Productivity of Processing Hardwood from Coppice Forests

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Abstract – Nacrtak

Approximately half of the Italian forest area is classified as coppice forest, mostly managed for the production of firewood. Chestnut (Castanea sativa Mill.) coppice stands make exception, as they also produce more valuable assortments, such as sawlogs, poles and fencing materials. Hence the significantly higher industrial activity in chestnut coppice stands, and the rapid introduction of mechanized harvesting. This study deals with four different harvester units used for processing (delimbing – bucking) chestnut trees from coppice stands, at the landing. For these four different machines, time studies were conducted in order to estimate productivity and compare the performance. The results show that the processors can reach high productivities (7.7 m^3/PMH_0–19.8 m^3/PMH_0). In one study the influence of tree form has been estimated, proving that the size of the branches and the shape of the stem have a significant effect on machine productivity. The difference can reach 2.3 m^3/PMH_0 for stems with a volume of 0.2 m^3.

Keywords: coppice forests, processor, CTL, time study, chestnut, harvester

1. Introduction – *Uvod*

In Italy, coppice forests represent an important landscape element and a significant economic resource. 54.5% of the Italian forest area is classified as coppice forest. In the past, these stands were clear-cut at 15 to 30 year intervals, leaving between 50 and 90 standards per hectare, with the purpose of: a) allowing the progressive regeneration of the stool base, b) diversifying production and c) improving stand structure. Since regeneration is obtained through stool resprouting, these stands have a multiple stem structure. Despite a general trend towards conversion into high forests, the majority of these stands are still managed through coppicing. 21% of the Italian coppice forests are based on Mediterranean oaks, 18% on chestnut (*Castanea sativa* Mill.), 16% on oaks, 15% on beech (*Fagus sylvatica* L.), 19% on hornbeam (*Carpinus betulus* L.), 1% on riparian trees and 10% on other species (INFC 2005, FAO 2005). Chestnut coppice is widespread all over Italy, but is particularly common in the Regions of Piedmont, Tuscany, Latium, Campania and Calabria. Chestnut coppice is seldom converted into high forest, because coppice stands are much less vulnerable to chestnut blight (*Cryphonectria parasitica*) compared to chestnut high forests. Assortments obtained from chestnut coppice are: sawlogs, poles, fencing, firewood and woodchips. Trees from coppice generally have small size and a basal sweep, since they grow as multiple stems from the tree stump. Stem crowding and basal sweep make mechanical felling difficult, which has slowed down the introduction of modern machinery to coppice management. However, most forest companies have recognized the crucial role of mechanization to increase work productivity and safety, so that a growing number of harvesters and processor heads are being deployed also in coppice operations. Felling is done by chainsaw to guarantee that the stump is cut near the ground level and that no fibers are pulled out.

This research was conducted on four different processors, in order to evaluate the factors affecting the productivity of processing (delimbing – bucking) pre felled chestnut trees from coppice stands, at the landing. All trees were felled by chainsaw. Logging was done by tractor or by cable yarder, but extraction was outside the scope of this study. The research was conducted in cooperation between the Institute of Forest Utilization and Work Science of the University of Freiburg and CNR IVALSA.

2. Material and Methods – *Materijal i metode*

2.1 Study layout – *Prikaz istraživanja*

Many studies have already dealt with the productivity of harvesters, showing that the main parameters influencing productivity are stem volume or DBH (Diameter at Breast Height), tree species and harvesting intensity (Heinimann 2001). This study is specifically concerned with the processing (delimbing – bucking) of chestnut stems obtained from coppice stands. This work was generally conducted at the landing and therefore the main parameters expected to affect machine productivity are: stem volume, number of logs obtained from the stem, machine type. In addition, tree form was assumed to have a potentially significant effect on machine productivity, and was tested as a covariate in one of the studies composing the overall experiment.

2.2 Study sites and harvesting system *Radilišta i sustavi pridobivanja drva*

The authors studied four different harvesting machines processing pre felled chestnut trees from coppice at the landing in Northern (Piedmont) and Central (Tuscany and Emilia Romagna) Italy. The machines were: an Arbro 400S on a JCB 8052 excavator, a Foresteri RH 25 on a CAT 312 L excavator, a Lako 55 Premio on a JCB JS 180 NL excavator and a Timberjack 1270B dedicated harvester with John Deere 762C head. Even though one machine was a dedicated harvester, all machines were part of this study. Trees were processed at the landing so that all studied machines had little need for moving. Therefore, locomotion technology (tracks or wheels) was likely to have a very small impact on productivity levels. The Foresteri Study is described as two separate experiments: in the treatment »Foresteri 1« the machine was

