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BIOMASS PRODUCTION AND ENERGY POTENTIAL OF SOME EASTERN COTTONWOOD (*Populus deltoides* Bartr. ex Marsh.) CLONES IN RELATION TO PLANTING SPACING

PRODUKCIJA BIOMASE I ENERGETSKI POTENCIJAL NEKIH KLONOVA CRNE TOPOLE (*Populus deltoides* Bartr. ex Marsh.) U ODNOSU NA RAZMAK SADNJE

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Abstract

The possibility of biomass production was studied in an experimental trial stand with four clones of Eastern cottonwood *Populus deltoides* Bartr. ex Marsh. cl.457, cl.450, cl.618 and cl. 55/65 and three stand densities a) 1.2 × 1.0 m (8330 plants·ha^{-1}), b) 1.2 × 0.75 m (11110 plants·ha^{-1}) and c) 1.2 × 0.5 m (16600 plants·ha^{-1}). Field trials were conducted on sandy-loamy form of fluvisol.

Total determined volume of trunk, bark, and branches in the first two-year cycle for the used Eastern cottonwood ranged from 27.391 m^3·ha^{-1} in clone 450 at planting distance of 1.2 × 1.0 m, subtreatment (a) to 42.006 m^3·ha^{-1} in clone 618, subtreatment (c) at planting distance of 1.2 × 0.5 m. After renovation of stand using the regeneration force of shoots from the tree stumps the produced wood mass in the second two-year cycle ranged from 54.664 m^3·ha^{-1} in clone 55/65, subtreatment (a) to 79.235 m^3·ha^{-1} in clone 450, subtreatment (b).

In additon to clone selection a significant influence on biomass yeald was also exerted by stand density (number of plants·ha^{-1}).

The largest amount of heat energy would be obtained in subtreatment (c) at density of 1.20 × 0.5 m by combustion of biomass of above ground part of clone 55/65: 364.02 GJ·ha^{-1} in the first cycle, and 659.83 GJ·ha^{-1} in the second, or a total of 1023.85 GJ·ha^{-1}.

KEY WORDS: poplar, clone, plant density, biomass, energy value.

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1. Introduction
Uvod

Increased participation of renewable energy sources in the total energetic balance is one of the strategic goals of the ever increasing number of countries. Foundation of energetic plantations for biomass production is in accordance with the world trends, and it is the basis for better usage of renewable energy sources without emitting the additional quantities of carbon dioxide (CO_2) the fossil fuels are loaded with.

Biomass is produced through photosynthesis when plants capture atmospheric carbon dioxide (CO_2) and release oxigen (O_2), which makes it a renewable and environmentally friendly source of energy and gives it considerable advantages over other fuels. According to the reasearch of Zenone et al, (2008) the average annual amount of CO_2 consumed by poplar varieties with short rotation at plant density of 12.500 plants·ha^{-1} ranged from 11.2 to 23.2 t CO_2·ha^{-1}·$year^{-1}$. In the 10-year period, with several short production cycles in dense poplar stands it would amount from 134 to 235 t·CO_2·ha^{-1} (taken over by Pašičko et al, 2009).

Shortage of wood as energy raw material requires control of technological procedures for accelerated wood production as a renewable resource in special types of short-rotation poplar coppice stands.

Due to their autovegetative propagation ability by cuttings, or by regeneration force of shoots from the tree stumps enabling selection of high genetic gain, the strong regeneration force of poplars allows several production cycles with minimal production costs.

Poplars and willows represent the greatest potential for biomass production in short rotation stands in our area. By selecting clones with appropriate characteristics for growing in very dense short rotation stands, it is possible to produce large quantity of biomass (by chipping of whole trees with branches, bark and roots at the end of production cycle), and it does not require production of technical wood of greater dimensions, because technology intended for this purpose uses chipped wood.

The fact that smaller trees are used for biomass production is the main factor that determines the elements of technology of targeted production of wood for energy purposes. Optimal use of genetic poplar potential in production of biomass is influenced by the choice of clone, type of planting material, and density of stand crucial for duration of the production cycle and number of rotations.

Short rotation stands in which felling of trees is performed each year, every second or third year are established with tested genetic material and stand density of ~ 15000 plants ha^{-1} (Tharakan et. al. 2003).

In regard to the poplar production technology numerous problems remain whose solution would influence the realization of the mentioned goals, and in particular the cost of investment in the process of establishment, development and protection of stand. These problems include the choice of habitat, soil preparation, choice and technology of planting material production, choice of the manner of planting, care measures, and stand protection.

In addition to poplars being the most productive forest tree species in our area, they also have several important characteristics making them fit for short rotation stand establishment such as a large selection of clones, the possibility of restoration by shoots from stumps after multiple cuttings, and uniform quality of planting material. Possibility to produce biomass in poplar stands of different production cycle duration has been studied for long period of time, which was confirmed by numerous literature citations (Marković et al. 1986, Rončević et. al. 2002, 2011, Klašnja et al. 2002, 2003, 2009, Andrašev et al, 2003, Orlović et al, 2004, Kajba et al, 2004).

