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COST-EFFECTIVENESS ANALYSIS OF HARVESTER JOHN DEERE 1470D ECO III IN POPLAR (*POPULUS × CANADENSIS*) PLANTATIONS – CASE STUDY

ANALIZA ISPLATIVOSTI HARVESTERA JOHN DEERE 1470D ECO III U NASADIMA TOPOLA (*POPULUS × CANADENSIS*) – STUDIJA SLUČAJA

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SUMMARY

In the last few years, harvesters have been increasingly used in stands of deciduous tree species. The use of harvesters in Serbia began in 2008 with John Deere 1470D Eco III and it was used for felling trees and production of wood assortments in poplar plantations in the lowland area. The aim of this paper is to determine maximum profit by engaging a harvester in the given conditions, as well as to determine the total costs of the asset. Harvester achieved a total of 18,392 machine hours (MH), with an average of 1,415 hours per year. The average fuel consumption during the entire period was 16.3 l/h, or 0.76 l/m^3. The highest cost of spare parts was in the 6th year (around 66,000 euros) and in the 12th year (around 82,000 euros). The total cost of spare parts and services was 656,878 euros. Based on the planning that the number of work days per year is 200, an amortization period of 7 years is obtained (the point of intersection of current and average profit growth). Results of this research indicate that harvesters older than 7 years should be replaced with new machines, due to high maintenance costs. However, these are only initial researches, which will be continued with data on several harvesters that have been procured in the meantime.

KEY WORDS: harvester, poplar plantations, costs, productivity, amortization

INTRODUCTION
UVOD

The use of harvesters for felling trees and production of wood assortments has especially intensified in the last 20 years, throughout Europe. For example, in Finland, mechanized felling accounted for 98% of total felling of 50.8 million m^3 in 2006 (Finnish Forest Research Institute, 2006), in Germany about 50% (Hartsch et al. 2021), and is constantly increasing, as application of harvester contributes to profit (Kováč et al. 2013).

Compared to chainsaws, which are the forerunners of mechanized felling of trees and production of wood assortments, harvesters are characterized by a large initial investment, but also incomparably higher maintenance costs. On the other hand, the efficiency of harvesters can hardly be compared to the efficiency of chainsaws. In addition, the ergonomic characteristics of the harvester are such

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that there are almost no negative effects on the operator. Mechanized logging also has distinct advantages in terms of simplified logistics, increased safety at work (Bell 2002) and environmental protection (Abbas et al. 2018; Marchi et al. 2018).

Disadvantages of harvesters are monotony in work, which can lead to decreased concentration, while the complexity of some tasks can cause mental fatigue and psychological stress (Szewczyk et al. 2021). Additionaly, damage to the assortments can be caused by rollers on the harvester head (Karaszewski et al. 2016).

Although the original purpose of the harvester was to cut trees and produce wood assortments in coniferous stands, harvesters are also widely used in broadleavef stands. Slugen et al. 2014 investigated the effect of harvester in beech and oak stands. They came to the result that the productivity of harvester in beech stand, for an average tree volume of 0.22 m^3 is 4.98 m^3/h, and 5.35 m^3/h in oak stand for an average tree volume of 0.18 m^3. Research results by Pandur et al. 2018 indicate a high EROI of mechanized thinning in broadleaf stands. Although highly mechanized harvesting machines were used, that in relation to mechanization used in semi-mechanized harvesting system have much higher fuel consumption per PMH and generally require higher energy input in the system, their high productivity offsets the energy balance towards quite positive levels. Danilović 2011 investigated the harvester engaged by "Vojvodinašume" Public Company in 2008 and proved it to be an effective mean of work in poplar plantations.

The typical obstacles for harvester in broadleaf stands are mainly large tree sizes, bends and forks in the trunks and large branches. For these reasons, it is difficult to obtain specific log lengths according to the settings in the harvester on-board computer (Mederski et al. 2018). The problems that may occur in the research area are flooding, high demand for wood and a relatively short cutting period. Since the purchase of the harvester in 2008, the harvester has cut cca 1/3 to 1/2 of the annual allowable cut, with a minimum in the first year (13%) and a maximum in the eight year (cca 80% of the annual allowable cut of poplar). Therefore, every day when the machine does not work represents a double loss - the cost of the eventual malfunction and the monetary loss due to the machine inoperability. In the case study of Ghaffariyan 2015 the average utilisation rate for a harvester-processor was 77.3% while for the forwarder the utilisation averaged at 81.1%. The long-term machine utilization rates can be applied by the operation management to control the current level of machine utilization and to calculate the machine hourly cost accurately to obtain unit har- vesting costs. To verify the real impact of operational factors on the long-term machine performance, more detailed machine utilization case studies combined with machine productivity records will be required. Also, according to Kováč et al. 2013, the reliability of the machine decreases over time.

