicker branches in order to avoid subsequent stem forking. Occurrence of forks cannot be completely eliminated, but it can be minimized by proper and timely pruning of thicker lateral branches off the young standing poplar trees.

Moreover, Populus euramericana trees have an excess of moisture in the central part of the stem, which can greatly contribute to the occurrence of cracks in the lower, most valuable part of the stem during the felling operations, but even more during the vegetation. Cracks are most frequently developed when cutting large leaning trees.

The productivity of the harvester is also affected by the method of work used in the process of felling and processing wood assortments. Great progress has been made in the development of the methods and systems of work (Makkonen 1991, Glöde and Sikström 2001, Suadicani and Fjeld 2001, Andersson and Eliasson 2004, Nurminen et al. 2006, Jiroušek et al. 2007).

The productivity of the harvester-forwarder joint cutting system has been more frequently dealt with in the studies of American researchers than in the studies of European researchers who have mostly studied these systems separately (Nurminen et al. 2006).

There are some other factors influencing the harvester productivity, amongst which is the manner in which the harvester moves through the plantation during the harvest, as well as the number of trees cut from one standing point.

The aim of this article is to study the productivity of John Deere 1470D ECO III harvester when four different methods of work are used in the course of cutting poplar trees in the plantations with long rotation periods and to assess the effects of forks on the harvester productivity.

The initial hypotheses are:

⇒ There are significant differences between the investigated methods and

⇒ Forks have a considerable effect on the time needed for stem processing.

2. Material and Methods – *Materijal i metode*

The research was conducted in mature plantations of Populus×euramericana 'I-214' on the territory of Ravni Srem in Serbia. They cover an area of 6.89 ha.

Harvesting was carried out by John Deere 1470 D ECO III harvester equipped with a harvester head H 480 (Fig. 1). The harvester operator had two years of previous experience in operating the harvester, and many years of experience in operating a forwarder.

Recording was carried out in winter conditions in the period from December 2009 to February 2010. The weather conditions were favorable, with no precipitation. Before felling and processing wood assortments, larger undergrowth had been removed in order to facilitate the movement of the harvester through the cutting site. Main characteristics of the poplar plantation and terrain are shown in Table 1.

While felling and processing logs, the harvester moved along the longer side of the felling site, which is 750 m long. This was the only solution because of the direction of stem inclination, caused by prevailing winds characteristic in this part of Serbia.

Fig. 1 John Deere 1470D ECOIII Harvester
Slika 1. *Harvester John Deere 1470D ECOIII*

Table 1 Main characteristics of the plantation
Tablica 1. *Osnovne značajke plantaže*

Age of the plantation, years *Dob plantaže, godina*	25
Planting spacing, m *Razmak sadnje, m*	6×6
No.of trees per hectare at the time of establishment *Broj stabala po hektaru u vrijeme osnivanja nasada*	278
No.of trees per hectare at the end of rotation *Broj stabala po hektaru na kraju ophodnje*	192
Medium DBH, cm *Prosječni prsni promjer, cm*	40.4
Mean tree height, m *Prosječna visina stabla, m*	31.7
Total volume of assortments, m^3 *Ukupni obujam sortimenata, m^3*	2056.9
Average net volume of assortments per stem m^3/stem *Prosječni obujam sortimenata po stablu, m^3/stablu*	1.55
Slope, ° *Nagib terena, °*	≈ 0°
Cutting method *Način sječe*	clear cutting *čista sječa*
Soil type *Tip tla*	mollic gleysol *molični glej*

Four different methods of harvester work in the operations of felling and processing logs were recorded on one part of the compartment area (Fig. 2). The investigated methods differed depending on the harvester driving direction, its positioning-to-cut and the number of stems cut from one standing point. The following methods of the harvester work were investigated:

⇒ Method 1 – The harvester moves in reverse and cuts trees from the row to the left, observed from the moving direction. It cuts and processes one stem from one standing point. When it finishes cutting in one row, it moves to the beginning of the next row and starts harvesting in the same manner. The general direction of stem inclination is opposite to the direction of the harvester movement.

⇒ Method 2 – The harvester moves in reverse and cuts trees from the row to the left, observed from the moving direction. It cuts and processes assortments from one stem per standing point. The direction of stem inclination is opposite to the direction of the harvester movement. It starts cutting trees in the next row from the opposite side of the cutting site, by driving forward. The general direction of stem inclination is the same as the direction of the harvester movement. From one standing point, it cuts and processes one tree on its right hand side observed from the moving direction of the harvester. Felling and processing operations in the following rows are conducted in the same manner as in the previous two rows.

⇒ Method 3 – The harvester moves backwards between two rows, cuts a stem in the row to the right, and then in the row to the left, observed from the moving direction. It cuts and processes two stems from one standing point. The general direction of stem inclination is opposite to the direction of harvester movement. It starts harvesting stems in the next rows without changing the side and in the same manner as in the previous two rows.

⇒ Method 4 – The harvester moves backwards between two rows, cuts a stem in the row to the right, and then in the row to the left, observed

