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Original scientific paper

DOI: https://doi.org/10.5552/crojfe.2019.678

Biomass Yield and Fuel Properties of Different Poplar SRC Clones

Dinko Vusić, Davorin Kajba, Ivan Andrić, Ivan Gavran, Tin Tomić, Ivana Plišo Vusić, Željko Zečić

Abstract

The goal of the research was to determine the biomass yield and fuel properties of ten different poplar clones. The research was conducted in an experimental plot established in Forest Administration Osijek, Forest Office Darda, in the spring of 2014. The layout of the plot consisted of three repetitions per clone with 40 plants per repetition in spacing 3x1 m. Based on the DBH distribution, in the early spring of 2018, one sample tree of an average DBH per repetition was selected, thus forming a sample of 30 trees.

Average survival rate of the investigated trees after four vegetation periods was 74.54±13.85% ranging from 52.08% (Koreana) to 91.67% (SV885 and SV490). Average DBH of the sample trees was 8.2±1.9 cm, height 9.3±1.8 m and root collar diameter 10.7±1.9 cm. Moisture content in fresh state (just after the felling) ranged from 51.6% (Hybride 275) to 55.9% (SV885). Bark content averaged 18.4%, from 15.4% (Baldo) to 21.1% (V 609). Average nominal density of the sampled trees amounted to 383.5±35.9 kg/m^3. Bark ash content was on average ten times higher (6.44±0.65%) than wood ash content (0.64±0.07%) resulting in average ash content of 1.7±0.1% (taking the bark content into account).

The clone SV490 showed the highest biomass yield with 15.8 t/ha/year, while the lowest biomass yield was recorded for the clone Hybride 275 with 2.8 t/ha/year.

High inter-clonal productivity variation stresses the importance of selection work to find the most appropriate clones with the highest productivity potential for the given area where the poplar SRC plantations are to be established.

Due to high initial moisture content, if direct chipping harvesting systems are preferred, wood chips could be efficiently used in CHP (Combined Heat and Power) plants that operate on the principle of biomass gasification (where a gasifier is coupled to a gas engine to produce electric power and heat). In several CHP gasification plants operating in Croatia, wood chips with high initial moisture content (from traditional poplar plantations) are used as a feedstock that has to be pre-dried using the surplus heat. In this respect SRC poplar wood chips could make an ideal feedstock supplement.

Keywords: biomass, moisture content, nominal density, bark content, ash content

1. Introduction

The last decade has brought significant changes on the EU fuelwood market. Obligations of EU countries with respect to their national renewable action plans mobilized substantial amounts of forest biomass for production of wood chips and pellets (Vusić and Đuka 2015). In the production of bioenergy from wood, the main biomass resources are sustainably managed forests where the supply is governed by increment/annual cut, and the amount of direct biomass feedstock for energy is the result of market competition for lower quality wood with wood-based panels industry and pulp and paper industry (Vusić et al. 2018). For example, in Croatia, only 3 CHP facilities with instaled power of 6.74 MWel (8% of the 85MWel set as a 2020 goal in the Renewable energy action plan) were operational in 2014 (Vusić and Đuka 2015), and four years later, at the end of 2018, the number of operational CHP facilities reached 28 with instaled power of 58.33 MWel (www.hrote.hr). In the same period, pellet production in Croatia, that amounted to 192,662 t in 2014, incresed by roughly 100 000 t (www.unece.org). Increased demand for energy wood that folowed the exponential growth of the wood energy sector disclosed the fact that the future of bioenergy industry will strongly depend on the availability of suitable biomass resources and that new sources of wood fiber have to be explored in short term. Establishing dedicated energy plantations of fast growing wood species could be one of the promising ways to increase the amount of biomass on the market (Vusić et al. 2018).

Theoretical studies and practical field experiments have led to the introduction of bioenergy plantations in several regions of the world (Berhongaray et al. 2013). Interest in short-rotation bioenergy crops focuses mainly on their ability to produce large amounts of lignocellulosic biomass that can be used as fuel for heat or electricity generation (Durán Zuazo et al. 2013). Kajba et al. (2011) estemated 3 257 800 t DM/y as the technical potential of short rotation energy crops (SRC) production in Croatia on 46 850 ha of forest area and 235 650 ha of agricultural areas with moderately suitable soils and limited soil suitability. The estimated annual biomass yield ranged from 8 to 12 t DM/ha depending on the type of soil used for establishing SRC.