The aim of this paper is to determine maximum profit based on available data by engaging a harvester in the given conditions. The goal of this paper is to determine the maintenance costs and the total operating costs of the harvester in a poplar plantation.

MATERIAL, METHOD AND OBJECT OF RESEARCH
MATERIJAL, METODE I OBJEKAT ISTRAŽIVANJA

This study analysed the operation of the John Deere 1470D Eco III harvester from the time of purchase (2008) to the end of its use (2020 - 13 years in total). This harvester was engaged in poplar plantations within the area of "Vojvodinašume" Public Company (Table 1).

Harvester worked the whole time in 25-30 years old poplar plantations, performing clear-cuts, where the average diameter-at-breast-height was cca 50 cm. Considering that the harvester worked on the territory of the entire autonomous province of Vojvodina, the average tree volume per area was in a relatively large interval of 200-600 m^3/ha.

Data on the productivity as well as fuel and oil consumption were obtained from the department of Forest Utilization within the "Vojvodinašume" Public Company. Data on productivity were collected from daily work accounts. Fuel

Table 1. Harvester John Deere 1470D Eco III specifications
Tablica 1. Specifikacije harvestera John Deere 1470D Eco III

Operating weight / *Radna masa*		19,700 kg
Crane manufacturer / *Proizvođač hidraulične dizalice*		John Deere
Crane type / *Tip hidraulične dizalice*		210 H
Harvester head / *Harvesterska glava*	**Manufacturer / *Proizvođač***	John Deere
	Type / *Tip*	758 HD
	Max. cut diameter / *Maks. promjer rezanja*	72 cm
Engine / *Motor*		John Deere 6090HTJ
Number of cylinders / *Broj cilindara*		6
Engine power / *Snaga motora*		180 kW
Max. torque / *Maks. zakretni moment*		1250 Nm / 1400 rpm
Fuel tank capacity / *Kapacitet rezervoara za gorivo*		480 l
Speed / *Brzina*		0-22 km/h
Number of wheels / *Broj kotača*		6
Max. Reach horizontal / *Maks. horizontalni doseg*		8,6-11,0 m
Transport length / *Transportna duljina*		11.85 m
Transport width / *Transportna širina*		3 m
Transport height / *Transportna visina*		3.95 m

and oil consumption were gathered on the basis of signed dispatch notes on filling up energy sources at petrol stations. Harvester repair and maintenance costs were collected.

The data were systematized in tables in Microsoft Excel software program and as such were used for further analysis.

RESULTS
REZULTATI

The number of hours during which the harvester worked ranged from a minimum of 530 MH/year in the eleventh year to a maximum of 2,166 MH/year in the eighth year (Figure 1). In the eighth year, the harvester cut about 80% of the total poplar annual allowable cut of the entire forest holding. After the maximum was reached, that number was declining in the last year of use (13th year), when 911 hours of work were realized. Harvester achieved a total of 18,392 machine hours, with an average of 1,415 hours per year.

Productivity achieved by the harvester during the years is shown in Figure 2. The maximum productivity was achieved in the eighth year (almost 55,000 m^3/year), after which it was declining. The minimum productivity was achieved in the first and last year of harvester engagement (about 10,000 m^3/year), while the average annual productivity was 30,370 m^3/year. The total wood volume cut by the harvester for 13 years of use is slightly less than 395,000 m^3. After this period, the harvester was removed from company inventory.

The linear dependence of the annual productivity on the number of realized machine hours per year is presented by

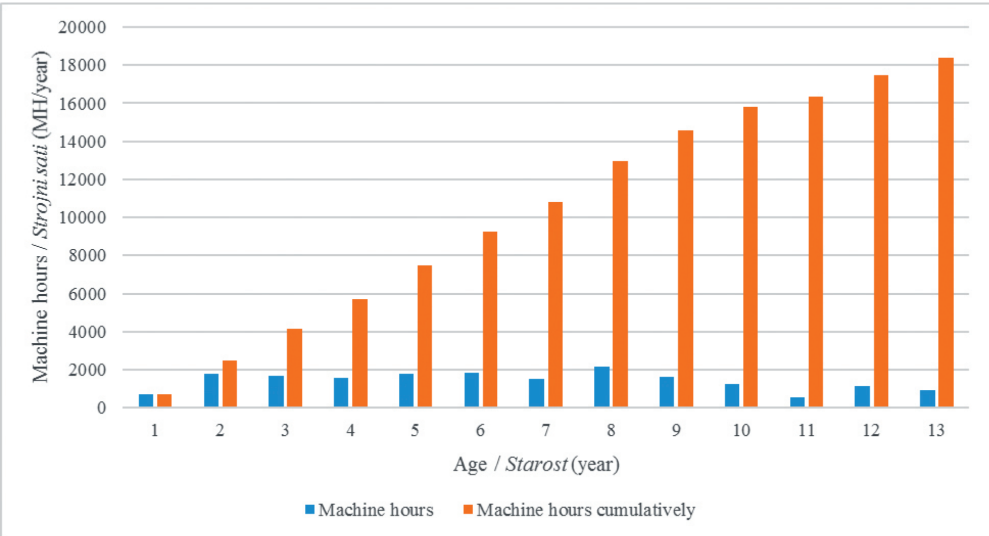

Figure 1. Machine hours of harvester during the years
Slika 1. Strojni sati harvestera tijekom godina