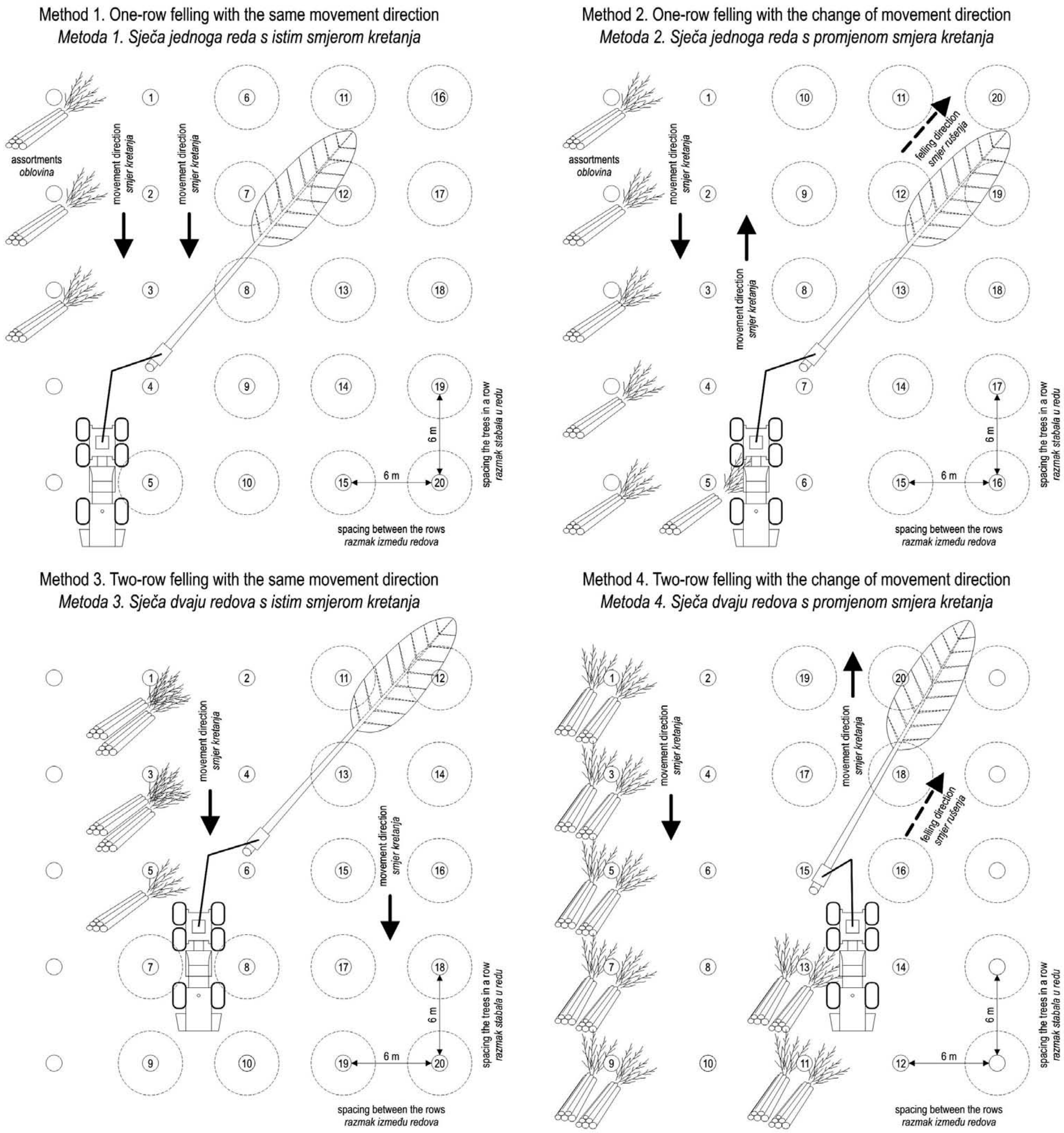

Fig. 2 Methods of harvester work
Slika 2. *Metode rada harvestera*

Table 2 The values obtained for the measured elements
Tablica 2. *Opis vrijednosti mjerenih elemenata*

Measured elements – *Mjereni elementi*	Method 1 *Metoda 1*	Method 2 *Metoda 2*	Method 3 *Metoda 3*	Method 4 *Metoda 4*
Number of analyzed stems *Broj analiziranih stabala*	350	310	356	311
Mean diameter at breast height, cm *Prosječni promjer na prsnoj visini, cm*	40.5	40.3	41.0	40.2
Mean diameter of the stems without forks, cm *Prosječni promjer stabala bez rašalja, cm*	39.7	39.5	40.2	38.7
Mean diameter of forked stems, cm *Prosječni promjer rašljavih stabala, cm*	46.0	44.0	47.3	47.7
Volume of assortments processed from the stems with the mean cut diameter, m^3 *Obujam sortimenata izrađenih od prosječnoga sječnoga stabla,* m^3	1.54	1.53	1.58	1.55
Volume of assortments processed from the mean stems without forks, m^3 *Obujam sortimenata izrađenih od srednjega stabla bez rašalja,* m^3	1.49	1.49	1.52	1.46
Volume of assortments processed from the mean forked stems, m^3 *Obujam sortimenata izrađenih od srednjega rašljavoga stabla,* m^3	1.93	1.78	2.03	1.90
The average number of assortments per stem *Prosječan broj sortimenata izrađenih od stabla*	4.1	4.3	4.4	4.4
Percentage of forked stems, % *Udjel rašljavih stabala, %*	12.3	14.4	13.5	13.8

from the moving direction. It cuts two stems from one standing point. The general direction of stem inclination is opposite to the direction of the harvester movement. It starts cutting trees in the next two rows from the opposite side of the felling site, by driving forward, in the direction of stem inclination. First, it cuts a stem in the row to the left, and then in the row to the right, observed from the moving direction. It cuts two stems from one standing point.

The average values of the measured elements for the analyzed stems, as well as the percentage of forked stems for the investigated methods, are presented in Table 2.

The research is based on the study of work and time. The time length of the working operations was measured on the chronometer, by the flowing method, with one second accuracy.

The following working operations were recorded:

⇒ Moving: it starts when the harvester wheels start moving from one standing point and ends when they stop in the next standing point

⇒ Positioning-to cut: it starts when the harvester wheels stop moving and ends when the harvester head grips the stem

⇒ Felling: it starts when the chain starts moving and ends when the tree falls onto the ground

⇒ Processing: it starts when the tree stem starts moving through the harvester head and ends when the harvester wheels start moving.

All the hang-ups in the felling and processing operations of the harvester work were recorded.

Apart from that, records were made of all trees that deviated from the desired felling direction, by stating the rate and cause of deviation.

Furthermore, a separate record was made of all forked stems, i.e. the stems that could not be processed without previous rotating the harvester head when cutting the limbs of the forks.

When the harvester moved backwards, wood assortment were processed on the spot that was on its right side, observed from the moving direction, at the distance of 2.5 m, and when it moved frontally it was on the same spot to the left.

The logs were positioned in such a way that they ensured free movement of the forwarder through the cutting site and easy transport of logs.

The most significant factors in processing logs into assortments of certain quality were minimal dimensions prescribed by the national standards for the quality of roundwood (SRPS) and the stem characteristics (knots and sweep). It has been research-proved that these two factors are crucial in the qualitative marking stems for cross-cutting (Danilović 2006). The logs were cross-cut through knots since in this way they can be regarded as an allowance and eliminated as a wood defect. At the same time, cracking of the face of the processed assortments was avoided.

Before the harvester started the work, the stems had been marked for cross-cutting and stem diameter at breast height had been measured. Afterwards, the diameter at stump height and the diameter at the thinner end of the log were measured as well. They were measured with the accuracy of up to a millimeter. The volume of the processed assortments was calculated by Huber formula with an accuracy of two decimal places.

The height of the trees was determined by using the height curve based on the sample of 234 trees.

Two criteria were used in the classification of stems for the purposes of the analyses within each investigated method. They are: diameter at breast height and forks.

The significance and the effects of these factors on the differences between the harvester working elements in cutting and processing wood assortments were determined by two-factor analysis of variance in the statistical program Statgraphics Plus. Regression analysis was applied to make a relationship between the variable.

3. Results – *Rezultati*

In the course of the research, a total 1327 stems were felled and processed. The mean cut diameter at stump height is 46.3 cm and at breast height 40.4 cm.

Out of the total number of cut and processed stems, forked stems account for 13.6%. Forked stems yield averagely 6.1 assortments, while the stems without forks yield 4.3 assortments with the average length of 5.1 m. The diameter at the thinner end of the log averages 20.1 cm.

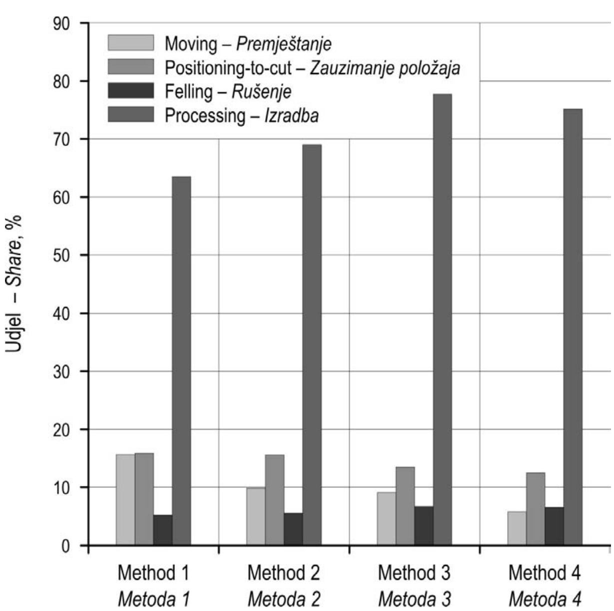

Fig. 3 Structure of the effective harvester working time
Slika 3. *Struktura efektivnoga vremena rada harvestera*

Fig. 3 shows the structure of the effective working time for each method studied.