Table 1 Site and study conditions
Tablica 1. *Mjesto i radni uvjeti*

Study *Istraživanje*	Foresteri 1	Foresteri 2	Lako	JohnDeere	Arbro
Area – *Područje*	Gaiole in Chianti (SI)	Abbadia S. Salvatore (SI)	Monzuno (BO)	Armeno (NO)	Signorino (PT)
Machine – *Stroj*	Excavator – *Bager* CAT 312 L (71 kW, 16 t)	Excavator – *Bager* CAT 312 L (71 kW, 16 t)	Excavator – *Bager* JCB JS 180 NL (92 kW, 19 t)	Harvester Timberjack 1270B (170 kW, 19 t)	Excavator – *Bager* JCB 8052 (34 kW, 5 t)
Head – *Glava*	Foresteri RH 25	Foresteri RH 25	Lako 55 Premio	John Deere 762C	Arbro 400S
Methods *Metoda*	Processing at cable yarder landing *Izradba na pomoćnom stovarištu žičare*	Processing at landing *Izradba na pomoćnom stovarištu*	Processing at landing *Izradba na pomoćnom stovarištu*	Processing at landing *Izradba na pomoćnom stovarištu*	Processing at landing *Izradba na pomoćnom stovarištu*
Species – *Vrsta*	Chestnut – *Kesten*	Chestnut – *Kesten*	Chestnut – *Kesten*	Chestnut with some birch *Kesten s brezom*	Chestnut – *Kesten*
Assortments *Sortimenti*	2.2 m long pulpwood; hornbeam and oak: 1,1 m long firewood *2,2 m celulozno drvo; grab i hrast: 1,1 m ogrjevno drvo*	2,5 m, 15–20 cm 2 m, 8–12 cm 3 m, 10–15 cm 5 m, 15–23 cm 5 m, 23–30 cm Pulpwood – *Celulozno drvo* Tops for chip production *Ovršine se iveraju*	Poles – *Stupovi* 3,5, 4,5 and 5,5 m (large end up to 20 cm, small end not smaller than 10 cm *promjer na debljem kraju <20 cm, a na tanjem >10 cm* Tops for chip production *Ovršine se iveraju*	Process Random lengths – *Izradba slučajnih duljina*	MDF pulpwood – *Drvo za ploče* Poles – *Stupovi* 3,5, 4,5 and 5,5 m (large end up to 20 cm, small end not smaller than 10 cm *promjer na debljem kraju <20 cm, a na tanjem >10 cm* Tops for chip production *Ovršine se iveraju*
DBH average $D_{1,30}$ *prosjek*	11.9 ± 4.1 cm	19.8 ± 5 cm	15.2 ± 4.4cm	14.0 ± 3.7 cm	17.8 ± 4.3 cm
DBH (min.–max.)	4–33 cm	12–33 cm	8–34 cm	5–29 cm	8–38 cm
Cycles – *Turnusi*	528	136	242	840	195
Obs. time *Snimljeno vrijeme*	9.1 h	2.1 h	9.4 h	13.7 h	5.8 h

working under a yarder, whereas in »Foresteri 2« it was tending to a skidder. Table 1 shows a synthetic description of study sites and machine characteristics.

2.3 Data collection – *Prikupljanje podataka*

Time-motion studies were carried out in order to evaluate machine productivity and to identify the variables that are most likely to affect it. Cycle times were split into a number of time elements considered as typical of the working process (Table 2). Time elements were recorded with a Husky Hunter hand held field computer running Siwork3 timestudy software.

For the purpose of the study, the harvested volume was measured directly after processing or it was calculated from the diameter at breast height (DBH), using volume tables. In the later case, between 10 and 20 tree heights and diameters were measured before processing the trees, in order to estimate a DBH-height curve. Using the calculated heights and measured DBH values, tree volumes could be estimated for each tree, using local volume tables. The DBH of each tree to be processed was marked on the stem or on the butt end, so that researchers could see and note it when recording time study data. In this study the productivity was estimated for the processed stem volume, excluding the volume eventually converted into chips (tops and branches). Waiting times were also excluded from calculations, because they originated from organizational causes and were not specifically related to the stems being processed or to the processing machines.

Data were pooled together for statistical analysis, after adding an indicator variable describing the specific test, namely: Foresteri 1, Foresteri 2, Lako, John Deere and Arbro. The use of indicator variables was introduced in order to test the statistical significance of categorical variables (here: machine type) in the regression analysis.