2. Object of investigation and working method
Objekt istraživanja i metoda rada

2.1. Object of investigation – Objekt istraživanja

Studies were done on the Trial field of the Institute of lowland forestry and environment in the vicinity of Novi Sad (N: 45°16'57", E: 19°52'40"). Area on which the studies were performed is suited at an altitude of 75 m and was flooded at high water-levels of the Danube until the construction of defensive embankment in 1928. According to the hydrographic position the pilot facility was suited on the medium high mountain terrains of alluvial plains of the Danube basin (Herpka, 1965), where natural conditions for marsh forest prevailed prior to the construction of the defensive embankment. Until the construction of the defensive embankment this soil was formed by the dominant pedological process called fluvial sedimentation (Ivanišević, 1993; Ivanišević, et al. 2000) with significantly lesser accumulation of organic matter (Ivanišević and Milanovskij, 1991), and after the construction of the embankment the prevailing pedological processes were influenced by ground water and plants formation (Pekeč, 2010; Pekeč, et al. 2011a, 2011b). According to the soil classification of Škorić, et al. (1985) this soil belongs to hydromorphic order, the class of undeveloped hydromorphic soils. According to soil systematic classification the soil at the pilot facility belongs to loamy fluvisol type. This soil is layered, very deep, carbonate through entire depth, with alkaline reaction of soil solution, with obvious signs of gleying process, and with physiologically active profile depth (rhizospehere zone) of 180 cm (Ivanišević, 1991, 1995).

Table 1. Analytical parameters of soils
Tablica 1. Analitički pokazatelji zemljišta

Horizon Horizont	Depth Dubina	pH	Humus	$CaCO_3$	Participle size composition (%) Granulometrijski sustav		Texture Class Teksturna klasa
					>0,02	<0,02	
	cm	H_2O	(%)	(%)	mm	mm	
Fluvisol, loamy form (Fluvisol, ilovaste forme)							
Amo,p	0–30	8.1	2.33	10.2	41.2	58.8	Loam – Ilovača
IG_{so}	30–65	8.2	0.78	12.6	63.2	36.8	Sandy loam – Pjeskovita ilovača
IIG_{so}	65–88	8.2	0.30	17.2	80.8	19.2	Loamy sand – Ilovasti pijesak
$IIIG_{so}$	88–129	8.3	0.50	15.9	74.0	26.0	Sandy loam – Pjeskovita ilovača
IVG_{so}	129–180	8.3	0.09	19.7	98.4	1.6	Sand – Pijesak
Average – Prosjek	0–180	8.2	0.70	15.1	71.5	28.5	Sandy loam – Pjeskovita ilovača

The morphological structure of this soil is as follows: $A_{mo,p}$-IG_{so}-IIG_{so}-$IIIG_{so}$-IVG_{so}-G_r. Humus accumulative horizon (A-horizon) is loam (30 cm thick) according to the textural type, where all physiological activities are taking place (Ivanišević, 1991, Galić, 2010). The humus content in A-horizon exceeds 2,33% (table 1). Due to a layered configuration the textural composition changes with the depth, mainly the sandy fraction increases. Humus fraction declines with depth, indicating a type of accumulative distribution of organic matter in the profile (Ivanišević, 1991, Ivanišević and Milanovskij, 1991). Ground water oscillates at the depth of 80 to 220 cm, which allows favorable moisturizing of the physiologically active profile, i.e. active rhizosphere zone (Pekeč, 2010).

This form of fluvisol in the physiologically active part of the profile, contains on the average some 7500 t·ha^{-1} of dust+clay fraction, 163 t·ha^{-1} of humus, and can potentially store some 2150 m^3·ha^{-1} of useful water (Ivanišević, 1991, Ivanišević, et al. 2000). Hence, from the aspect of benefits in terms of technological production of poplar biomass in short rotations this soil belongs to habitats of high fertility potential.

The climate in the tested area is moderately continental (Katić et al. 1979), with certain specificities. The coldest month was January with the mean air temperature of 1.1 °C, and the hottest one July with 20.3 °C, the mean annual air temperature was 10.9 °C.

Average rainfall for the area in which the testing was done was 592 mm. From the mean annual amount of rainfall some 333 mm or 56% fell during the vegetation period (Katić et al. 1979).

Under such ecological conditions soil cover was formed on alluvial deposits of pronounced variable textural composition, with abrupt changes of microrelief on small areas (Rončević and Ivanišević, 1982; Živanov and Ivanišević, 1985).