When the first working method was used, the moving time made 15.7% of the harvester total effective working time and amounted to 0.36 min/stem or 0.23 min/m^3. Out of the total amount of moving time, 60.2% was spent on moving from one stem to another, while the rest of the time was spent on moving from one row to another, or on the return of the harvester from the end of the row in which it had performed the cutting operations to the beginning of the next row. The average driving speed of the harvester, when it moved from one row to another, was 59.9 m/min and 41.1 m/min when it moved from one tree to another.

When the second method was used, the moving time made 9.9% of the harvester total effective working time and amounted to 0.22 min/stem or 0.16 min/m^3. With the the third method, the harvester spent 8.5% of its total effective working time on moving, i.e. 0.18 min/stem or 0.11 min/m^3. Out of the total amount of moving time, 64.7% was spent on moving from one tree to another, while the rest of the time was spent on moving from one row to another.

The percentage of transition time was the lowest when the fourth method was used and it accounted for 5.8% of the harvester total effective working time and amounted to 0.12 min/stem or 0.08 min/m^3.

The results of the two-factor analysis of variance show that there are statistically significant differences in the average moving time values between the investigated methods (F-203.1, p-0.000).

The size of the stem and the degree of its forking do not have a significant effect on the differences in the transition time (p>0.05).

There are statistically significant differences in the average moving time between the first and the other three methods of work (Table 3). The effects of other factors such as undergrowth, soil moisture or topography do not differ between the studied areas.

The average positioning time ranged from 12.1 to 15.9% of the effective working time and was from 0.26 to 0.37 min/stem or from 0.25 to 0.18 min/m^3, depending on the method used. It was the longest when the first method was used (0.37 min/stem or 0.25 min/m^3) and the shortest when the fourth method was used (0.26 min/stem or 0.17 min/m^3).

The respective values for the second method were 0.34 min/stem or 0.22 min/m^3 and 0.28 min/stem or 0.18 min/m^3 for the third (Table 5).

The investigated methods of work showed statistically significant differences (F-11.65, p-0.000) in the

Table 3 Average time of working elements for different working methods (Duncan multiple range test)
Tablica 3. *Prosječni utrošci vremena radnih sastavnica pri različitim metodama rada (Duncan multiple range test)*

Working elements *Radne sastavnice*	Method 1 *Metoda 1*	Method 2 *Metoda 2*	Method 3 *Metoda 3*	Method 4 *Metoda 4*	Covariate *Nezavisna varijabla*
Average time consumption, min/stem – *Prosječni utrošci vremena, min/stablo*					
Moving – *Premještanje*	0.36 a	0.22 b	0.18 b	0.12 b	–
Positioning-to-cut – *Zauzimanje položaja*	0.37 a	0.34 a	0.28 b	0. 26 b	–
Felling – *Rušenje*	0.121 a	0.124 a	0.136 b	0.138 b	–
Processing – *Izradba*	1.48 a	1.53 a	1.57 a	1.58 a	Stem volume – *Obujam stabla*, $p<0.05$

a, b – time consumptions of working elements without differences between working methods
– *utrošci vremena radnih sastavnica bez značajnih razlika među metodama rada*

average positioning time values. Stem forking contributed greatly to the differences in the harvester positioning time. This means that the harvester operator spent a considerably greater amount of time on positioning when felling forked stems.

The average positioning time did not differ between the first and the second, as well as between the third and fourth method of harvester work (Table 3), which proved that the driving direction of the harvester in the cutting and processing operations did not affect the positioning time, while the number of trees cut from one standing point had a significant effect on the positioning time and differentiated the investigated methods into two homogeneous groups.

Felling time ranged from 5.2 to 6.7% of the effective working time, depending on the method of work, i.e. from 0.12 min/stem or 0.09 min/m^3 in the first method to 14 min/stem or 0.1 min/m^3 in the fourth method. The investigated methods of work showed statistically significant differences (F-8.41, p-0.000) in the average felling time values. The average felling time did not differ between the first and second, as well as between the third and fourth method of harvester work (Table 3). Furthermore, forking and stem volume contributed to the differences in the cutting and felling time ($p<0.05$).

Cutting and felling time increases with the growth of stem volume due to larger crowns or less space available for free stem felling. There is a linear relationship between the variables (Fig. 4).

Minimum stem processing time was 0.22 and maximum 5.91 min/stem. Processing time took up the greatest percentage of the total effective time and amounted to 70% (Fig. 3)

The average processing time did not differ significantly between the investigated methods of work (F-1.02, p-0.381). In the average it ranged from 0.91 to 1.0 min/m^3, depending on the investigated method of work.

Stem forking has a significant effect on the stem processing unit time (F-173.9, p-0.000). The average time needed for processing a stem without forks amounted to 0.89 min/m^3 and 1.35 min/m^3 for stems with formed forks.

Processing time increases with the growth of stem volume. The relationship between the stem volume and stem processing time is expressed by regression equations (Table 4).

The model of the function that was selected after testing several different models shows a moderately strong relationship between the variables. The relationship between the stem size and processing time is moderately strong. In other words, the relationship between these two variables accounts for less than half of the variations (Table 4).

The relationship between stem volume and the time spent on cutting and felling is linear (Tab. 3).

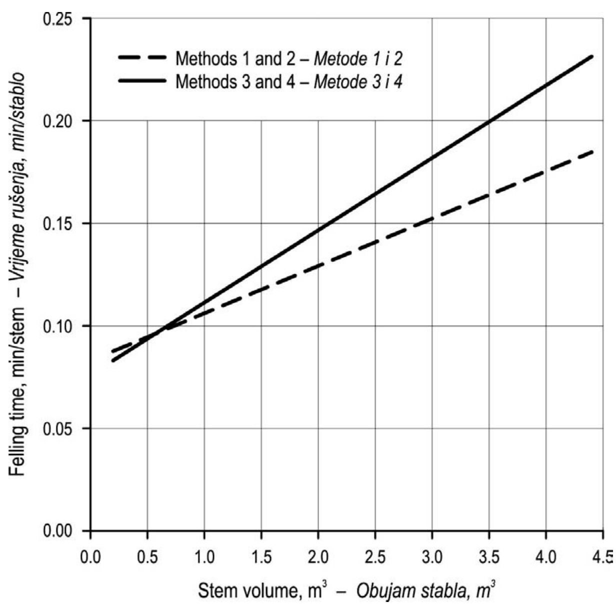

Fig. 4 Dependence of felling time on stem volume
Slika 4. *Ovisnost vremena rušenja o obujmu stabla*

Table 4. Functions and function parameters
Tablica 4. *Funkcije i parametri funkcija*

Working elements *Radne sastavnice*		Function *Funkcija*	Parameters – *Parametri* a	b	R^2
Felling – *Rušenje*	Method 1 and 2 – *Metoda 1 i 2*	$t_f = a + b \cdot V \left[\frac{\text{min}}{\text{tree}}\right]$	0.083	0.023	0.061
	Method 3 and 4 – *Metoda 3 i 4*		0.076	0.035	0.101
Processing – *Izradba*	Stems without forks – *Stabla bez rašalja*	$t_{pr} = a \cdot V^b \left[\frac{\text{min}}{\text{tree}}\right]$	0.764	1.147	0.415
	Forked stems – *Rašljava stabla*		1.164	1.129	0.492
	All stems – *Sva stabla*		0.781	1.259	0.449

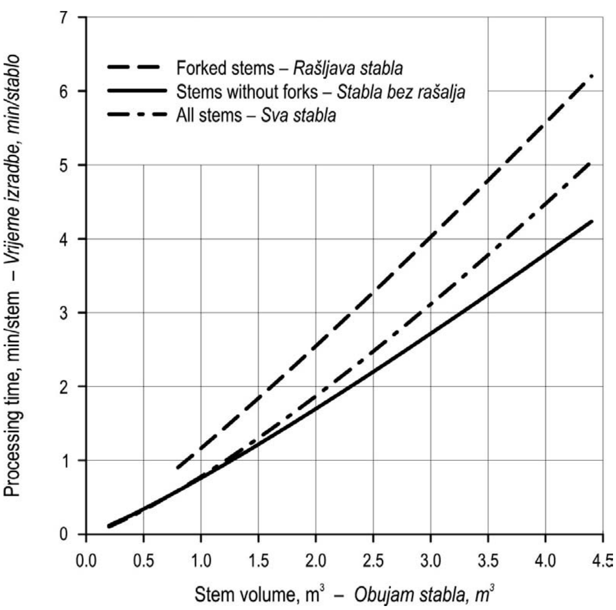

Fig. 5 Dependence of processing time on stem volume
Slika 5. *Ovisnost vremena izradbe drva o obujmu stabla*

Non-productive time accounted for 34.91% of the total time of harvester work. Out of the total non--productive time, 18.4% was spent on justified and unjustified interruptions.