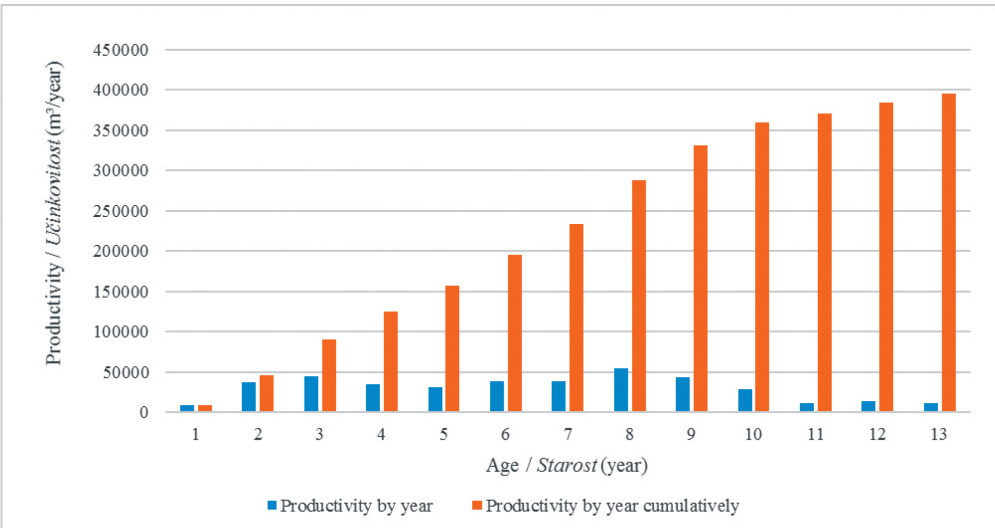

Figure 2. Productivity of harvester during the years
Slika 2. Produktivnost harvestera tijekom godina

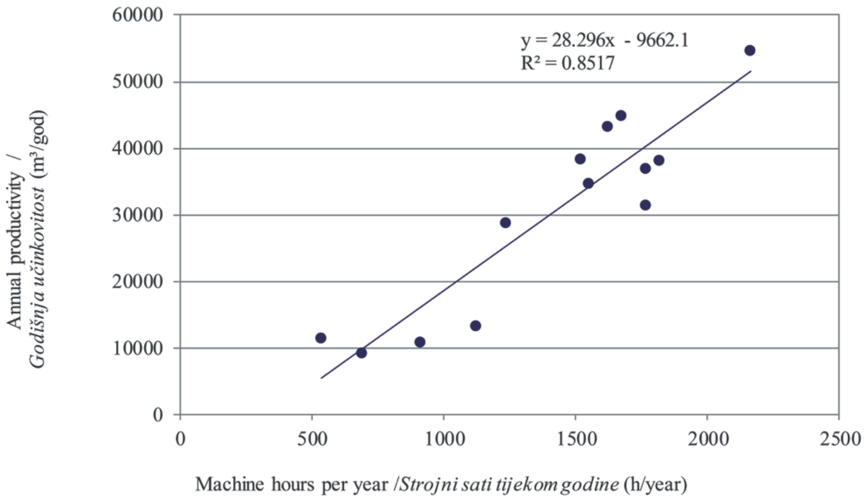

Figure 3. Dependence of annual productivity on number of realized machine hours per year
Slika 3. Ovisnost godišnje produktivnosti o broju strojnih sati ostvarenih tijekom godine