The effect of tree form was investigated only in one test (Arbro), by introducing an ordinal covariable with 5 different levels, namely: Level 1 – Small branches, straight stems; Level 2 – Big branches or bad form; Level 3 – Big branches and bad form, or very big branches; Level 4 – Very big branches and bad form, or fork and big branches; Level 5 – Forked several times, or many big and very big branches. This approach is widely accepted, and is recurrent in the scientific literature on this specific subject (Spinelli et al. 2002).

2.4 Statistical analysis – *Statistička analiza*

Analysis of variance was used to identify the influence of nominal variables on the model. Regression techniques were used to determine the relationship between productivity and work conditions. Statistical analysis was conducted with software package SPSS 18.0 for Windows. The analytical procedure developed as follows (as proposed by Stampfer et al. 2010): 1 – Determining the statistical significance of co-variables through the analysis of variance; 2 – Testing non-linear relationships of co-variables; 3 – Analysis of the interactions between factors and co-variables; 4 – Regression analysis; 5 – Test of the regression model (residual analysis).

3. Results – *Rezultati*

3.1 Model calculation – *Model kalkulacija*

Table 3 shows a first descriptive statistics of test results, whereas Table 4 presents the results of the regression analysis. Net productivity excluding delays can be modeled as follows:

Table 2 Time elements: definitions and breaking points
Tablica 2. *Radni zahvati: definicije i fiksažne točke*

Move *Premještanje*	Machine starts moving – machine stops *Stroj se kreće – stroj se zaustavlja*
Grab *Zahvatanje*	Machine turns into direction of tree – head arms close around the tree *Zauzimanje položaja – harvesterska se glava zatvara*
Process *Izradba*	Starts debranching and cross cutting – completes debranching and performs the last crosscut, severing the tree top *Početak kresanja grana i trupljenja – završetak kresanja grana i zadnjega trupljenja, odrezivanje ovršine*
Stack *Slaganje*	Moves the top to the top pile – top falls on the pile, head arms open *Premještanje ovršine na složaj – ovršina pada na složaj, harvesterska se glava otvara*
Product management *Uhrpavanje sortimenata*	Take assortments and moves them to the appropriate pile – assortments dropped on the pile, head arms open *Uhrpavanje sortimenata – sortiment pada na složaj, harvesterska se glava otvara*
Other *Ostalo*	Other working steps *Ostali radni zahvati*

$$PROD = 17.551 + 4.839\ln(vol) + 0.552LOGS + ((9.707 + 1.203\ln(vol) \times DF1) + ((20.022 + 6.432\ln(vol) \times DF2) + (10.123 \times DJD) \quad (1)$$

where:

$PROD$ net productivity, m^3/PMH_0
vol stem volume, m^3
$LOGS$ number of logs per tree, n
DF_1 Dummy variable Foresteri 1 (1 = yes, 0 = no)
DF_2 Dummy variable Foresteri 2 (1 = yes, 0 = no)
DJD Dummy variable John Deere (1=yes, 0 = no)

With an adjusted R^2 of 0.667, the equation shows a good fit. The p-value <0.001 demonstrates the high statistical significance of our model. A dummy variable for the Lako was not included into the model because the Arbro and the Lako had no significant differences in productivity. That means that the model can be used indifferently for Arbro and Lako, after setting all dummy variables to 0.

3.2 Machine productivity – *Proizvodnost*

Fig. 1 shows the relationship between net productivity and stem size, calculated with functions presented above. The Foresteri appeared as the best performer, outproducing even the dedicated harvester. However, one must keep in mind the very wide spread of the data recorded for the dedicated harvester, which leaves significant room for adjustment. The Lako on a JCB JS 180 NL and the Arbro on a JCB 8052 excavator had the same productivity, despite the very different size and mechanical characteristics. Operator effect was most likely to account for this odd result.