Justified interruptions included breaks, consultations, harvester maintenance, breakfast, odd jobs and technical failures. Out of the total non-productive time, 24.2% was taken by preliminary work time, while the average time used for breaks amounted to 19.6% of the total interruption time length. Lunch breaks amounted to 18.4%. The interruptions which occurred when the chain fell off when felling larger stems with the diameter at stump height above 55 cm averaged 16.2% of the total interruption time. Other interruptions included harvester maintenance, consultations and odd jobs.

Extra working time of the harvester, which is derived by excluding all unnecessary and unjustified interruptions from the non-productive working time, amounts to 28.5%. Felling and processing time per unit product varies with the method of work and the differences are primarily caused by the positioning and moving time (Table 5).

The timber volume of a stem with a mean cut diameter is 1.55 m^3. The effective time needed for processing a stem with a mean cut diameter is from 1.35 to 1.54 min/m^3, depending on the working method. Based on the results of the analysis of variance, it can be concluded that there are statistically significant differences in this time between the used methods of harvester work (F-2.82, p-0.038), as well as between the stems with and without forks (F-98.2, p-0.000). There are also statistically significant differences between the fourth and the other three working methods.

The total effective time spent on stem felling and processing can be calculated by the following mathematical equation (Eq. 1):

$$t_e = \frac{1}{V}\left(\sum_{j=1}^{4}\alpha_j \cdot t_{m_i} + \sum_{j=1}^{4}\beta_j \cdot t_{p_i} + t_f + t_{pr}\right)\left[\frac{\text{min}}{\text{m}^3}\right] \qquad (1)$$

$$\alpha_j = \begin{matrix} 0, i \neq j \\ 1, i = j \end{matrix}, \quad \beta_j = \begin{matrix} 0, i \neq j \\ 1, i = j \end{matrix}$$

Table 5 Harvester moving and positioning time depending on the method of work
Tablica 5. *Vrijeme premještanja i zauzimanja položaja harvestera za primijenjene metode rada*

Working elements *Radne sastavnice*	Method 1 *Metoda 1*	Method 2 *Metoda 2*	Method 3 *Metoda 3*	Method 4 *Metoda 4*
Moving t_m, min/stem – *Premještanje t_m, min/stablo*	0.36	0.22	0.18	0.12
Positioning-to-cut t_p, min/stem – *Zauzimanje položaja t_p, min/stablo*	0.37	0.34	0.28	0.26

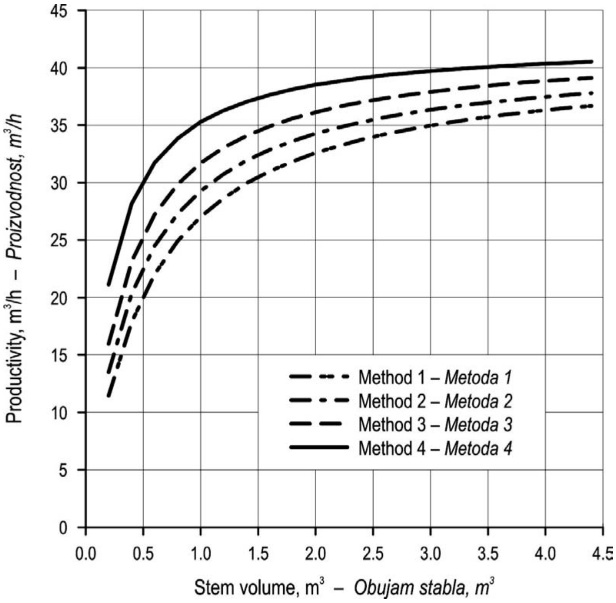

Fig. 6 Harvester productivity vs. work method
Slika 6. *Ovisnost proizvodnosti harvestera o primijenjenoj metodi rada*

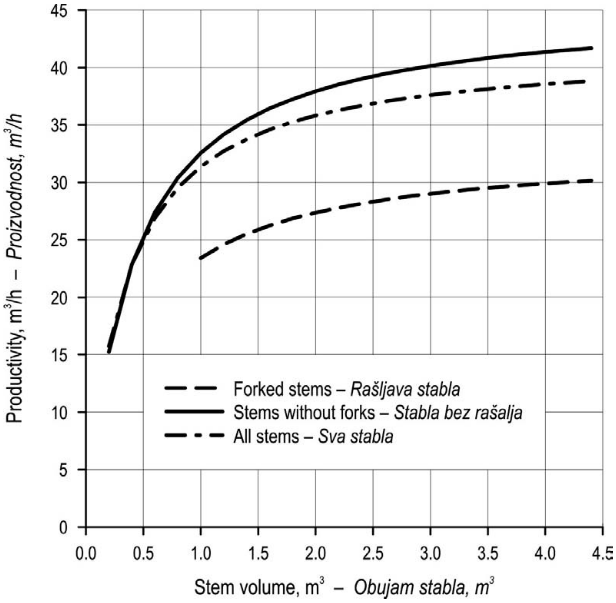

Fig. 7 Influence of stem forkness on harvester productivity
Slika 7. *Utjecaj rašljavosti stabala na proizvodnost harvestera*

where:

t_m – moving time (Table 5)
t_p – positioning time (Table 5)
t_f – felling time (function in Table 4)
t_{pr} – processing time (function in Table 4)
V – stem volume

The average productivity ranges from 39.0 to 44.4 m^3/h, depending on the method of work. The time needed for processing a stem with a mean cut diameter depending on the method of work, provided that the extra time is included, ranges from 1.73 to 1.98 min/m^3, which means that the harvester achieves the average productivity of 30.3 to 34.7 m^3/h. The highest productivity is achieved when the harvester moves between two rows and cuts two stems from one standing point (Method 4), and the lowest when it moves backward and cuts stems from one row, i.e. one stem from one standing point (Method 1). The average productivity of the harvester, when the second method is used, amounts to 32.3 m^3/h, and 34.0 m^3/h when the third method is used.

The productivity of the harvester increases with the growth of timber volume. The relationship between the productivity and the stem diameter is presented in Fig. 6

The productivity of the harvester in felling and processing forked stems is lower than the productivity achieved in felling stems without forks (Fig. 7).

The relationship between the stem volume and productivity is expressed by regression equations (Table 6).

Direct costs of John Deere 1470D ECOIII harvester work are calculated on the basis of 1600 operating hours and they amount to 121.3 EUR/h. Cost calculation for the harvester work was made on the basis of input data (Table 7).