2.2 Working method – Metoda rada

Trial stand with four clones and three planting distances was established with the aim to discover the most favorable technology for production of biomass in stands with a two-year rotation period, under field conditions.

I. Clones

1) *Populus deltoides* Bartr. ex Marsh. cl. 457

2) *Populus deltoides* Bartr. ex Marsh. cl. 450

3) *Populus deltoides* Bartr. ex Marsh. cl. 618

4) *Populus deltoides* Bartr. ex Marsh. cl. 55/65

II. Planting distances

a. 1.20 × 1.00 m (8330 plants·ha^{-1})

b. 1,20 × 0.75 m (11110 plants·ha^{-1})

c. 1.20 × 0.50 m (16660 plants·ha^{-1})

Within these studies the production of biomass for energy is analyzed in two production cycles.

When establishing the first cycles cuttings of 20 cm to 25 cm long were soaked in water for 24 hours before planting on a well-prepared soil.

According to the set research goals, hoeing around the plants and inter-row processing were performed for each of the applied treatments at the same time and in the same manner. Results of the survival of the trial stand per treatment were determined in the first half of September of the same year the trial stand was established.

At the end of the first year the diameters and heights were measured, in the second year the measurements were performed just prior to felling, and the samples for laboratory testing were taken.

Immediately after felling the whole trees were measured, as well as the bark mass after debarking in moist condition. For the determination of moisture content, wood samples were oven dried at 105 °C to a constant weight. All analyses were done in duplicate and the results were expressed on a dry weight basis.

The specimens were dried at room temperature until moisture content was 8%–10%, and after that the samples were ground into wood flour suitable for pellet pressing. The calorific value was determined for ground air-dried samples. Pellets were made by a special device producing pellets ranging from 0.60 g to 0.85 g. Samples were combusted in C200 IKA Werke calorimeter. There were three replications for each sample.

The renewal of the trial stand in the second cycle was done using regeneration force of shoots from the tree stumps. During the first vegetation period of the regeneration from the stump the shoot reduction was performed by leaving the best developed shoot on each stump.

3. Results and discusion
Rezultati istraživanja i diskusija

3.1. Taxation elements – Taksacijski elementi

Diameters and heights of medium-sized trees, number and volume of trees per hectare for each cycle are given in Table 2.

As far as survival of cuttings is concerned there were no statistically significant differences and the percentage of survival for all clones was 91.6%. The least percentage of survival of 89% was obtained in clone 618, in clone 450 (91%), while in clones 457 and 55/65 this percentage was 93%. At the end of the first two-year cycle the diameters ranged from 2.9 to 3.7 cm, and heights from 5.4 to 6.2 m. In the second cycle significantly higher values of diameters and heights were obtained due to the coppice vigor. Diameters ranged from 3.9 to 5.1 cm, and heights from 6.6 to 7.5 m.

Analysis of variance for diameters showed that there were no statistically significant differences between clones in the first cycle. However, differences in diameters influenced by various stand densities were highly significant. Among clones in the first cycle there were statistically significant differences in heights, influenced by genetic variability of clones, while differences in heights competing for living space (planting distances) were statistically highly significant. Mean variance analysis at the end of the second cycle revealed that differences among diameters as well as among heights were significantly different. In all clones the greatest dimensions were achieved at planting distances of 1.2 × 1.0 m, and the least 1.2 × 0.5 m (Table 3).

The total determined volume of wood, bark, and branches in the first two-year cycle for clones of Eastern cottonwood ranged from 27.391 $m^3 \cdot ha^{-1}$ in clone 450 at planting distance 1.2 × 1.0 m, subtreatment (a) to 42.006 $m^3 \cdot ha^{-1}$ in clone 618, subtreatment (c) at planting distance of 1.2 × 0.5 m (Table 2).

By renewing the stand using regeneration force of shoots from the tree stumps the produced wood mass in the second two-year cycle ranged from 54.664 $m^3 \cdot ha^{-1}$ in clone 55/65 subtreatment (a), to 79.235 $m^3 \cdot ha^{-1}$ in clone 450 sub-

Table 2. Basic parameters of trial stand development in the I and II cycle
Tablica 2. Osnovni pokazatelji razvoja pokusnog nasada u I i II turnusu