Apart from the biomass yield, there are two main areas that should be explored prior to large-scale implementation of SRC as a bioenergy feedstock on national level, both having crucial influence on the economical prospect of the undertaking:

⇒ the possibility of implementing mechanization in each stage of the production process (Tylek et al. 2017) and in each step of the procurement chain, with the goal of minimizing the unit cost of production and

⇒ optimizing the quality of the biomass feedstock produced with the goal of maximizing the income.

Biomass yield is strongly influenced by selection of apropriate clones (Kajba and Andrić 2012), suitable soil type (Benetka et al. 2014), irrigation and fertilization (Benetka et al. 2002, Potočić 2006), but also by selecting the method of cultivation (Proe et al. 2002, Benomar et al. 2012, Klašnja et al. 2012). Manzone et al. (2014) reported two different methods of cultivation in Italy: very Short Rotation Coppice (vSRC), with very high density, from 5500 to 14 000 plants ha^{-1} and harvested with a rotation period of 1–4 years, and Short Rotation Coppice (SRC) with a high density from 1000 to 2000 plants ha^{-1} harvested with a rotation of 5–7 years. Same authors stress the fact that in Europe farmers prefer the vSRC cultivation model, while in Italy, recently, the farmers prefer the SRC method, because the most recent poplar hybrids have enhanced productivity and improved the biomass quality (high calorific value) as a result of a better wood/bark ratio. Therefore, it can be stated that the method of cultivation has a strong efect on the quality of biomass produced. Differences in bark and wood content in woody biomass is also pointed by Guidi et al. (2008) as a parameter that directly affects the quality and economic value of biomass as an energy source. According to the solid biofuel standards (HRN EN ISO 17225-1:2014), moisture content, particle size distribution and ash content are crucial parameters that define the quality of wood chips. Together with the density of the wood, these parameters define the amount of energy that can be produced out of a certain green biomass volume. Typical values of ash content for poplar SRC (2%) are much higher than those for debarked energy wood (0.3%). Although some experiments have shown that the heating value of bark is quite similar to that of wood (Adler et al. 2005), in SRC biomass bark content is, nevertheless, considered to be a negative characteristic (Guidi et al. 2008) due to the fact that most minerals taken up by trees are accumulated within the bark causing relatively high ash content of the biomass feedstock with high bark share. High initial moisture content of the poplar SRC biomass, due to the anatomical characteristics of wood reflected also in the lower nominal density compared to hardwood species, can pose a problem in the feedstock quality if direct chipping harvesting method is to be applied. Berhongaray et al. (2013) diferentiate two main harvesting approaches developed for SRC: the harvest-and-chip system and the harvest-and-storage system - the first usally based on a self-propelled cut-and-chip front harvester (forage harvester with and a coppice header) or on a tractor-pulled cut-and-chip side harvester, and the latter based on a tractor-pulled whole stem harvester. The main disadvantage of the harvest-and-chip system is the production of wet chips with limited possibility of long term storage and risk of dry matter losses (Kofman 2012, Berhongaray et al. 2013) that implicates the need for ugrent use (with low calorific value related to high moisture content) or artificial drying (with additional use of energy). The main advantage of the harvest-and-storage system is the possibility of using natural drying of wet stems prior to chipping. Another parameter that limits the selection of apropriate harvesting machinery is the cutting diameter, again closely related to the cultivation method, i.e. spacing and rotation defining the dimensions of the stems.