Table 6 Statistic elements of regression models
Tablica 6. *Statistički elementi regresijskih modela*

Method – *Metode*	Function – *Funkcija*	a	b	t_a	t_b	R^2
Method 1 – *Metoda 1*	$P=\frac{1}{a+\frac{b}{v}}\left[\frac{m^3}{h}\right]$	0.0244	0.013	7.1	2.8	0.221
Method 2 – *Metoda 2*		0.0242	0.01	9.4	2.8	0.274
Method 3 – *Metoda 3*		0.0238	0.008	12.8	2.9	0.263
Method 4 – *Metoda 4*		0.0236	0.005	16.1	2.5	0.213
Stems without fork – *Stabla bez rašalja*		0.022	0.009	23.9	7.45	0.481
Forked stems – *Rašljava stabla*		0.030	0.012	10.5	2.6	0.340
All stems – *Sva stabla*		0.024	0.008	28.4	4.8	0.311

Table 7 Machine cost data
Tablica 7. *Podaci o troškovima stroja*

Purchase price, EUR *Nabavna cijena*, EUR	442900
Engine output power, kW *Snaga motora, kW*	180
Machine life, years *Radni vijek stroja, godine*	5
Salvage value, % of purchase price *Preostala vrijednost, % od nabavne cijene*	10
Machine utilization rate,% *Stupanj iskoristivosti stroja, %*	80
Repair and maintenance cost, % of depreciation *Troškovi popravaka i održavanja, % od amortizacije*	50
Interest rate, % of average yearly investment *Kamatna stopa, % prosječne vrijednosti investicije*	5.5
Insurance and tax rate, % of average yearly investment *Osiguranje i takse, % prosječne vrijednosti investicije*	5
Fuel consumption rate, L/h *Utrošak goriva, L/h*	14.8
Fuel cost, EUR/L *Cijena goriva, EUR/L*	1.1
Oil and lubrication consumption rate, L/h *Utrošak ulja i maziva, L/h*	0.62
Oil and lubrication cost, EUR/L *Cijena ulja i maziva, EUR/L*	2.5
Operator's wage, EUR/h *Zarada vozača, EUR/h*	5.7

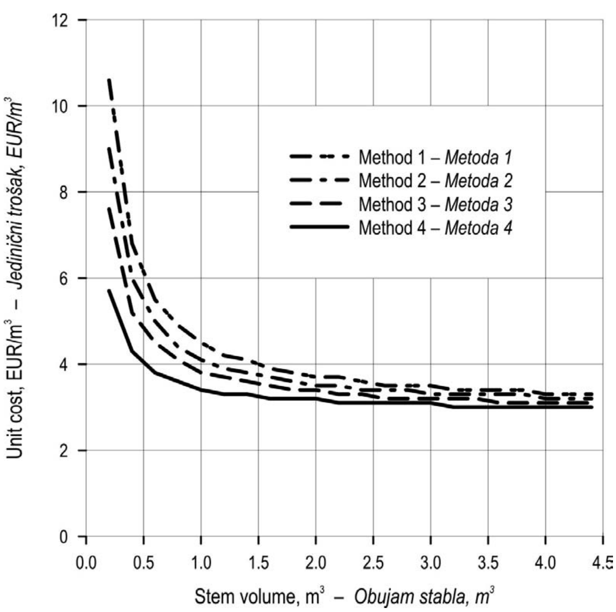

Fig. 8 Harvester unit costs depending on methods of work
Slika 8. *Jedinični troškovi harvestera u ovisnosti o primijenjenoj metodi rada*

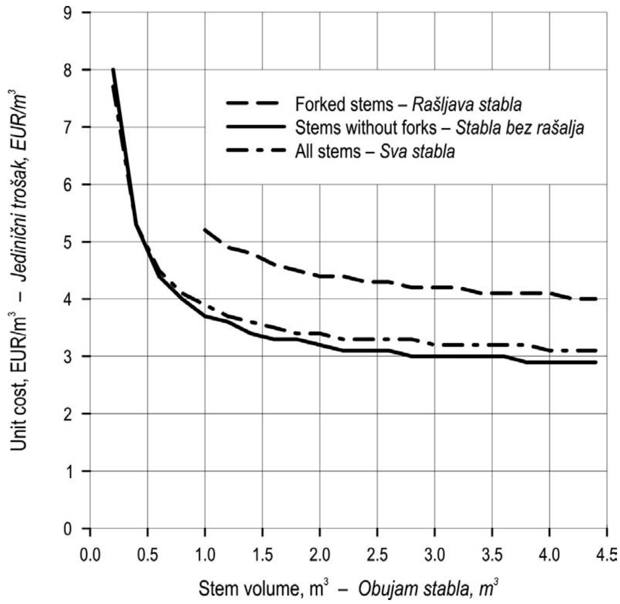

Fig. 9 Influence of stem forkness on unit costs
Slika 9. *Utjecaj rašljavosti stabala na jedinične troškove*

The Unit costs of work are calculated on the basis of direct costs of work and the productivity, achieved by the harvester in different working methods of felling and popalr plantation, vary with the method of work. The costs are the lowest when the Method 4 is used and amount to 3.5 EUR/m^3, and the highest with the the first method, amounting to 4.0 EUR/m^3.

Costs per unit product decrease with the growth of timber volume, due to the increase in the productivity achieved by the harvester (Fig. 8).

Furthermore, the average unit costs of felling forked stems or the stems whose processing requires rotating of the harvester head are higher than the average costs of processing a unit product from stems with the same dimensions but without forks.

On the basis of these results it can be concluded that Method 4 is economically most convenient for mature poplar plantations.

4. Discussion – *Rasprava*

At the end of the production cycle, the productivity of John Deere 1470D ECOIII harvester, employed in the clear-cutting of poplar trees varied from 30.3 to 34.7 m^3/h, depending on the method of work.

The achieved outputs are lower in comparison with the outputs achieved by the harvester in clear-cutting of mature conifer stands (e.g. spruce) (Eliasson et al. 1999) and higher than the outputs achieved in hard broadleaved stands (beech) mature for felling.

Poplar trees have less dense and consequently less hard wood than hard broadleaves. It makes their wood easier for processing. Felling and processing stems with a lower rate of branching, less noticeable sweeps and without major forks can be carried out without any significant delays. The damage to the processeed assortments is minimal, especially during the vegetative resting period.

Large trees (above 55 cm in diameter at stump height) are not always possible to fell in the desired direction. The percentage of such trees was 4.1% of the total number of felled trees. Deviation from the desired felling direction was often greater than the distance between the trees in a row, which often caused damage to the adjacent standing trees, or the trees that had already been felled. This happened more often when felling and cutting forked trees because their individual inclination was significantly different from the general inclination direction of the trees in the stand. Minor deviations occurred when felling thinner stems. They often got stuck in the forks of adjacent standing trees and required more time for felling. Apart from that, it caused a significant breakage of standing trees.

When felling forked trees with larger diameters at stump height, it took more time to position the harvester in order not to threaten the operator safety. In this case the distance between the harvester and the tree was approximately 2.5 m, and when felling and cutting thinner stems the distance was about 4 m.

It follows that when the harvester moves between two rows and cuts stems from both rows, the harvester operator has to perform an additional positioning before felling a tree, which means that it is not always possible to fell two trees from one standing point without moving the harvester.

Operating the harvester is easier when the first method of work is used because the operator can focus his attention on the trees in one row, which causes less mental fatigue in comparison with the working methods that imply frontal movement of the harvester between the rows. Operating the harvester does not involve only physical activities. The harvester operator responsibilities are to follow a series of variable conditions and to respond to a specific situation in the best possible manner (Nonaka et al. 1995). Furthermore, we are dealing with voluminous work, which must be qualitatively divided into several different phases if we want to achieve maximum financial effect.