Table 3 Descriptive statistics
Tablica 3. *Deskriptivna statistika*

	Foresteri 1	Foresteri 2	Lako	John Deere	Arbro
	5% Quantile – Mean – 95% Quantile *5. percentile – aritmetička sredina – 95. percentil*				
Cycle time [100/min] *Vrijeme turnusa, cmin*	45-78-136	50-82-132	93-160-247	30-78-169	96-153-261
Productivity [m^3/PMH_0] *Proizvodnost, m^3/h*	1.8-7.7-17.4	8.6-19.8-34.4	0.9-5.4-10.3	8.3-16.8-34.6	4.1-9.2-14.9
Stem volume [m^3] *Obujam debla, m^3*	0.02-0.10-0.26	0.09-0.28-0.60	0.03-0.13-0.30	0.11-0.22-0.39	0.08-0.23-0.44
Logs [n/tree] *Broj trupaca, n/stablu*	3.0-7.1-14,7	1.7-3.3-5.0	1.0-2.0-3,0	1.0-2.2-4.0	1.0-2.8-4.0
	Mean – Aritmetička sredina				
Trees/PMH_0[n] *Broj stabala, n/h*	83.9	72.8	41.8	77	39
Logs/PMH_0[n] *Broj trupaca, n/efek. satu*	517	241	83	168	110

Table 4 Statistical significance of model variables
Tablica 4. *Statistički značaj odabranih varijabli*

Model *Model*	Non standardized coefficient *Nestandardni koeficijenti*		Standardized coefficient *Standardni koeficijenti*	t-value *t-vrijednost*	Significance *Značajnost*
	Coefficient *Koeficijent*	Std. error *Standardna pogreška*	Beta		
Constant – *Konstanta*	17.551	0.586		29.926	<0.001
ln(stem volume)	4.839	0.250	0.459	19.386	<0.001
Logs – *Trupci*	–0.552	0.055	–0.210	–9.995	<0.001
Dummy Foresteri 1	9.707	0.998	0.524	9.727	<0.001
Dummy Foresteri 2	20.022	1.191	0.613	16.813	<0.001
Dummy John Deere	10.123	0.305	0.602	33.184	<0.001
Dummy Foresteri 1 × ln(stem volume)	1.203	0.356	0.183	3.374	<0.001
Dummy Foresteri 2 × ln(stem volume)	6.432	0.720	0.312	8.933	<0.001

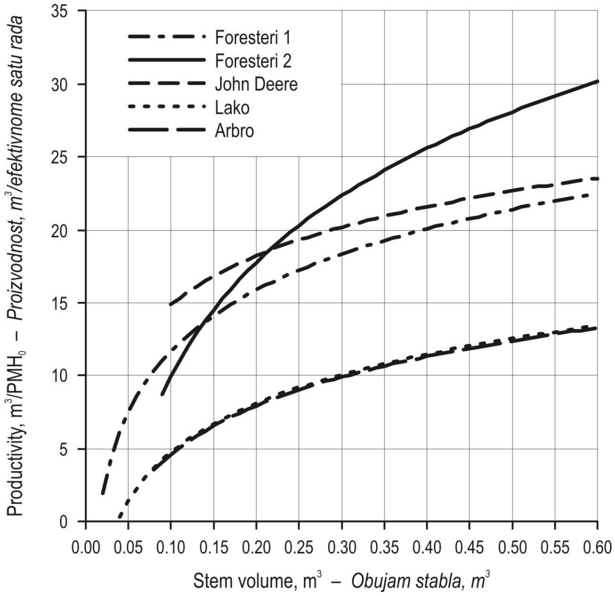

Fig. 1 Net productivity as a function of stem volume, for the different tests
Slika 1. *Neto proizvodnost u ovisnosti o obujmu debla za različite studije*