Taxation elements / Taksacijski elementi		cl. 457			cl. 450			cl. 618			cl. 55/65		
		a	b	c	a	b	c	a	b	c	a	b	c
I cycle (I ciklus)													
2nd year	**d** [cm]	3.6	3.3	3.1	3.6	3.3	2.9	3.7	3.5	3.2	3.7	3.3	3.1
	h [m]	6.1	5.8	5.8	5.8	5.7	5.4	6.0	5.9	5.8	6.2	5.8	5.8
N [trees·ha^{-1}]		7746	10332	15494	7746	10110	14994	7330	9888	14827	7830	9999	15660
V [m^{3}ha^{-1}]		28.637	31.017	41.350	27.391	29.888	33.139	28.120	33.644	42.006	30.920	30.017	41.793
II cycle (II ciklus)													
2nd year	**d** [cm]	5.0	4.3	4.0	5.1	5.1	4.0	5.2	4.5	4.0	4.7	4.2	3.9
	h [m]	7.2	6.7	6.6	7.0	6.8	6.7	7.5	7.0	6.7	7.1	6.9	6.9
V [m^{3}ha^{-1}]		61.511	57.971	74.871	62.280	79.235	73.422	64.964	62.816	72.604	54.664	55.082	75.037
I+II cycles (I+II ciklus)													
V [m^{3}ha^{-1}]		90.148	88.988	116.221	89.671	109.123	106.561	93.084	96.460	114.610	85.584	85.099	116.083

Planting distances (Razmaci sadnje)

a. 1.20 × 1.00 m (8330 plants·ha^{-1})
b. 1,20 × 0.75 m (11110 plants·ha^{-1})
c. 1.20 × 0.50 m (16660 plants·ha^{-1})

Table 3. Values of F-test of two-way factorial analisys of variance
Tablica 3. Vrijednosti F-testa dvofaktorske analize varijance

	Survival Preživljavanje	I cycle – I ciklus		II cycle– II ciklus	
		d	h	d	h
Clone Klon	2.16^{ns}	1.80^{ns}	6.19^{**}	15.71^{***}	4.59^{*}
Spacing Razmak	0.07^{ns}	18.14^{***}	9.22^{***}	8.20^{***}	16.50^{***}
Clone × Spacing Klon × Razmak	0.50^{ns}	0.28^{ns}	0.63^{ns}	3.00^{ns}	4.00^{*}

treatment (c). Within the same planting distances biomass production in the second cycle is larger for 40 % to 60% compared to the first cycle.

The results of these studies confirmed the real possibility of renewal of dense poplar stand using regeneration force of shoots from the tree stumps after felling. When establishing the stand of this type special attention should be paid to choice of clone with rapid growth in the juvenile developmental stage and genetic characteristics of stump regeneration after felling, as possibility to regenerate the stands with shoots from the stumps in several cycles.

3.2. Estimated weight of biomass – Procijenjena težina biomase

Biomass produced in this type of stands can be used as raw material for panel production and chemical processing (fiber production), but its primary purpose is energy production. Achieved yields of highly productive clones of Eastern cottonwood indicated that the selection of clones during stand establishment should be paid special attention, because it is one of the basic parameters providing maximum biomass production with the same costs of investment in intended poplar stands for bio-energy production. Mass volume of wood is considered the basic parameter of its quality, because several other traits such as structural, physical, and mechanical wood properties are in close correlation with the mass of volume. Clone 618 achieved the minimum value of the wood mass volume (368 kg·m^{-3}) Kopitović and Klašnja (1991), Herpka (1980), while the value for the clone 450 (395 kg·m^{-3}), for clone 457 (420 kg·m^{3}), and wood of clone 55/65 achieved the maximum value (447 kg·m^{-3}) Herpka (1980).

Many authors emphasized the significance of the selection for the fiber characteristics and mass volume of poplar wood, hence the quantity of the produced energy Goyal (1999), Ivkovich (1996). Klasnja et al (2003/a, 2003/b, 2005) confirmed these studies and concluded that mass of wood does not changes significantly with aging.

The weight of biomass is estimated based on produced volume and value of the mass volume of wood. At the end of the first two-year cycle the weight of biomass ranged from 10.35 t·ha^{-1} in clone 618 at density of (1.2 × 1.0 m) to 18.68 t·ha^{-1} in clone 55/65 at density of (1.2 × 0.5 m). During the second cycle the weight of biomass ranged from 22.54 t·ha^{-1} in clone 618 at density of (1.2 × 1.0 m) to 33.86 t·ha^{-1} in clone 55/65 at density of (1.2 × 0.5 m) due to the regeneration force of shoots from the tree stumps (Table 4).

Beside the influence of the clone selection and the regeneration force of shoots from the tree stumps on the produced weight of biomass, the planting density was also influenced. The best effects are achieved at densities (c) 1.20 × 0.50 m.

It can be seen from the Table 4 that in addition to clone selection the stand density (number of plants·ha^{-1}) also exerted a significant influence on yield of biomass.