The time needed to drive the harvester from one row to another, when the first method is used, averages 39.8% of the total moving time, which affects the total time needed for felling and processing a unit product, i.e. the achieved productivity of the harvester. However, this time should be seen as the time for a mental break of the harvester operators, who certainly appreciate it. However, we cannot assess the extent of its positive effect on the mental fatigue of the workers on the basis of this research. The moving time does not depend on the size of the trees, but on the planting density and the number of trees cut from one standing point (Klunder and Stokes 1994, Eliasson et al. 1999, Krpan and Poršinsky 2002, Nurminen et al. 2006).

When the harvester moves backwards and cuts trees to the right observed from the moving direction, there is much more free space available for felling and the visibility is better because there is not a standing tree in front of the tree that is being felled. In this case, the angle at which the harvester cuts the tree in relation to its moving axis usually ranges from 0 to 25° (Fig. 2). Since there are no standing trees in the area from 0 to 10°, it is easier to perform the felling operations. The situation is the same when the third method is used, except that the felling area on the right side observed from the moving direction is free for felling from 0 to 20°. When the second and the fourth methods are used, this space is occupied by standing trees that make it more difficult to fell trees in the desired direction, especially if they are forked.

Felling trees with large diameters and trees that deviate from the general felling direction increases the amount of time needed for felling. In this case the operator drives the harvester to a position in which he can use the harvester grip to push the tree in the desired felling direction. The safety of the operator is assessed for each individual operation. The direction of the felled tree affects the time needed for stem processing because of additional manipulation with the stems in order to position the assortments in such a way to allow free movement of the forwarder.

Processing time does not vary significantly with the working method of the harvester, but there are statistically significant differences in the average time needed to process stems with and without forks. Longer time is needed to process forked stems because the harvester head has to be rotated 180° to cut off the limbs of the forks.

The harvester operator has to rotate the harvester head, then to cut the stem just below the fork in order to achieve maximum wood assortment utilization, and finally he needs some time to lift the rest of the forked stem off the ground and cut it up.

Since the forks have a significant effect on the stem processing time (Fig. 6), in the early years of plantation development, it is necessary to remove thick branches that lead to the formation of large forks. This is especially true when it comes to clones of vigorous growth.

In comparison with mountainous regions, where both stem and terrain characteristics are of great importance, terrain characteristics are not regarded crucial for the use of harvester in lowland areas.

Terrain characteristics do not have a direct effect on the harvester working performances, because it can approach each tree and take the most suitable felling and processing position. The indirect effects of the terrain characteristics can be observed through the impact of flood waters on the occurrence of multiple sweep in the lower or the most valuable part of the stem, which subsequently affects the stem processing time on the one hand and the extent of damage caused by the harvester head on the other hand.

The damage was analyzed on the sample of 74 stems or 286 logs. The results show that cracks appeared on the face of the logs in 7.56% of all logs, while mechanical injuries in the form of dents accounted for 16.8%. The average depth of damage was 3.2 cm, the maximum 12 cm.

The first log had no mechanical injuries, the second had injuries in 19.8% of all cases, while the damage on the third and the fourth log occurred in 77.4% of all cases. Mechanical injuries that occurred in the upper part of the tree stem did not have a significant effect on the quality of the processed assortments since this part of the stem rarely yields best quality assortments.

Stem characteristics greatly affect the harvester productivity, but not to such extent to call for the application of the combined method, as is the case with the final fellings of hard broadleaves.

It follows that from the technical point of view, the use of harvester in felling and processing soft broadleaves is more convenient than its use in felling and processing hard broadleaves, because stem characteristics produce less significant effects on the harvester productivity, primarily due to lower wood density.

Results of this kind have also been reached by other authors who have studied the efficiency of the harvester in the stands of different tree species. They agree that the use of harvester in natural stands of hard broadleaves is less effective and more costly than its use in conifer cultures and plantations of soft broadleaves (Krpan et al. 2004).

There are certain other factors that affect the harvester productivity. They are: operator skills, terrain conditions, felling intensity, felling time, etc. (Makkonen 1991, Eliasson 1998, Stampfer 1999, Nurminen et al. 2006). These factors were not important for this research because the harvester was operated by only one worker on the flat terrain in winter working conditions.

This research has proved just like the studies of other authors that stem size affects the productivity of the harvester (Brunberg et al. 1989, McNeel and Rutherford 1994, Kellogg and Bettinger 1994, Lageson 1997, Glode 1999).

The initial hypotheses that the method of harvester work and stem forking have significant effects on the harvester productivity in the mature poplar plantations have been confirmed.

5. Conclusions – *Zaključci*

The average productivity of John Deere 1470 D ECO III harvester, used in the regular cuttings of poplar trees in *Populus × euramericana* 'I-214' plantations varied from 30.3 to 34.7 m^3/h, depending on the method of work.

The harvester is the most productive when it moves backwards between two rows and cuts two stems from one standing point, first a stem in the row to the right and then a stem in the row to the left, observed from the moving direction. It starts felling trees in the next two rows from the opposite side of the felling site. The same method of felling is used except that the harvester now moves frontally.

Moving and positioning time has the greatest effect on the average productivity of the harvester and varies with the method of work, while the stem processing time does not vary with the used methods and does not affect its productivity.

The average time needed to process forked stems amounts to 1.35 min/m^3 and it is considerably longer than the average time needed to process stems without forks, which amounts to 0.89 min/m^3, because there is no need to rotate the harvester head when processing them.

The effects of the forks on the harvester productivity can be reduced by removing thicker lateral branches off the young poplar trees.

Felling and processing wood assortments in mature poplar plantations does not require the employment of the combined method since the harvester can perform the felling and processing of wood assortments without any major delays. Therefore, it can be concluded that from a technical point of view John Deere 1470D ECOIII harvester is an efficient working instrument of clear-felling in poplar plantations.

6. References – *Literatura*

Andersson, J., Eliasson, L., 2004: Effects of three harvesting work methods on Harwarder productivity in final felling. Silva Fennica 38(2): 195–202.

Brunberg, T., Thelin A., Westerling S., 1989: Basic data for productivity standards for single-grip harvesters in thinning. The Forest Operations Institute of Sweden. Report 3: 21.

Danilović, M., 2006: Study of quality factors in poplar *Populus* × *euramericana* 'I-214' and *Populus* × *euramericana* 'Ostia' plantations from the aspect of the application of national and European quality standards. PhD Thesis, Forestry Faculty of Belgrade University, 204 p.

Eliasson, L. Bengtsson, J., Cedergren, J., Lageson, H, 1999: Comparison of single-grip harvester productivity in clear- and shelterwood cutting International Journal of Forest Engineering 10(1): 43–48.

Eliasson, L., 1998: Analyses of single-grip harvester productivity. Doctoral thesis. Swedish University of Agricultural Sciences. Department of Operational Efficiency. Umeå. 24 p.

Eliasson, L., 2000: Effects of establishment and thinning of shelter-woods on harvester performance. International Journal of Forest Engineering 11(1): 21–27.

Glöde, D., 1999: Single and double grip harvesters productive measurements in final cutting of Shelterwood. International Journal of Forest Engineering 10(2):63–74.

Glöde, D., Sikström, U., 2001: Two felling methods in final cutting of shelterwood, single-grip harvester productivity and damage to the regeneration. Silva Fennica 35(1): 71–83.