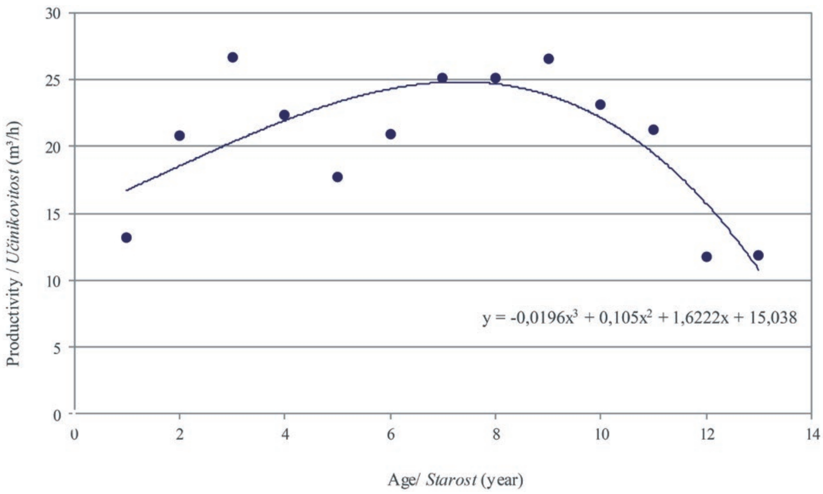

Figure 4. Dependence of productivity per hour on harvester age
Slika 4. Ovisnost produktivnosti po satu o starosti harvestera

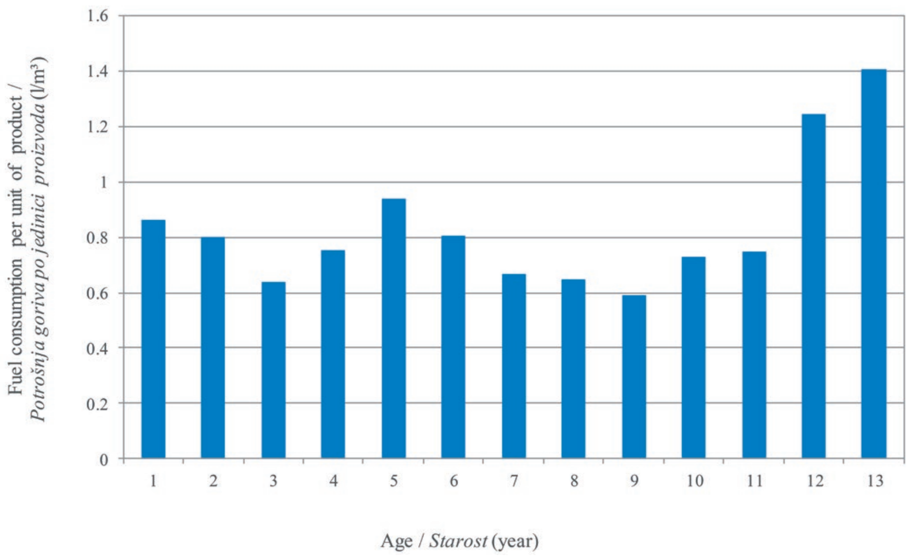

Figure 5. Dependence of fuel consumption per unit of product (l/m³) on harvester age
Slika 5: Ovisnost potrošnje goriva po jedinici proizvoda (l/m³) o starosti harvestera

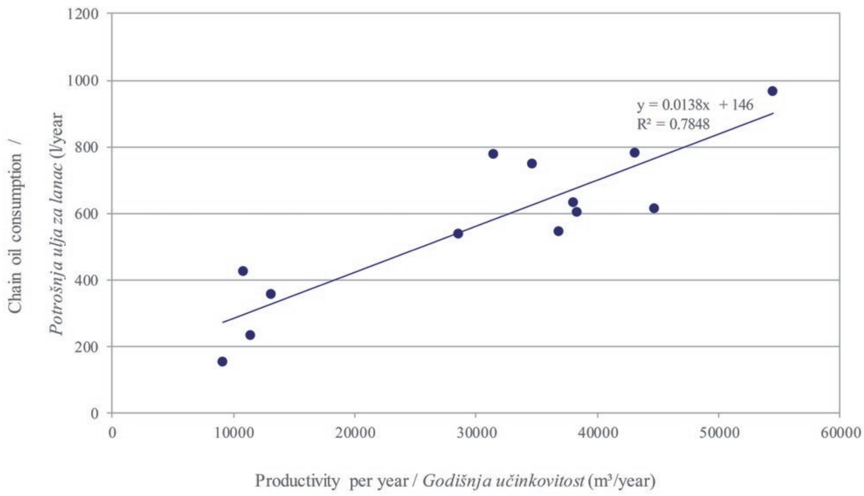

Figure 6. Dependece of chain oil consupmtion on productivity
Slika 6: Ovisnost potrošnje ulja za lanac o produktivnosti

the function y = 28.296x - 9662.1, where y is the achieved productivity, and x is the number of harvester machine hours per year.

The dependence of productivity per hour on harvester age is shown in Figure 4. This function shows that by the age of 7 the productivity was increasing, after which its productivity stagnated in the next year and then decreasing after the 8th year, reaching its minimum at the age of 13.

Fuel consumption per unit of product is shown in Figure 5. The obtained results show that fuel consumption was decreasing in the first three years, then increasing until the 5th year of harvester's age, after which it begins to decline, and then increased significantly after the age of 11.

Average fuel consumption during the entire period of use was 16.3 l/h, or 0.76 l/m³.