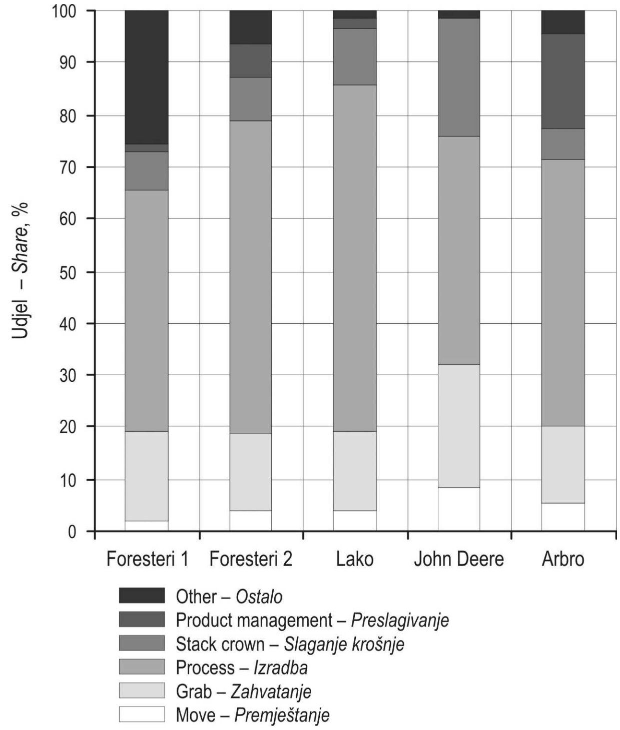

Fig. 2 Breakdown of net cycle time
Slika 2. *Raščlamba vremena turnusa*

3.3 Breakdown of Cycle times – *Raščlamba vremena turnusa*

In all five studies, »moving« time had a very low incidence over total cycle time, accounting for a proportion of 2.2% (Foresteri 1) to 8.5% (John Deere). The time for »grabbing« trees represented between 15% and 24% of the total net work time. In terms of absolute time, »grabbing« took between 12 and 23 100/min per cycle, with the Arbro and the Lako needing the longest time (23 100/min). »Processing« time represented the largest proportion of cycle time, in all studies, its percent contribution increased with tree DBH. In absolute terms, the average duration of processing time per tree was: Foresteri 1: 40 100/min. (with a average DBH of 11.9 cm), Foresteri 2: 49 100/min. (avg. DBH 19.8 cm), Lako: 96 100/min. (avg. DBH 15.2, John Deere: 34 100/min (avg. DBH 14 cm, Arbro 78 100/min. (avg. DBH 17.8 cm). »Stacking« tops after processing took between 6 and 11% of the total cycle time with the Foresteri, Lako and Arbro machines, but grew up to 23% with the John Deere dedicated harvester (18 100/min). The Lako also needed 15 100/min per cycle in order to stack tops after processing. »Product management« included moving processed assortments to different stacks and cleaning the work place. The contribution of this work step to the total cycle time was the highest with the Arbro, where it amounted to 18% (28 100/min. absolute time per cycle). In that case, the operator often grabbed the stems multiple times to »organize« the woodpile. The incidence of »other« time was the highest with Foresteri 1, because the processor worked by the cable yarder and performed additional ancillary tasks, such as moving the stems away from the yarder chute and to the work area.

3.4 Delays and daily work production – *Prekidi i dnevni učinak*

Delay events lasting no more than 15 minutes accounted for 10% to 20% of the total study time. The incidence of delays increased to 14 to 19%, if all events were included, regardless of their duration (Fig. 3).

The daily work production is calculated by the equation (2):

$$PROD_{\text{day}} = \frac{vol_{total}}{(t_{total} \times 1.44) \times 8} \qquad (2)$$

where:

$PROD_{\text{day}}$ daily production (8 hour working day), m^3
vol_{total} total processed volume, m^3
t_{total} total productive working time, PMH_0

In this equation 31% delay time (multiplication factor 1.44) is included as the result of a meta analysis of delay times for processing (Spinelli and Visser 2008). The daily work production derive 42.9 m^3/day for the Foresteri 1, 109.8 m^3/day for the Foresteri 2, 93.1 m^3/day for the John Deere, 30.0 m^3/day for the Lako and 51.1 m^3/day for the Arbro.