Hånell, B., Nordfjell, T., Eliasson, L., 2000: Productivity and costing of shelterwood harvesting. Scandinavian Journal of Forest Research 15(5): 561–569.

Hartsough, B. R., Cooper. D. J., 1999: Cut-to-length harvesting of short rotation Eucalyptus. Forest Products Journal 49(10): 69–75.

Jiroušek, R., Klvač R., Skoupý, A., 2007: Productivity and costs of the mechanised cut-to-length wood harvesting system in clear-felling operations. Journal of Forest Science 53(10): 476–482.

Kärhä, K., Rönkkö, E., Gumse S.I. 2004. Productivity and cutting costs of thinning harvesters. International Journal of Forest Engineering 15(2): 43–56.

Krpan, A. P. B., Poršinsky, T., 2001: Harvester Timberjack 1070 in Croatia. Šumarski list 125(11–12): 619–624.

Krpan, A. P. B., Poršinsky, T., 2002: Proizvodnost harvestera Timberjack 1070 pri proredi kulture običnog bora. Šum. list 126(11–12): 551–561.

Krpan, A. P. B., Poršinsky, T., Stankić, I., 2004: Efficiency of Mechanical Felling and Processing in Soft and Hardwood broadleaved stands – Part 3: Efficiency of harvester in natural thinning stands of hardwood broadleaf species). Šumarski list 128(9–10): 495–508.

Kellogg, L. D., Bettinger, P., 1994: Thinning productivity and cost for mechanized cut-to-length system in the Northwest Pacific coast region of the USA. International Journal of Forest Engineering 5(2): 43–52.

Klunder, R. A., Stokes, B. J., 1994: Productivity and cost of three harvesting methods. Southern Journal of Applied Forestry 18(4):168–174.

Lageson, H., 1997: Effects of thinning type on the harvester productivity and on the residual stand. International Journal of Forest Engineering 8(2): 7–14.

Makkonen, I., 1991: Silver Streak single-grip harvester in Nova Scotia. Forestry Engineering Research Institute of Canada, FERRIC, Pointe Claire, Que. Field Note TR–94: 18.

McNeel, J. F., Rutherford, D., 1994: Modelling harvester-forwarder system performance in a selection harvest. International Journal of Forest Engineering 6(1): 7–14.

Nakagawa, M., Hamatsu, J., Saitou, T., Ishiđa, H., 2007: Effect of tree size on productivity and time required for work elements in selective thinning by a harvester. International Journal of Forest Engineering 18(2): 24–28.

Nonaka, I., Takeuchi, H., 1995: The knowledge-Creating Company. Oxford University Press. 1995. New York.

Puttock, D., Spinelli, R., Hartsough, B. R., 2005: Operational trials of cut-to-length harvesting of poplar in a mixed wood stand. International Journal of Forest Engineering 16(1): 39–49.

Nurminen, T., Korpunen, H., Uusitalo, J., 2006: Time consumption analysis of the mechanized cut-to-length harvesting system, Silva Fennica 40(2): 335–363.

Ovaskainen, H., Uusitalo, J., Väätäinen, K., 2004: Characteristics and Significance of Harvester Operators' Working Technique in Thinnings. International Journal of Forest Engineering 15(2): 67–77.

Sirén, M., 1998: One grip harvester operation, its silvicultural result and possibilities to predict tree damage. PhD Thesis, Finnish Forest Research Institute, Research Papers 694, 179 p.

Stampfer, K., Steinmüeller, T., 2001: A new approach to derive a productivity model for the harvester »Valmet 911 Snake«, International mountain logging and 11th Pacific Northwest Skyline Symposium, Institute of forest and mountain risk engineering, University of Agricultural science Vienna, Austria.

Stampfer, K., 1999: Influence of terrain conditions and thinnings regimes on productivity of a trackbased steep slope harvester. In: Proceedings of the International Mountain Logging and Tenth Pacific Nortwest Symposium, March 28 – April 1, 1999, Cornvallis, Oregon 78–87 p.

Suadicani, K., Fjeld, D., 2001: Single-tree and group selection in montane Norway spruce stands: Factors influencing operational efficiency. Scandinavian Journal of Forest Research 16(1): 79–87.

Tufs, R. A., Brinker, R. W., 1993: Walmet's woodstar series harvesting system: A case stady. Southern Journal of Applied Forestry 17(2): 69–74.

Tufts, R. A., 1997: Productivity and cost of the Ponsse 15-series, cut-to-length harvesting system in southern pine plantations. Forest Products Journal 47(10): 39–46.

Wester, F., Eliasson, L., 2003: Productivity in final felling and thinning for a combined harvester-forwarder (Harwarder). International Journal of Forest Engineering 14(2): 45–51.

Sažetak

Djelotvornost harvestera John Deere 1470D ECOIII u topolovim plantažama

U nastojanju za većom razinom mehaniziranosti pridobivanja drva, u šumarstvu u Srbiji od 2008. godine za sječu i izradbu drva u topolovim plantažama duge ophodnje koristi se harvester John Deere 1470D ECOIII. Budući je cilj zamjena radnika sjekača harvesterima na mjestima na kojima postoje uvjeti za mehaniziranu sječu i izradbu drva, najviše zbog pomanjkanja kvalificirane radne snage. Primjena malih harvestera u proredama mekih listača logično je rješenje, ali je njihov udjel u ukupnoj površini plantaža u Srbiji vrlo malen. Poslednjih petnaest godina uglavnom se osnivaju plantaže simetričnoga rasporeda sadnje namijenjene proizvodnji obloga drva za mehaničku preradbu.

Imajući na umu činjenicu da sjekači pri sječi i izradbi drva u topolovim plantažama zrelim za sječu ostvaruju velike učinke, među ostalim i zbog toga što je posljednjih godina sve više zastupljena izradba višemetarskoga prostornoga drva, primjena harvestera promatrana s ekonomskoga aspekta može biti isplativa samo pri njihovim visokim učincima.

Primjena harvestera u redovitim sječama topole naizgled je jednostavno rješenje s obzirom na to da je riječ o čistoj sječi na ravnim terenima, homogenoj strukturi sastojine s aspekta dimenzija i rasporeda stabala te o drvu male tvrdoće. U svim, pa i u ovim uvjetima rada postoji velik broj čimbenika koji utječu na proizvodnost sredstava za rad, među kojima su najznačajniji terenski uvjeti te značajke stabala.

Topolove plantaže duge ophodnje nalaze se na terenima ograničene nosivosti s visokom razinom podzemnih voda te s čestim poplavama koje dovode do izražene zakrivljenosti donjega dijela stabla. Osim toga stabla su velikih dimenzija s izraženim vanjskim značajkama (granatost, zakrivljenost, rašljavost i dr.).

Utjecaj značajki stabala na djelotvornost harvestera ogleda se u prekidima rada, osobito pri kresanju jačih grana, oštećenju donjega najvrednijega dijela debla stabla zbog višestruke zakrivljenosti, kao i zastoja pri trupljenju rašlji.

Pojava rašljavosti stabala listača česta je pojava, međutim udjel se tih stabala može znatno smanjiti uzgojnim mjerama, kao što su korekcija vrha mladih biljaka te kresanje grana s mladih dubećih topolovih stabala.

Također euroameričke topole imaju izraženu vlažnost srca debla, što značajno utječe na raspucavanje donjega najvrednijega dijela stabla pri njegovu rušenju. Utjecaj na proizvodnost harvestera imaju i ostali čimbenici, među kojima su i metode rada.

Cilj je ovoga rada da se istraži djelotvornost harvestera John Deere 1470D ECOIII u topolovim plantažama duge ophodnje primjenom četiriju različitih metoda rada te da se ocijeni značenje, odnosno utjecaj rašljavosti stabala na djelotvornost strojne sječe i izradbe drva harvesterom.