Harvester chain oil consumption as function of productivity is shown in Figure 6. Chain oil consumption increased linearly with increasing annual productivity, which is shown by the linear function y = 0.0138x + 146, where y is chain oil consumption and x is the harvester annual productivity.

Similar to fuel consumption per unit of product, chain oil consumption was dercreasing in the first three years, then increased in the fourth and fifth year, and decreased again in the sixth year and thereafter was slowly increasing until the age of 12. There was also a significant increase of chain oil consumption in the 13th year of harvester's age (Figure 7).

The maintenance costs of the harvester by year and cumulatively are shown in Figure 8. The highest cost of spare parts were in the 6th year (around 66,000 euros) and in the

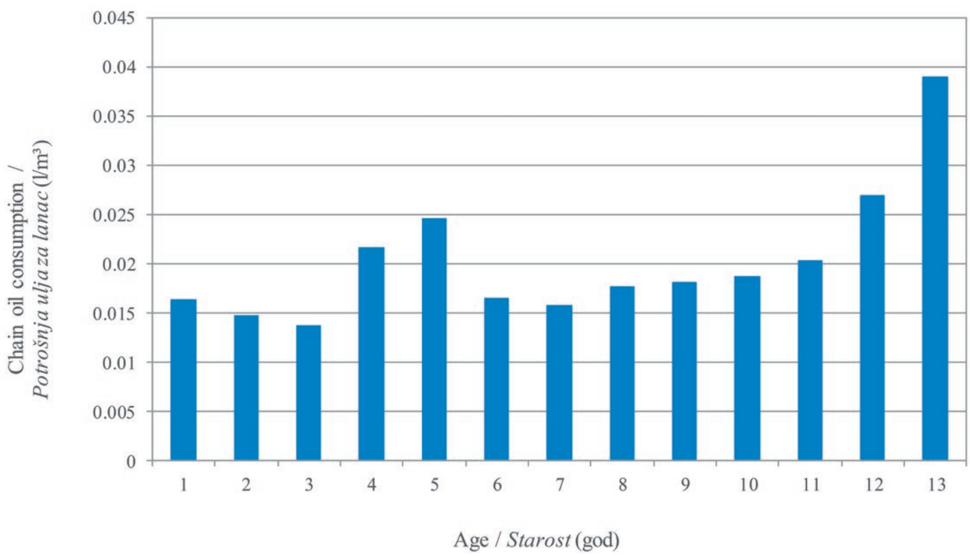

Figure 7. Dependence of chain oil consumption on harvester age
Slika 7. Ovisnost potrošnje ulja za lanac o starosti harvestera

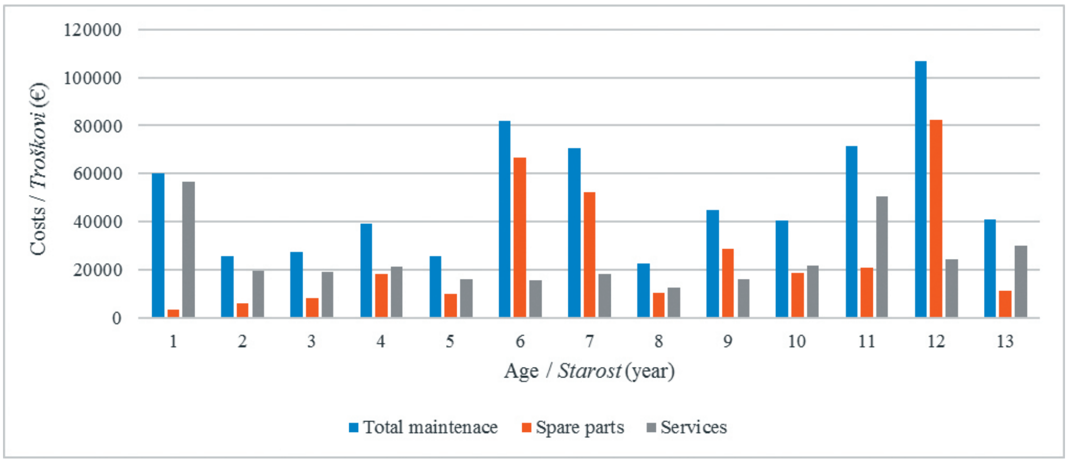

Figure 8. Maintenance costs of harvester during engagement
Slika 8. Troškovi održavanja harvestera tijekom rada