3.3 Energy value of biomass – Energetska vrijednost biomase

In order to estimate the quantity of energy obtained by complete felling of trees after the first and the second two-year cycles, the caloric values of the high heating value were de-

Table 4. Estimated quantity of biomass per treatments of trial stand and area unit.
Tablica 4. Procjenjena količina biomase i energije po tretmanima pokusnog nasada i jedinici površine

Clone – Klon		457			450			618			55/65		
Planting Distance Razmak sadnje		a	b	c	a	b	c	a	b	c	a	b	c
I Cycle 2 year	V_I [m^3·ha^{-1}]	28.64	31.02	41.35	27.39	29.89	33.14	28.12	33.64	42.01	30.92	30.02	41.79
	ρ [kg·m^{-3}]	420	420	420	395	395	395	368	368	368	447	447	447
	W [t·ha^{-1}]	12.03	13.03	17.37	10.82	11.81	13.09	10.35	12.38	15.46	13.82	13.42	18.68
II Cycle 2 year	V_{II} [m^3·ha^{-1}]	61.51	58.12	74.86	62.36	79.33	73.36	61.24	62.81	72.54	54.78	54.37	75.74
	ρ [kg·m^{-3}]	420	420	420	395	395	395	368	368	368	447	447	447
	W [t·ha^{-1}]	25.83	24.41	31.44	24.63	31.34	28.98	22.54	23.11	26.69	24.49	24.30	33.86

Legend: V_I,V_{II} – wood volume in the I and II cycle, respectively; ρ – wood mass volume; W – wood weight.
Legenda: V_I,V_{II} – volumen drveta u I i II ciklusu, respektivno; ρ – volumna masa drveta; W – težina drveta.

Table 5. Content of ash and high heating value per clones and trunk parts.
Tablica 5. Sadržaj pepela i gornja toplotna moć po klonovima i dijelovima stabla

Clone Klon	Ash content, [%] Sadržaj pepela			Caloric value, [MJ·kg⁻¹] Kalorična vrijednost		
	Trunk Stablo	Bark Kora	Barkless trunk Stablo bez kore	Trunk Stablo	Bark Kora	Barkless trunk Stablo bez kore
457	3.14	5.33	0.41	18.542	18.545	18.532
618	2.86	5.74	1.77	19.554	20.106	18.818
450	4.84	6.34	1.42	18.986	19.956	18.438
55/65	3.87	7.57	1.06	19.487	20.510	18.357

termined for samples of wood and bark of tested clones according to standard methodology in the bomb calorimeter.

Caloric value of wood and bark of tested clones ranged from 18.542 MJ·kg^{-1} in clone 457 to 19.554 MJ·kg^{-1} in clone 618 (table 5). According to these data the heating value of bark was higher than that of wood and it ranged from 18.545 to 20.106 MJ·kg^{-1} and deviations were positive in all clones in relation to wood (Table 5). These results were similar to the mean values of heating value of trunks aged 3–5 years Ciria et al.(1996), and they were somewhat lower in comparison to the appropriate value of 20.239 MJ·kg^{-1} of grown up trees (Klašnja et al. 1998).

Energy value of biomass is directly related to the heating value of wood of tested clones, and also with other factors influencing the quantity and quality of produced biomass. The main objective of biomass combustion is to release the large amount of heating energy, and only harmless products of combustion through chimney (water vapor and carbon dioxide), and to retain only ash in furnace as noncombustible materials adopted from soil in the process of biomass production. All tested clones belonged to the group of Eastern cottonwood (*Populus deltoides* Bartr. ex Marsh.) and their caloric values were similar and ranged from 18.542 MJ·kg^{-1} in clone 457 to 19.554 MJ·kg^{-1}in clone 618 (Table 5). These results were similar to literature data obtained by Klašnja et al (2009) for the group of clones. Benetka et al (2002) provided data of heating values ranging from 18.60 MJ·kg^{-1} to 19.27 MJ·kg^{-1} for poplar trees aged 1–3 years.

Values of estimated quantity of energy that would be obtained in two two-year cycles depending on clone and planting density are given in Table 6 and Figure 1.

It is evident from these data that the quantity of energy produced in the second cycle was significantly greater compared to the first cycle, which was the result of better rooting ability and strong regeneration force of selected clones.

The greatest amount of heating energy of 364.02 GJ·ha^{-1} would be obtained by combustion of biomass of the above ground part of clone 55/65, subtreatment (c) at density of 1.2 × 0.5 m in the first cycle, and 659.83 GJ·ha^{-1} in the second or a total of 1023.85 GJ·ha^{-1}.

Within the group of tested clones of Eastern cottonwood (*Populus deltoides* Bartr. ex Marsh.) the minimum quantity of heating energy of 202.38 GJ·ha^{-1} would be obtained for clone 618, subtreatment (c) at density of 1.2 × 1.0 m by combustion of biomass of the above ground part in the first cycle, and 440.75 GJ·ha^{-1} in the second, or the total of 643.13 GJ·ha^{-1} (Fig. 1).

It is evident from the mentioned figure that there were no significant differences in the quantity of the produced energy in the first cycle, while in the second cycle clone 450 had significantly higher values at density of 1.2 × 0,75 m, and clone 55/65 at density of 1.2 × 0.5 m.