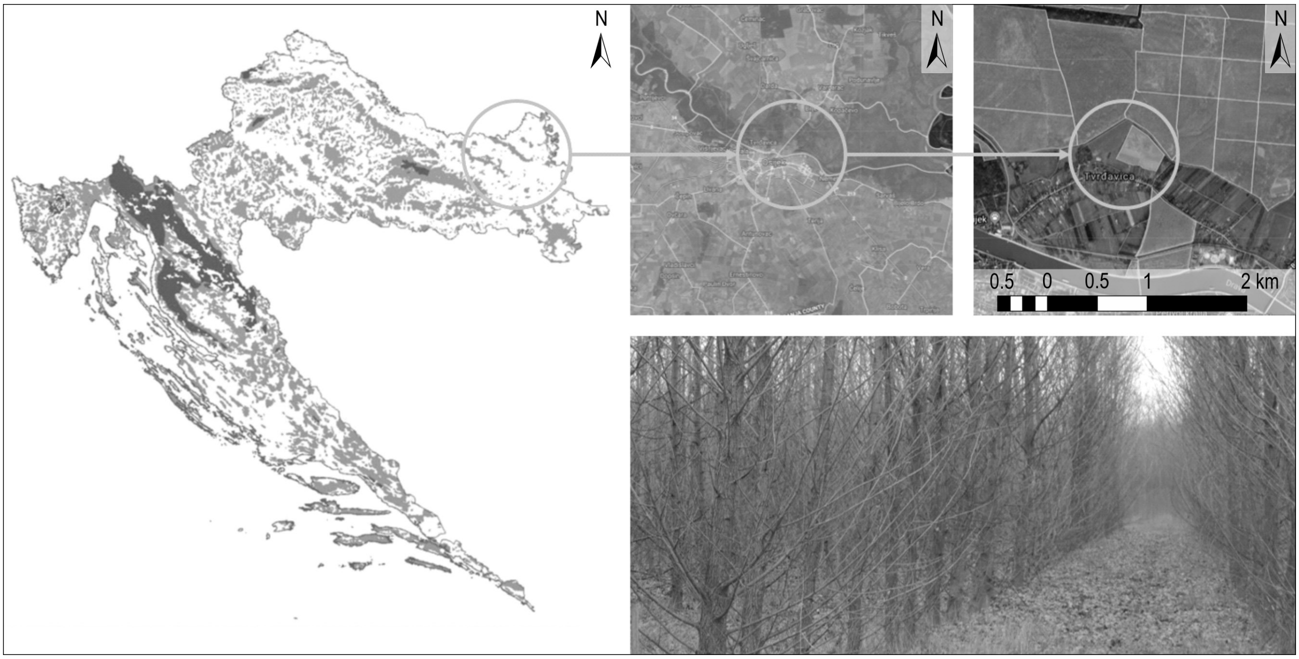

Fig. 1 Location of the experimental plot

The goal of the research was to determine the biomass yield and fuel properties of ten different poplar clones tested in an experimental plot established in the eastern part of the Republic of Croatia, where there are favorable conditions for the establishment of poplar SRC and the management of poplar plantations has a strong tradition.

2. Materials and Methods

The research was conducted in an experimental plot (Fig. 1) established by unrooted cuttings in the spring of 2014 in Forest Administration Osijek, Forest Office Darda, Forest Nursery Tvrđavica (45°34'32''N (18°41'10''E).

In total, ten different poplar clones were tested (Table 1). The layout of the plot consisted of three repetitions per clone with 40 plants (4 rows x 10 plants) per repetition in spacing 3x1 m. Neither irrigation nor fertilization was applied. The plot was surrounded by a shelter belt formed with clone 'M1'.

In the early spring of 2018, survival rate was determined and DBH (diameter at breast height) of the remaining trees was measured. Sub-sample for survival rate and DBH distribution determination consisted of inner rows (excluding first and last plant in the row) per each repetition, i.e. 16 trees per repetition. Based on the DBH distribution, one sample tree of an average DBH per repetition was selected, thus forming a sample of 30 trees.

Table 1 Tested poplar clones

Clone	Taxon	Place of origin
'Antonije'	*P. deltoides* × *P. nigra* × *P. deltoides*	Serbia
'Baldo'	*P. deltoides* × *P. deltoides*	Italy
'Delrive'	*P. deltoides*	France
'Hybride 275'	*P. nigra* × *P. maximowiczii*	Germany
'Koreana'	*P. trichocarpa* × *P. koreana* × *P. maximowiczii*	Germany
'Matrix 21'	*P. trichocarpa* × *P. maximowiczii*	Germany
'Max 4'	*P. nigra* × *P. maximowiczii*	Germany
'SV490'	*P. trichocarpa* × *P. deltoides*	Hungary
'SV885'	*P. trichocarpa* × *P. deltoides*	Hungary
'V 609'	*P. deltoides* × *P. nigra*	Croatia

Each sample tree was felled and mass in the fresh state, root collar diameter, DBH and height were measured. Sample discs were taken from the root collar up every 1.30 m till the 3 cm minimum diameter with bark (in total 176 sample discs).

Volume and mass of the sample discs in the fresh state were determined. Bark was peeled from the sample discs and gravimetric analyses were performed according to the standard HRN EN ISO 18134-2:2015.