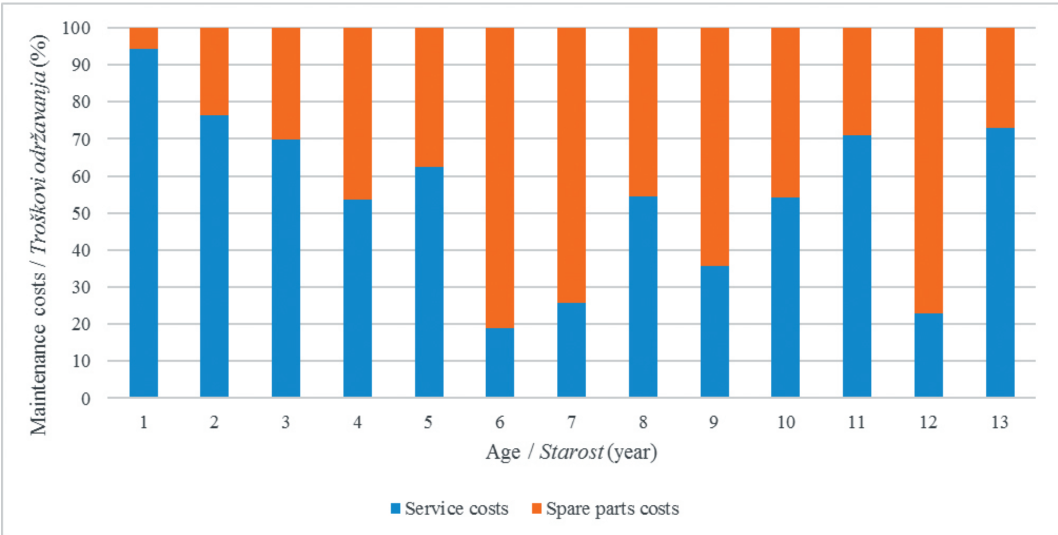

Figure 9. The share of service and spare part costs in total maintenance costs
Slika 9. Udio troškova servisa i rezervnih dijelova u ukupnim troškovima održavanja

12th year of harvester's age (around 82,000 euros). The total cost of spare parts during 13 years, as long as the harvester was engaged, was 656,878 euros.

The share of service and spare part costs in total maintenance costs was changing during the years (Figure 9). Service costs mainly prevailed in the total maintenance costs,

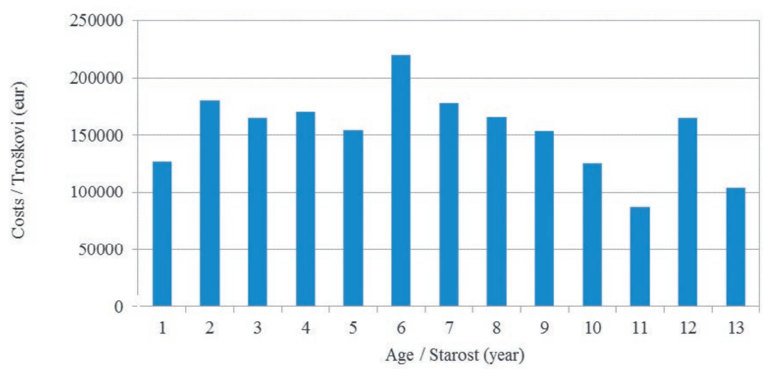

Figure 10. Annual costs of harvester engagement
Slika 10. Godišnji troškovi harvestera tijekom godina

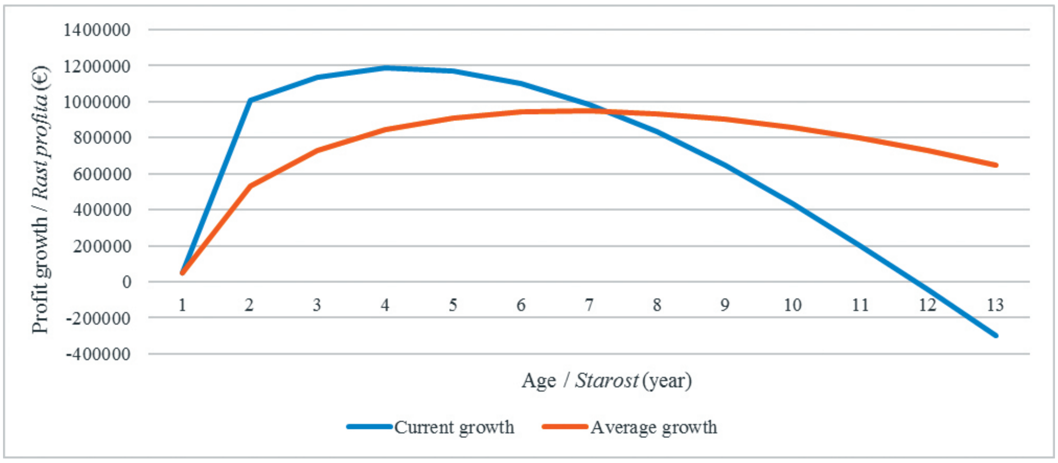

Figure 11. Profit growth
Slika 11. Rast dobiti

especially in the first years (up to the age of 6). However, in the 6th and 12th year, in addition to the costs of regular maintenance, there were also complementary spare part costs (replacement of the harvester head due to damage caused by delimbing). Average cost of the harvester repair was 17.2 € per machine hour.