These differences probably occured due to stronger regeneration force in the second cycle compared to other clones.

Table 6. Estimated quantity of energy per treatments of trial stand and area unit.
Tablica 6. Procjenjena količine energije iz biomase po tretmanima pokusnog nasada i jedinici površine.

Clone – Klon		457			450			618			55/65		
Planting Distance Razmak sadnje		a	b	c	a	b	c	a	b	c	a	b	c
I Cycle 2 year	Q [MJ·kg⁻¹]	18.542	18.542	18.542	18.986	18.986	18.986	19.554	19.554	19.54	19.487	19.487	19.487
	Q [GJ·ha⁻¹·yr⁻¹]	111.53	120.8	161.04	102.72	112.11	124.26	101.19	121.04	151.15	134.65	130.76	182.01
II Cycle 2 year	Q [MJ·kg⁻¹]	18.542	18.542	18.542	18.986	18.986	18.986	19.554	19.554	19.54	19.487	19.487	19.487
	Q [GJ·ha⁻¹·yr⁻¹]	239.47	226.30	291.48	233.81	297.51	275.10	220.37	225.94	260.95	238.62	236.76	329.91
I+II Cycle	Q [GJ·ha⁻¹·yr⁻¹]	175,50	173.55	226.26	168,26	204.81	199.68	160.78	173.49	206.05	186.64	183.76	255.96
	Q [GJ·ha⁻¹]	702,00	694.21	905,03	673,06	819,24	798,74	643.13	693,97	824,20	746,55	735,05	1023,85

Legend: Q – energy (heat).
Legenda: Q – energija (toplina).

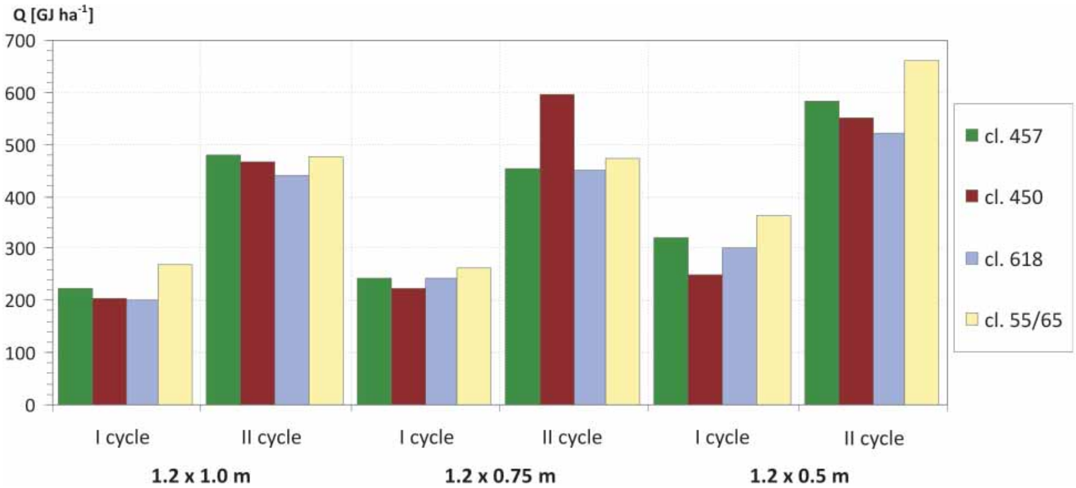

Figure 1. Energy value of biomass GJ·ha^{-1}.
Slika 1. Energetska vrijednost biomase GJ·ha^{-1}

This trait should be taken into consideration while selecting clones for stand establishment for biomas production in short rotations and their restoration using regeneration force of shoots from tree stumps after felling.

4. Conclusions
Zaključci

The results of the presented research of two two-year cycles suggested that technology of dense planting of Eastern cottonwood (*Populus deltoides* Bartr. ex Marsh.) on fluvisol soil is one of the realistically possible ways for producing poplar wood intended for energy purposes.

The weight of biomass was estimated based on produced volume and value of the volume mass of wood. At the end of first two-year cycle, stand established with cuttings, the weight of biomass ranged from 10.35 t·ha^{-1} in clone 618 at density of (1.2 × 1.0 m) to 18.68 t·ha^{-1} in clone 55/65 at density of (1.2 × 0.5 m). Due to the regeneration force of shoots from tree stumps the weight of biomass in the second cycle ranged from 22.54 t·ha^{-1} in clone 618 at density of (1.2 × 1,0 m) to 33.86 t·ha^{-1} in clone 55/65 at density of (1.2 × 0.5 m).

When establishing stands of this type, special attention should be pied to selection of clones and planting density on appropriate soil (habitat).