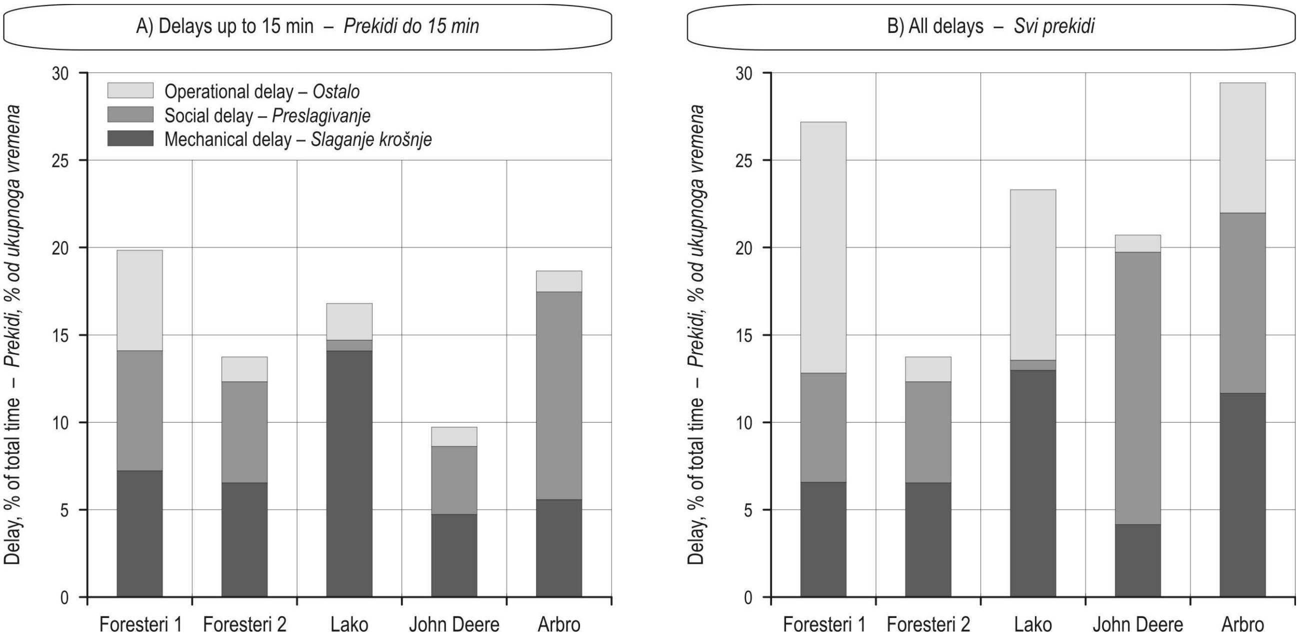

Fig. 3 Incidence of delay time on total study time
Slika 3. *Učestalost prekida u snimljenom vremenu*

3.5 Effect of tree form on machine productivity *Utjecaj oblika stabla na učinak stroja*

The effect of tree form on productivity was estimated by correlation test for the Arbro study only, and it was taken as a general example. The five form factors described above showed a significant effect on productivity (confirmed by the Kendal-Tau and Spearman-Rho tests at the 0.01 level). Form factor was also used as an independent variable in multiple regression analysis, which returned an adjusted $R^2 = 0.775$. The equation is represented in Fig. 4 and reads as follows:

$$PROD_{\text{Arbro}} = 22.47 + 6.25 \times \ln(vol) - 0.864 \times LOGS - 0.573 \times f \qquad (3)$$

where:

$PROD_{\text{Arbro}}$ Net productivity, m^3/PMH_0
vol stem volume, m^3
LOGS number of logs per tree, n
f tree form

An ANOVA shows that 68.1% of the scattering can be explained by the variable stem volume, while the tree form explains 2.4% of the total variability and the number of logs 5%.

3.6 Costs – *Troškovi*

The calculated unit costs per m^3 ranged from 5.05 €/m^3 (for Foresteri 2) to 18.50 €/m^3 (for Lako). Detailed results and machine costs are shown in Table 5. Very low cost was recorded especially for highly productive machines (Foresteri and John Deere) and cheap machines (Arbro). Hence, both strategies seem to give good results: the choice between them may depend on the annual work output.

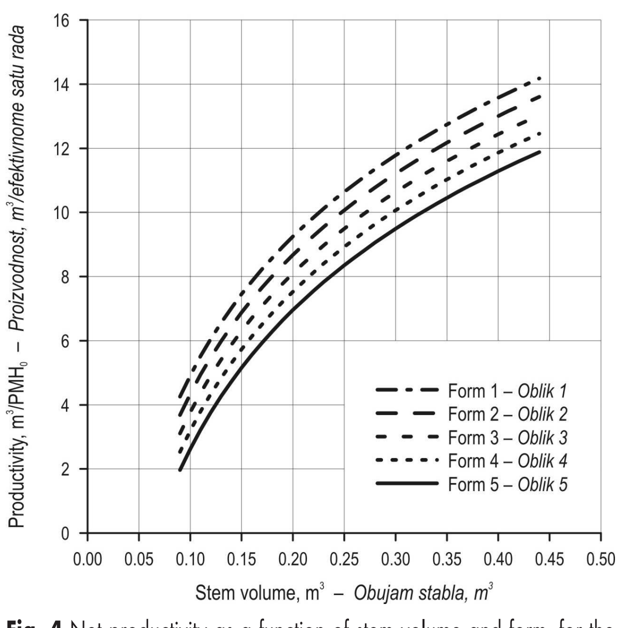

Fig. 4 Net productivity as a function of stem volume and form, for the Arbro study
Slika 4. *Ovisnost neto proizvodnosti o obujmu i obliku debla za studiju Arbro*