Istraživane su se metode razlikovale u ovisnosti o smjeru kretanja harvestera, o njegovu položaju u odnosu na red koji siječe te broju stabala koja siječe s jednoga stajališta.

Istraživanje je provedeno u plantaži topole (Populus × euramericana 'I-214') na području ravnoga Srijema u Srbiji, na površini od 6,89 ha u razdoblju od prosinca 2009. do veljače 2010. godine. Primjerne površine na kojima je obavljeno snimanje različitih metoda rada postavljene su duljom stranicom sječine, a radni su uvjeti bili isti za sve četiri istraživane metode rada. Srednji je promjer stabala na panju iznosio 46,3 cm, a na prsnoj visini 40,4 cm.

Pri istraživanju je primijenjen studij rada i vremena, a trajanje radnih operacija snimano je protočnom metodom kronometrije.

Vrijeme rada harvestera podijeljeno je na ove radne sastavnice: premještanje vozila, zauzimanje položaja, rušenje stabla te izradba drva.

Posebno su evidentirana rašljava stabla, odnosno stabla koja nije bilo moguće izraditi bez prethodnoga zakretanja harvesterske glave pri trupljenju krakova rašlji. Udjel tih stabala na svim četirima primjernim površinama iznosi 13,6 %.

Pri izradbi sortimenata presudne su bile minimalne dimenzije propisane odredbama nacionalnih normi za oblo drvo i značajke debla stabla (kvrge i zakrivljenost). Poželjno trupljenje drva preko kvrga zbog smanjena raspucavanja izrađene oblovine bilo je posebno važno s obzirom na mogući utjecaj na utrošak vremena izradbe drva.

Stabla za analizu u okviru svake od istraživanih metoda razvrstana su po dva kriterija. Prvi je kriterij bio promjer na prsnoj visini stabla, a drugi rašljavost stabla.

Razlike između srednjih vrijednosti značajki istraživanih metoda rada te između srednjih vrijednosti značajki rašljavih i stabala bez rašalja istražene su dvostrukom analizom varijance. Zavisne su varijable bili utrošci vremena sastavnica rada harvestera, a faktori metoda rada te rašljavost stabla. Osim toga uključena je i kovarijàbla za elemente gdje je postojala potreba, odnosno gdje su ispunjeni uvjeti za njezino uključivanje.

Udio vremena premještanja vozila u efektivnom vremenu rada značajno se razlikuje u ovisnosti o primijenjenoj metodi rada te iznosi od 5,8 do 15,7 %; najveći je u prvoj, a najmanji u četvrtoj metodi rada. Na razlike je najviše utjecalo vrijeme premještanja harvestera s kraja jednoga na početak drugoga reda.

Smjer kretanja harvestera pri sječi i izradbi drva nema značajan utjecaj na vrijeme zauzimanja položaja, dok broj stabala koje harvester siječe s jednoga stajališta značajano utječe na vrijeme zauzimanja položaja i diferencira istraživane metode u dvije homogene skupine. Utrošci vremena iznose od 12,1 % do 15,9 % efektivnoga vremena rada, odnosno 0,25 m^3 (prva metoda rada) do 0,18 min/m^3 (četvrta metoda rada).

Rašljavost je stabla, također, značajno utjecala na vrijeme zauzimanja položaja harvestera, odnosno vozač je harvestera utrošio više vremena na zauzimanje položaja pri rušenju rašljavih stabala zbog uklještenja stabla koje se ruši u rašlje preostalih dubećih stabala ili zbog pojave raspucavanja pridanka pri sječi stabla koje se ruši. Udio vremena rušenja stabala u efektivnom vremenu po istraživanim metodama rada iznosi od 5,2 do 6,7 %, pri čemu su razlike vezane uz prostor bez dubećih stabala. Primjera radi, kada se harvester kreće unazad i kada se siječe stablo s desne strane promatrano u smjeru kretanja, oslobođen je veći prostor i preglednost tijekom rušenja jer se ispred stabla koje harvester ruši ne nalazi dubeće stablo. U ovom slučaju kut pod kojim harvester ruši stabla u odnosu na os kretanja vozila je 0 do 25° (slika 2), s tim što se u prostoru od 0 do 10° ne nalaze dubeća stabala, pa je lakše rušenje. Takva je situacija prisutna i u trećoj metodi rada, s tim što je prostor za rušenje stabla s desne strane promatran sa smjerom kretanja slobodan do 20°. Pri primjeni druge i četvrte metode rada u tom se prostoru nalaze dubeća stabla koja otežavaju rušenje stabala u željenom smjeru, a posebno rašljavih. Promjer stabla nema značajan utjecaj na utrošak vremena rušenja, iako stabla promjera na panju iznad 55 cm nije bilo uvijek moguće srušiti u željenom smjeru. U tim je slučajevima zauzimanje položaja harvestera trajalo dulje, ponajprije zbog sigurnosti pri radu.

Pri tome se harvester kreće između redova i siječe stabla iz oba reda, a vozač harvestera dodatno zauzima položaj prije rušenja stabla, odnosno nije u mogućnosti da u svim slučajevima sruši dva stabla s jednoga stajališta bez pomicanja vozila.

Vrijeme izradbe drva stabla iznosi u prosjeku oko 70 % efektivnoga vremena rada i ne razlikuje se značajno među istraživanim metodama te, ovisno o istraživanim metodama rada, iznosi od 0,91 do 1,0 min/m^3. Veza je između obujma stabla i utroška vremena izradbe drva povezana.

Rašljavost stabla značajno utječe na vrijeme izradbe drva, odnosno između prosječnoga vremena izradbe rašljavih stabala i stabala bez rašalja postoje značajne statističke razlike. Prosječno vrijeme izradbe stabala bez rašalja iznosi 0,89 min/m^3, a rašljavih stabala 1,35 min/m^3. Na veće utroške vremena izradbe rašljavih stabala utjecalo je zakretanje harvesterske glave pri trupljenju krakova rašlji.

Prosječni učinci u ovisnosti o metodi rada harvestera kreću se od 30,3 do 34,7 m^3/h uz dodatno vrijeme od 28,5 %. Najveći je učinak harvester ostvario kada se kretao između dvaju redova i kada je sjekao dva stabla s jednoga stajališta (metoda 4), a najmanje kada se kretao unazad i kada je sjekao stabla iz jednoga reda, odnosno jedno stablo po stajalištu (metoda 1). Prosječan učinak harvestera pri primjeni metode 2 iznosi 32,3 m^3/h, a pri metodi 3 prosječan je učinak 34,0 m^3/h.

Izravni troškovi rada harvestera John Deere 1470D ECOIII izračunati na na osnovi 1600 pogonskih sati i iznose 121,3 EUR/h.

Jedinični su troškovi najmanji pri primjeni metode rada 4 te iznose 3,5 EUR/m^3, a najveći pri metodi rada 1 i iznose 4,0 EUR/m^3. Na osnovi ovih istraživanja izlazi da je najveća djelotvornost harvestera kada se primjenjuje metoda rada 4.

Značajke topolovih stabala u plantažama duge ophodnje imaju velik utjecaj na djelotvornost rada harvestera, ali ne toliko da uvjetuju primjenu kombinirane ručno-strojne sječe i izradbe drva motornim pilama lančanicama sa strojnom sječom harvesterom, kao što je to često slučaj u sastojinama tvrdih listača.

Ključne riječi: harvester, topolove plantaže, značajke stabla, metode rada, proizvodnost, troškovi

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