Advantage should be given to clones with rapid growth in the juvenile stage of development and genetic traits of regeneration of stumps after felling, which enables restoration of stands using shoots from stumps in several cycles. The greatest amount of heating energy of 364,02 GJ·ha^{-1}would be obtained in subtreatment (c) at density of 1.2 × 0.5 m by combustion of biomass of the above ground part of clone 55/65 in the first cycle, and 659.83 GJ·ha^{-1} in the second or the total of 1023.85 GJ·ha^{-1},

Within the group of tested clones of Eastern cottonwood (*Populus deltoides* Bartr. ex Marsh.) the minimum quantity of heating energy of 202,38 GJ·ha^{-1} would be provided in subtreatment (a) at density of 1.2 × 1.0 m by combustion of above ground part of biomass in clone 618 in the first cycle, and 440.75 GJ·ha^{-1} in the second, or the total of643.13 GJ·ha$^{-1.}$

By introducing into production the clones of Eastern cottonwood (*Populus deltoides* Bartr. ex Marsh.), which were selected for chosen characteristics, a significant influence could be exerted on biomass yield per area unit in short cycles.

Combined with proper choice of clones at appropriate planting density and duration of production cycle, and with necessary care measures all needed prerequisites for a successful establishment of plantations for energy production (so called "energetic plantations") from renewable natural sources could be achieved.

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Sažetak

U cilju iznalaženja najpovoljnije tehnologije proizvodnje biomase za energetske potrebe, istraživanja su obavljena na Pokusnom dobru Instituta za nizijsko šumarstvo i životnu sredinu u neposrednoj blizini Novoga Sada u nasadima sa dvogodišnjim proizvodnim ciklusom, u poljskim uvjetima sa četiri klona i tri razmaka sadnje u dva turnusa. Klonovi u pokusu pripadaju američkoj crnoj topoli (*Populus deltoides* Bartr. ex Marsh.): cl. 457, cl. 450, cl. 618, cl. 55/65. Razmaci sadnje su: (a) 1,20 × 1,00 m ili 8.330 biljaka·ha^{-1}; (b) 1,20 × 0,75 m ili 11.110 biljaka·ha^{-1} i (c) 1,20 × 0,50 m ili 16.660 biljaka·ha^{-1}.

Zemljište na kojemu su obavljena istraživanja sustavno pripada tipu fluvisol, formi ilovastoj. Ovo zemljište je cijelom dubinom karbonatno i oglejano, vrlo duboko, sa fiziološki aktivnom dubinom oko 200 cm. Morfološka građa ovoga zemljišta je $A_{mo,p}$-IG_{so}-IIG_{so}-$IIIG_{so}$-IVG_{so}-G_r. Humusno akumulativni horizont (A-horizont) u teksturnom pogledu je ilovača, debljine 30 cm i ona je glavni nositelj fiziološke aktivnosti, sa sadržajem humusa preko 2,3 %. S dubinom se mijenja teksturni sastav, uglavnom raste udio frakcija pijeska, a opada udio humusa, što upućuje na akumulativni tip rasporeda organske materije u profilu. Podzemna voda oscilira na dubini od 90 do 220, cm što omogućuje povoljno vlaženje fiziološki aktivnog dijela profila, tj. aktivne zone rizosfere.

U ispitanom području klima je umjereno kontinentalna, s izvjesnim specifičnostima. Najhladniji mjesec je siječanj sa srednjom temperaturom zraka od –1,1 °C, najtopliji lipanj sa 20,3 °C, a srednja godišnja temperatura zraka je 10,9 °C. Prosječna količina padavina za područje na kojemu su obavljena istraživanja je 592 mm. Od prosječne godišnje količine padalina u vegetacijskom periodu padne 333 mm ili 56 %.

Prvi turnus je osnovan s reznicama dužine 20–25 cm, koje su predhodno potapane u vodi 24 sata.

U pogledu postotka primanja reznica nema statistički značajnih razlika i prosjek primanja za sve klonove iznosi 91,6%. Najmanji je postotak prijema (89 %) kod klona 618 zatim klona 450 (91 %), dok su klonovi 457 i 55/65 imali postotak prijema od 93 %.

Na kraju prvog dvogodišnjeg turnusa promjeri se nalaze u intervalu od 2,9 cm do 3,7 cm, a visine od 5,4 m do 6,2 m. Analize varijanci za promjere pokazuju da u prvom turnusu nema statistički značajnih razlika između klonova (glavni tretmani). Međutim, razlike u promjerima koje su uvjetovane različitim gustoćama nasada (podtretmani) statistički su vrlo značajne. U prvom turnusu među klonovima postoje statistički značajne razlike u visinama, što je uvjetovano genetskom varijabilnošću klonova, dok su u borbi za životnim prostorom (razmaci sadnje) razlike u visinama statistički vrlo značajne.