Table 5 Machine and unit costs
Tablica 5. *Troškovi stroja i jedinični trošak*

Machine *Stroj*	Machine costs, €/h *Troškovi stroja, €/h*	Unit costs, €/m^3* *Jedinični trošak, €/m^3*
Foresteri 1	100	12.90
Foresteri 2	100	5.05
Lako	100	18.51
John Deere	130	7.74
Arbro	70	7.60

* unit costs calculated on the basis of productivity per PMH0
** jedinični trošak izračunat je na osnovi učinka po efektivnom satu rada*

4. Discussion and Conclusions *Rasprava i zaključci*

The excavator-base Foresteri deployed at a yarder landing (Foresteri 1) processed chestnut trees with an average diameter at breast height (DBH) of 11.9 cm. Net productivity averaged 7.7 m^3 and 89 trees per productive machine hour (PMH$_0$), excluding delays. In most cases (457 cycles) the operator processed one tree at a time. In some other cases he processed 2 (61 cycles), 3 (27 cycles) or 4 (1 cycle) trees at a time. The calculation of different productivity functions for total processed tree volume by cycles could not reveal a difference in total productivity when processing more than one tree at a time. However, the productivity was higher when processing several small trees at a time, compared to processing them one by one. When teaming with a skidder (Foresteri 2), the same machine reached a net productivity of 19.8 m^3 or 70 trees per productive machine hour. Productivity was higher than in the previous study, because trees were substantially larger, with an average DBH of 19.8 cm. Trees form was also better in the second study. Finally, the first study was conducted at a cable yarder landing, where the machine had to move with much care in order to avoid damage to the tower, the guy lines and other surrounding people and equipment.

The productivity of the John Deere harvester was 16.8 m^3 or 77 trees/PMH$_0$. A single calculated correlation between stem volume and productivity was weak, due to a number of factors, and especially to the important and confounding effect of assortment type, which was not included in the regression. Nevertheless, the significance of this function is very high, due to the very large number of observations used to calculate it.

The Lako harvester processed trees with an average DBH of 15.2 cm. The average tree volume was 0.13 m^3. The productivity of this unit was 5.4 m^3 or 41 trees per productive machine hour.

The Arbro 400S was the only stroke harvester in the study: as such, it fed stems through the delimbing knives using an alternating slide boom, rather than rollers, like the other units observed. The average net productivity was 9.2 m^3 and 39 trees/PMH$_0$. The range of tree DBH varied between 8 and 38 cm, with an average of 17.8 cm.

The study showed that a full range of mechanical processors can be successfully deployed for handling whole chestnut trees, obtained from coppice harvesting. The processors reached high productivity and incurred low costs. Therefore, CTL technology offers a good alternative to motor-manual work in chestnut coppice stands to process trees at the landing (Spinelli et al. 2009). Working at the landing and using piles allowed the incidence of moving time, and increasing the proportion of the actual processing (delimbing-bucking) time. Furthermore, all machines worked in coppice clearcuts (the most common silvicultural treatment in coppice stands), with the advantage of a concentrated volume removal.

On the other hand, coppice harvesting presents all the disadvantages related to small tree harvesting. Stem quality is another significant factor affecting productivity, as shown in the Arbro study.

It should be particularly noted that different product strategies were followed in different studies, and that a more accurate comparison of machine productivity between tests could only be made if all machines were used to produce the same assortment range. The effect of assortment type on harvester productivity has already been shown by other studies, reporting productivity differences between 12 and 34% as a result of different product strategies (Emeryat et al. 1996 and 1997, Martin et al. 1996, Sauter and Grammel 1996, Spinelli and Spinelli 2000). Furthermore, productivity differences could partly derive from different operator skills. The 5 machines used for the study were operated by 5 different professionals, each representing a potential source of unaccounted variability (Gellerstedt 2002, Purfürst 2009). The operator effect has already been shown to affect machine productivity up to 40% (Ovaskainen et al. 2004). Therefore, the results of these studies must be interpreted with caution, avoiding definite conclusions.