Ash content was determined for bark and wood samples following the standard HRN EN ISO 18122:2015. Moisture content, bark to wood ratio (on dry mass basis), ash content and nominal density of the samples were recalculated as weighed averages (by sample fresh mass) and expressed per sample tree. Ash content of biomass per clone was calculated based on average bark to wood ratio and determined ash content of bark and wood.

Fresh masses of sample trees were recalculated to (oven dry) biomass based on the average moisture content. Biomass yield was calculated based on the planting density (3333 N/ha), observed survival ratio and age of the plot.

Results of fuel properties were compared to typical values of poplar short rotation coppice solid biomass fuels reported in HRN EN ISO 17225-1:2014.

3. Results and Discussion

3.1 Biomass Yield

Average DBH of the sample trees was 8.2±1.9 cm, height 9.3±1.8 m and root collar diameter 10.7±1.9 cm. Moisture content in fresh state (just after the felling in April 2018) ranged from 51.6% ('Hybride 275') to 55.9% ('SV885'). Average nominal density of the sampled trees amounted to 383.5±35.9 kg/m^3.

Similar results of moisture content (53.2%) were found by Vusić et al. (2014) in a poplar SRC experiment conducted in the same period of the year, indicating the need for optimizing the harvesting season or to consider natural drying opportunities. Moisture content results, reported by Berhongaray et al. (2013), were slightly higher than 50% for freshly harvested willow and poplar SRC biomass in an experiment conducted in February and aimed at making comparative analysis of the harvest-and-chip system and the harvest-and-storage system. In spite of its financial drawbacks, the authors point out that harvest-and-storage system has the advantage to let the biomass air-dry on the field until it reaches the required moisture content before chipping the material, thus increasing the quality of the biomass delivered and as a consequence the price of the biomass chips.

Results of nominal density were higher than 323±12 kg/m^3 mean nominal density of the sampled poplar sprouts ranging from 200 kg/m^3 to 467 kg/m^3 reported by Johansson and Hjelm (2012) and 341±24 kg/m^3 (284–375 kg/m^3) reported by Klašnja et al. (2013).

Root collar diameter as an indicator of the limitation in selecting the harvesting equipment ranged from 5.10 cm to 9.90 cm (for clone 'Hybride 275') to 11.25 cm to 14.15 cm (for clone 'Delrive'). Berhongaray et al. (2013) stated maximum cutting diameter of 15 cm for the self-propelled cut-and-chip harvester, 4–6 cm for the tractor-pulled cut-and-chip harvester and 15–20 cm for the tractor-pulled whole stem harvester. Therefore, it can be stated that both harvesting systems (the harvest-and-chip system and the harvest-and-storage system) could be used for the harvesting of the investigated clones with the exception of the tractor-pulled cut-and-chip harvester of the harvest-and-chip system. However, the present share of the harvest-and-chip system reported in the study conducted by Vanbeveren et al. (2017) indicates that it is more likely

Table 2 Moisture content and nominal density

Clone	Moisture content, %			Nominal density, kg/m^3		
	Average±s.d.	Min.	Max.	Average±s.d.	Min.	Max.
'Antonije'	54.36±0.47	53.83	54.65	373.76±9.58	363.83	382.96
'Baldo'	55.81±1.80	54.01	57.61	357.85±21.92	343.25	383.06
'Delrive'	52.64±1.70	50.74	54.03	380.54±47.83	333.70	429.30
'Hybride 275'	51.59±1.96	49.38	53.09	365.07±39.43	320.57	395.63
'Koreana'	52.08±0.10	51.97	52.14	386.71±56.79	334.36	447.08
'Matrix 21'	52.97±3.51	50.69	57.02	389.57±35.55	352.23	423.00
'Max 4'	53.44±1.20	52.33	54.71	378.44±7.29	370.19	383.99
'SV490'	54.32±0.88	53.62	55.30	382.95±11.62	372.83	395.64
'SV885'	55.93±1.44	54.41	57.28	433.42±59.06	366.31	477.52
'V 609'	51.90±1.26	50.95	53.32	402.29±28.99	369.22	423.32

Table 3 Root collar diameter

Clone	Root collar diameter, cm		
	Average±s.d.	Min.	Max.
'Antonije'	10.32±0.62	9.80	11.00
'Baldo'	11.30±0.30	10.95	11.50
'Delrive'	12.48±1.50	11.25	14.15
'Hybride 275'	7.50±2.40	5.10	9.90
'Koreana'	10.30±1.75	8.85	12.25
'Matrix 21'	10.03±2.11	8.05	12.25
'Max 4'	11.45±2.04	10.15	13.80
'SV490'	12.15±2.05	9.95	14.00
'SV885'	10.07±0.74	9.25	10.70
'V 609'	11.13±1.11	9.95	12.15

that harvest-and-chip system would be used (single pass cut-and-chip technique was represented in 127 out of 166 studies reviewed). Same authors point out operational flexibility with regards to plant species, shoot age and diameter, planting density and field stocking as the reasons for the enduring popularity of the harvest-and-chip system.