The total annual costs of harvester ranged from a minimum of about 87,000 €/year, to maximum of about 220,000 €/year. An average annual cost was about 153,000 €/year (Figure 10).

The total costs, observed cumulatively for 13 years of harvester engagement, amounted to about 2,000,000 euros.

The increase in profit, if all wood volume was cut down by the harvester is shown in Figure 11. It can be observed that the current growth of profit had its maximum in the 4th year followed by a decline and in the 7th year it intersected average growth line. These values were obtained by replacing the amortization expense for the part of the elapsed period with the total value of the amortization. This way the total expenditures for different lifespans were simulated. Revenue was obtained on the basis of performance and an average price of 41.5 €/m^3. The value of profit is the difference between income and expenses, which is discounted at a discount rate of 4%.

Based on the above assumptions, and the number of 200 working days per year, an amortization period of 7 years was obtained (the point of intersection of current and average profit growth). According to the data on the number of realized machine hours, at the end of the 7th year of the harvester engagement, slightly less than 11,000 machine hours were realized (calculated value of machine life was 12,800 machine hours).

Table 2. Indicators of cost-effectiveness of engaging harvester in poplar plantations
Tablica 2. Pokazatelji isplativosti angažiranja kombajna u nasadima topola

Harvester age / *Starost harvestera* (year)	Total cumulative expenditure / *Ukupni troškovi kumulativno* (€)	Total cumulative income / *Ukupni prihodi kumulativno* (€)	Total cumulative profit / *Ukupna dobit kumulativno* (€)	Discounted profit / *Diskontirana dobit* (€)	Current growth of discounted profit / *Tekući rast diskontovane dobiti* (€)	Average growth in discounted profit / *Prosječni rast diskontirane dobiti* (€)
1	174,543	1,111,931	937,389	899,893	899,893	899,893
2	346,012	2,343,375	1,997,363	1,840,770	940,877	920,385
3	514,408	3,692,654	3,178,246	2,811,909	971,139	937,303
4	679,730	5,150,283	4,470,553	3,797,049	985,139	949,262
5	841,979	6,698,967	5,856,987	4,775,628	978,579	955,126
6	1,001,155	8,313,602	7,312,447	5,723,875	948,247	953,979
7	1,157,258	9,961,278	8,804,020	6,615,759	891,884	945,108
8	1,310,287	11,601,273	10,290,986	7,423,810	808,051	927,976
9	1,460,242	13,185,058	11,724,816	8,119,833	696,023	902,204
10	1,607,125	14,656,296	13,049,171	8,675,515	555,682	867,551
11	1,750,934	15,950,840	14,199,907	9,062,939	387,424	823,904
12	1,891,670	16,996,736	15,105,066	9,255,022	192,083	771,252
13	2,029,332	17,714,219	15,684,887	9,225,872	-29,149	709,682

Table 2 shows the cost-effectiveness indicators of harvesting in poplar plantations (revenues, expenditures and profits). At the end of the usage period, the discounted profit was 9,225,872 €. However, as can be noticed from the table, the average profit growth reached its maximum (945,108 €), and then declined. That information could tell us that after the age of 7, we should sell the harvester and buy a new one. However, since this is only a case study and the research will be continued.

DISCUSSION
RASPRAVA

The total wood volume cut by the harvester during 13 years of engagement is slightly less than 400,000 m^3. The productivity of the harvester was directly related to the number of realized machine hours (R^2 = 0.997).

In the 13 years harvester achieved about 18,000 machine hours. The recommended number of machine hours in manufacturer's brochure was 12,800, so the harvester realized about 50% more machine hours. In this study harvester achieved an average of 1,414 machine hours per year, while according to the study of Magagnotti et al. (2017) the number of hours achieved in various European countries in the period between 2000 and 2017 ranged from 1,184 to 2,042 hours per year. Holzleitner et al. (2011) found that the highest annual engagement of harvesters was 3,120 machine hours and this was recorded in a multi-shift working operations in the rehabilitation of windbreaks in Sweden. The same study concluded that the average working time of harvesters in Austria is in one shift and 1,650 machine hours per year.

Fuel consumption of the harvester was relatively uniform by the age of 9, and then began to grow exponentially, reaching its maximum at the age of 13, with average of 16,3 l/h, or 0.76 l/m^3. In the study by Lijewski et. al., 2013 harvester consumption in pine culture was 0.80 l/m^3, while Väätäinen et al. (2006) found that harvester fuel consumption was about 12.79 l/h. The situation is similar with chain oil consumption - relatively uniform consumption was recorded until the age of 10, and then a sharp increase in consumption, with a maximum in the last year. This could be explained by the fact that the amortization life of the machine expired at the age of 8 (a total of 12,965 machine hours have been achieved up to this year) and that due to machine wear and tear there is an increase in fuel and oil consuption.