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Sažetak

Proizvodnost strojne izradbe tvrdih listača iz panjača

U Italiji su otprilike polovica šuma šume panjače čija je osnovna namjena proizvodnja ogrjevnoga drva. Za razliku od ostalih, panjače pitomoga kestena (Castanea sativa *Mill.) služe za proizvodnju vrednijih sortimenata kao što su pilanski trupci, stupovi, kolje za ograde, ogrjevno drvo i drvno iverje. Stoga je proizvodna aktivnost puno veća u kestenovim panjačama te se uvode strojne metode pridobivanja drva.*

Cilj je ovoga istraživanja odrediti proizvodnost četiriju različitih strojeva prilikom izradbe drva na pomoćnom stovarištu. Istraživane su četiri harvesterske glave Arbro 400S na bageru JCB 8052, Foresteri RH 25 na bageru CAT 312L, a Lako 55 Premio na bageru JCB JS 180NL i harvester Timberjack 1270B s harvesterskom glavom John Deere 762C. Istraživanje je provedeno na pet različitih radilišta (tablica 1), a bavi se isključivo samo izradbom drva (kresanje grana i trupljenje). Svi su se radovi izvodili na pomoćnom stovarištu, a glavni čimbenici koji utječu na proizvodnost bili su: obujam stabla, broj sortimenata dobivenih iz stabla, vrsta stroja. Dodatno je istraživan utjecaj oblika stabla (debla) na proizvodnost stroja. Za izračunavanje učinka uziman je samo obujam izrađene oblovine.

Pri istraživanju je proveden studij rada i vremena u kojem su radni zahvati podijeljeni prema tablici 2. Obujam je izrađenih sortimenata mjeren odmah nakon izradbe ili je bio računat preko prsnoga promjera iz lokalnih obujamnih tablica koje su napravljene samo za ovo istraživanje.

Nakon prikupljanja podataka napravljena je statistička analiza kako je preporučuju Stampfer i dr. (2010) te je svakomu stroju dodijeljena opisna varijabla: Foresteri 1, Foresteri 2, Lako, Arbro, John Deer. Rezultati su statističke analize prikazani u tablicama 3 i 4. Tablica 3 prikazuje rezultate deskriptivne statistike, dok tablica 4 prikazuje rezultate regresijske analize te statistički značaj odabarnih varijabli.

Učinak je strojeva prikazan na slici 1, na kojoj je vidljiva ovisnost učinaka o obujmu stabla. Najveći je učinak imao Foresteri 2, 109,8 m^3/dan, koji je imao veći učinak čak i od jednozahvatnoga harvestera (93,1 m^3/dan). No, mora se imati na umu velik raspon snimljenih podataka za harvester, što ostavlja mogućnost za daljnju obradu. Iako su priključene na različite bagere, harvesterske glave Lako i Arbro imale su istu proizvodnost. Usporedno s izradom studija rada i vremena procjenjivan je utjecaj oblika debla na učinak izradbe drva (slika 4), koja je obuhvaćena samo u studiji Arbro. Oblik je debla korišten kao nezavisna verijabla, s vrijednostima od 1 do 5 (1 – male grane i ravno deblo; 2 – debele grane ili loš oblik debla; 3 – debele grane i loš oblik debla ili vrlo debele grane; 4 – vrlo debele grane i loš oblik debla ili debele grane i rašljavo deblo; 5 – više rašlji na deblu).

Raščlamba vremena turnusa za pojedine studije prikazana je na slici 2, gdje su radni zahvati podijeljeni kako je opisano u tablici 2. Značajno je da je studija za Foresteri 1 imala najveći udjel »ostalih radnih zahvata« zato što se radilo o pomoćnom stovarištu žičare te je stroj uz osnovne zadatke morao obavljati i pomoćne zadatke (othrpavanje istovarne rampe žičare). Raspon jediničnih troškova strojne izrade debala kretao se od 5,05 €/m^3 do 18,51 €/m^3 (tablica 5).

Provedeno je istraživanje dokazalo da se u kestenovim panjačama uspješno mogu primijeniti mehanizirane metode izradbe drvnih sortimenata, koje osiguravaju visoku proizvodnost uz niske troškove rada. Stoga su mehanizirane metode zadovoljavajuća alternativa ručno-strojnomu radu.

No, čitatelji moraju uzeti u obzir izradbu različitih proizvoda koji su se izrađivali u istraživanim studijama, što je već dokazano u prijašnjim istraživanjima (Emeryat i dr. 1996, 1997, Martin i dr. 1996, Sauter i Grammel 1996, Spinelli i Spinelli 2000), te isto tako moraju uzeti u obzir kvalitetu stabala koja utječe na proizvodnost, što je dokazano u studiji Arbro. Nadalje, na razlike u proizvodnosti može utjecati vještina operatera (Gellerstedt 2002, Purfürst 2009) jer je svakim od istraživanih strojeva upravljao drugi operater. Iz navedenoga izlazi da se rezultati ove studije moraju tumačiti s oprezom kako bi se izbjegli kategorički zaključci.

Ključne riječi: panjače, procesor, sortimentna metoda, studij vremena, kesten, harvester

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