Biomass production per tree followed DBH increase, and DBH explained 93.72% of the biomass variability (Fig. 2). The clone 'SV490' showed the highest productivity with 20.7±7.5 kg of biomass per tree, while the lowest productivity was recorded for the clone 'Hybride 275' with 5.3±3.5 kg of biomass per tree. On average, ten investigated clones (30 sampled trees) produced 13.5±6.2 kg of biomass per tree (in four vegetation periods/seasons). Median value of the biomass production amounted to 14 kg/tree separating three of the researched clones, 'Max 4' (15.5±5.3 kg/tree), 'Baldo' (16.1±2.5 kg/tree) and 'V 609' (16.4±5.4 kg/tree) in the third quartile, and 'Delrive' (19.9±5.3 kg/tree) and 'SV490' (20.7±7.5 kg) into the fourth.

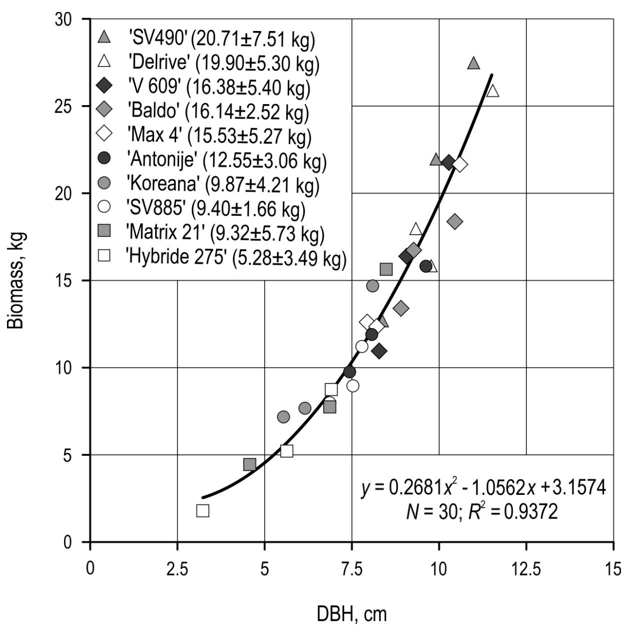

Fig. 2 Biomass production vs. DBH

Average survival rate of the investigated trees was 74.54±13.85% ranging from 52.08% ('Koreana') to 91.67% ('SV885' and 'SV490'). The clone 'SV490' showed also the highest biomass yield with 15.8 t/ha/year, while the lowest biomass yield was recorded for the clone 'Hybride 275' with 2.8 t/ha/year (Table 4). Half of the investigated clones showed biomass yield above 9.6 t/ha/yr, that was recalculated as an average biomass yield in 25 different experiments presented by Byrd (2013) based on the data reported in Johansson and Karačić (2019).

3.2 Fuel Properties

Bark content averaged 18.4%, from 15.4% ('Baldo') to 21.1% ('V 609'). Results were simmilar to the ones reported by Vusić et al. (2014), who found average bark content to be statistically different between clone 'S1' (17.3%) and clone 'M1' (20.7%). Guidi et al. (2008) reported bark content (in dry state) in the range from 33.9% for DBH 1 cm to 15.1% for DBH 9 cm.

Bark ash content was on average ten times higher (6.44±0.65%) than wood ash content (0.64±0.07%),

Table 4 Survival rate and biomass yield

Clone	Survival rate, %	Biomass yield, kg/ha/year
'SV490'	91.67	15 819
'Delrive'	77.08	12 782
'V 609'	81.25	11 090
'Baldo'	81.25	10 927
'Max 4'	75.00	9705
'Antonije'	77.08	8061
'SV885'	91.67	7180
'Koreana'	52.08	4283
'Matrix 21'	53.75	4174
'Hybride 275'	64.58	2841