The total costs of the harvester engagement during the 13 years amounted to about 2,000,000 euros. When these costs are divided by the total amount of wood volume felled by the harvester (about 400,000 m^3), a unit cost of about 5 €/m^3 is obtained. If we compare these unit costs with the costs of conventional felling, where the average value is about 3.5 €/m^3, we come to the conclusion that this way of cutting is about 50% more expensive than the manual way. However, if other aspects are taken into account (productivity, ergonomics and safety at work), then this way of cutting trees and production of wood assortments can be considered very efficient.

When the aspect of profit is taken into account, it was found that it reached its maximum in the 7th year, after which it was decreasing. At the end of the 7th year of the harvester's engagement, 10,799 machine hours were realized. Given that the recommended work life of the machine was 12,800 machine hours, it can be considered that the machine reached its maximum at about 85% of the recommended number of machine hours.

There is no any statistical dependence in value of maintenance costs during the years. The same conclusion was reached by Spinelli and Visser (2008), who found that repair costs have a large variability between machine types and cumulative machine hours. In this study, the maximum values of maintenance costs were achieved at 6 and 12 years of age, due to replacement of the harvester head caused by damage during delimbing. A total of about 300,000 euros were spent on maintenance costs. According to Holzleitner et al. (2011) the average cost of harvester repair was 20.2 € per machine hour, as oppose tos 17.2 € per machine hour gained in this study.

Based on many years of monitoring the costs of larger (129 kW) and smaller (86 kW) harvesters in pine, larch and spruce plantations, it was found that engine power does not affect operating costs in the power class between 70-140 kW (Dvořák et al. 2019). Authors conclude that labour costs had the largest share in total direct costs and typically ranged between 16 and 30% of total costs. Väätäinen et al. (2006) found that maintenance costs accounted for 5.3% of total costs, as oppose to 15% gained in this study.

Total costs depend on the costs of labour, materials and services, as well as the legislation in a particular country (Dvořák et al. 2020).

CONCLUSIONS
ZAKLJUČCI

Based on the available data, it was determined that the maximum profit due to engaging harvester for cutting trees in poplar plantations is achieved at about 85% of the total number of machine's machine hours recommended by the manufacturer (in this case it was in the 7th year). The research showed that after the 7th year the profit was declining, and reached its minimum in the last year of engagement. Maintenance costs had their maximums in the 6th and 12th year due to major malfunctions which led to the replacement of the harvester head.

The maximum productivity was achieved in the 8th year of harvester's age. After this period, in the 9th year, a sudden increase in fuel and chain oil consumption occured and this trend continued until the end of the engagement. This most likely occured as a result of the machine wear and tear thus reaching its maximum cost-effective use.

Although the unit costs of the used harvester were 50% higher than the unit costs of motor-manul cutting trees by chainsaws, fully mechanised harvesting had other benefits, primarily reflected in work safety and incomparably less physical load of workers. Consequently, several more harvesters were bought procured in this company, and their number is constantly increasing.

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SAŽETAK

Posljednjih nekoliko godina harvesteri se sve više koriste u sastojinama listopadnih vrsta drveća. Korištenje harvestera u Srbiji počelo je 2008. godine sa John Deere 1470D Eco III i služio je za sječu stabala i proizvodnju drvnih sortimenata u nasadima topola u nizinskom području. Cilj ovoga rada je odrediti maksimalnu dobit angažiranjem harvestera u zadanim uvjetima, kao i utvrditi ukupne troškove sredstava. Harvester je postigao ukupno 18,392 strojna sata (MH), s prosjekom od 1,415 sati godišnje. Prosječna potrošnja goriva tijekom cijelog razdoblja iznosila je 16.3 l/h, odnosno 0.76 l/m^3. Najveći trošak rezervnih dijelova bio je u 6. godini (oko 66,000 eura) i u 12. godini (oko 82,000 eura). Ukupni troškovi rezervnih dijelova i usluga bili su 656,878 eura. Na temelju planiranja da je broj radnih dana u godini 200, dobiva se razdoblje amortizacije od 7 godina (točka presjeka tekućeg i prosječnog rasta dobiti). Ova informacija nam govori da bismo nakon 7. godine trebali harvester prodati i kupiti novi. No, ovo su samo početna istraživanja, koja će se nastaviti s podacima o nekoliko harvestera, koji su u međuvremenu nabavljeni.

KLJUČNE RIJEČI: harvester, nasadi topola,troškovi, učinkovitost, amortizacija