Analiza varijanci srednjih vrijednosti, na kraju drugog turnusa, ukazuju da su razlike i za promjere i za visine signifikantno različite. Kod svih klonova najveće dimenzije postignute su u razmacima sadnje 1,20 × 1,0 m, a najmanje u razmacima 1,2 × 0,5 m. U drugom turnusu, zbog jačine izbojne snage, svi klonovi bilježe znatno više vrijednosti promjera i visina. Promjeri se nalaze u intervalu od 3,9 cm do 5,1 cm, a visine od 6,6 m do 7,5 m.

Ukupno utvrđena masa drveta, kore i granjevine u prvom dvogodišnjem turnusu za korištene klonove američke crne topole *Populus deltoides* Bartr. ex Marsh. nalazi se u intervalu od 27,391 m^3·ha^{-1} kod klona 450 u podtretmanu (a) pri razmaku 1,2 × 1,0 m, do 42,006 m^3·ha^{-1} kod klona 618 u podtretmanu (c) pri razmaku sadnje 1,2 × 0,5 m.

Obnavljanje pokusnog nasada izvršeno je korištenjem izbojne snage iz panjeva. Tijekom prvog vegetacijskog razdoblja obnove iz panja izvršena je redukcija izbojaka, na način što je ostavljen po jedan najbolje razvijen izbojak na svakom panju.

Obnavljanjem nasada putem izdanačke moći iz panjeva proizvedena drvna masa u drugom dvogodišnjem turnusu nalazi se u intervalu od 54,664 m^3·ha^{-1} kod klona 55/65 u podtretmanu (a), do 79,235 m^3·ha^{-1} kod klona 450 u podtretmanu (c).

Rezultati ovih istraživanja potvrđuju realnu mogućnost obnavljanja nasada topola guste sadnje korištenjem izdanačke moći panjeva nakon sječe. Kod osnivanja nasada ovog tipa posebnu pozornost treba posvetiti izboru klona, sa svojstvima brzog rasta u juvenilnoj fazi razvoja i genetskim svojstvima regeneracije panjeva nakon sječe, kao mogućnosti obnavljanja nasada putem izbojaka iz panjeva u više turnusa. To pokazuju i razlike u proizvedenoj masi koja je za 49,7 % veća u drugom nego u prvom turnusu, u prosjeku za sve klonove i sve razmake sadnje.

Na temelju proizvedene mase i vrijednosti volumne mase drveta procijenjena je težina biomase. Na kraju prvog dvogodišnjeg turnusa težina biomase nalazi se u intervalu od 10,35 t·ha^{-1} kod klona 618 pri gustoći 1,20 × 1,00 m, do 18,68 t·ha^{-1} kod klona 55/65 pri gustoći 1,20 × 0,50 m. U drugom turnusu, zbog jačine izbojne snage, težina biomase nalazi se u intervalu od 22,54 t·ha^{-1} kod klona 618 pri gustoći 1,20 × 1,00 m, do 33,86 t·ha^{-1} kod klona 55/65 pri gustoći 1,20 × 0,50 m.

Da bi se mogla izvršiti procjena količine energije koja se dobija potpunom sječom stabala poslije prvog i poslije drugog dvogodišnjeg turnusa, određene su kalorične vrijednosti gornje toplinske moći za uzorke drveta i kore ispitivanih klonova prema standardnoj metodologiji u kalorimetrijskoj bombi.

Kalorične vrijednosti drveta i kore ispitanih klonova nalaze se u intervalu od 18,542 $MJ \cdot kg^{-1}$ kod klona 457 do 19,554 $MJ \cdot kg^{-1}$ kod klona 618.

Energetska vrijednost biomase neposredno je povezana s toplinskom moći drveta korištenih klonova, ali i s ostalim čimbenicima koji utječu na količinu i kvalitetu proizvedene biomase. Iz ovih podataka je vidljivo da je značajno veća količina energije proizvedena u drugom turnusu u odnosu na prvi, što je rezultat boljeg zakorjenjivanja i jake izbojne moći odabranih klonova.

Najveća količina toplinske energije dobila bi se u podtretmanu (c) pri gustoći 1,20 × 0,50 m, sagorijevanjem biomase nadzemnog dijela klona 55/65 i to 364,02 $GJ \cdot ha^{-1}$ u prvom turnusu, 659,83 $GJ \cdot ha^{-1}$ u drugom turnusu ili ukupno 1.023,85 $GJ \cdot ha^{-1}$.

U okviru grupe korištenih klonova američke crne topole *Populus deltoides* Bartr. ex Marsh. minimalna količina toplinske energije bi se osigurala u podtretmanu (a) pri gustoći 1,20 × 1,00 m sagorijevanjem nadzemnog dijela biomase kod klona 618 i to 202,38 $GJ \cdot ha^{-1}$ u prvom turnusu, 440,75 $GJ \cdot ha^{-1}$ u drugom turnusu ili ukupno 643,13 $GJ \cdot ha^{-1}$.