Table 5 Ash content

Clone	Ash content, %		Bark content, %	Average ash content, %
	Wood	Bark		
'Antonije'	0.63	6.57	20.76	1.87
'Baldo'	0.74	7.88	15.39	1.84
'Delrive'	0.74	6.93	17.07	1.80
'Hybride 275'	0.68	6.58	16.92	1.68
'Koreana'	0.52	6.05	19.21	1.58
'Matrix 21'	0.60	6.19	16.43	1.52
'Max 4'	0.59	6.75	19.83	1.82
'SV490'	0.67	5.76	16.79	1.52
'SV885'	0.68	5.87	21.06	1.77
'V 609'	0.56	5.83	20.16	1.62

which resulted in average ash content of 1.7±0.1% (taking the bark content into account). Results of the research are simmilar to 0.59±0.04% (0.52–0.69%) of ash content in poplar wood reported by Klašnja et al. (2013) and confirm the report of Vusić et al. (2014), who determined great differences in ash content of bark (5.83% for clone 'S1' and 5.96% for clone 'M1') compared to ash content of wood (0.49% for clone 'S1' and 0.53% for clone 'M1'), concluding that the results of ash content together with the share of bark define the feedstock in terms of its suitability for the end-user as solid biofuel. Manzone et al. (2014) stated that material with high bark content has a low market price because of lower heating value and high ash content. Vusić et al. (2014) reported that the calorific value of the bark was 3% lower than the calorific value of the wood due to the ash content differences. Average ash content of all investigated clones is lower than the tipical value for poplar SRC (2.0%), but it is in the range of typical variation (1.5% to 3.4%) as defined in HRN EN ISO 17225-1:2014. Due to the high ash content as a consequence of high bark share and the limited possiblity of debarking, biomass produced is an unsuitable feedstock for production of high value solid biofuels like high quality pellets. A1 quality grade pellet is limited with 0.7% ash content and A2 pelet is limited with 1.2% ash content (HRN EN ISO 17225-2:2014).

4. Conclusions

High inter-clonal productivity variation stresses the importance of selection work to find the most appropriate clones with the highest productivity potential for the given area where the poplar plantations are to be established. Research results pointed out that clone 'SV490' had the highest biomass yield potential per tree, as well as the highest biomass yield potential per hectare (when determined survival rates were applied). In addition, four other investigated clones showed above average biomass yield.

As a consequence of high bark and ash content, wood chips produced in poplar SRC established with selected clones are designated for direct transformation to energy, i.e production of densified high quality/high value solid biofuels is limited. Due to high initial moisture content, if direct chipping harvesting systems are preferred, wood chips could be efficiently used in CHP (Combined Heat and Power) plants that operate on the principle of biomass gasification (where a gasifier is coupled to a gas engine to produce electric power and heat). In several CHP gasification plants operating in Croatia, wood chips with high initial moisture content (from traditional poplar plantations) are used as a feedstock that has to be pre-dried using the surplus heat. In this respect, SRC poplar wood chips could make an ideal feedstock supplement.

Acknowledgments

Planting material for establishing the experimental plot was provided by Bavarian Office for Forest Seeding and Planting (ASP), Teisendorf, Germany within the project »Testing of poplar clones from EU member states for the use in short rotation coppice (SRC) culture«. Establishment of the plot and logistical help in field measurements was provided by »Croatian Forests« Ltd. Zagreb, Forest Administration Osijek.

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Authors' addresses:

Assist. prof. Dinko Vusić, PhD *
e-mail: vusic@sumfak.hr
Prof. Davorin Kajba, PhD
e-mail: davorin.kajba@zg.t-com.hr
Prof. Željko Zečić, PhD
e-mail: zecic@sumfak.hr
University of Zagreb
Faculty of Forestry
Svetošimunska cesta 25
10000 Zagreb
CROATIA

Ivan Andrić, PhD
e-mail: andricivan86@gmail.com
Andrije Hebranga 7
43500 Daruvar
CROATIA

Ivan Gavran, MSc
e-mail: gavran_ivan@hotmail.com
Hrvatskog proljeća I. odv. 6
44440 Dvor
CROATIA

Tin Tomić, MSc
e-mail: tintomic_93@hotmail.com
Stjepana Radića 44
35425 Davor
CROATIA

Ivana Plišo Vusić, MSc
e-mail: ipliso@gmail.com
Banski vinogradi 26b
10090 Zagreb
CROATIA

* Corresponding author

Received: April 24, 2019
Accepted: June 18, 2019