# ENERGY POTENTIAL OF POPLAR PLANTATIONS IN TWO SPACINGS AND TWO ROTATIONS

## ENERGETSKI POTENCIJAL NASADA TOPOLA SA DVA RAZMAKA SADNJE I DVIJE DUŽINE OPHODNJE

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**Summary**

The article presents the results which are related to the biomass yield of five poplar clones in the testing phase: *P. deltoides* cl. 'B-229', *P. deltoides* cl. 'B-81', *P. deltoides* cl. '182/81', *P. deltoides* cl. 'PE 19/66', and Euramerican poplar *P.* × *canadensis* cl. 'Pannonia', in experimental plantations of seven years, with planting space of 6×6 m (278 plants ha$^{-1}$) on two soil types. Also, the analysis of the biomass yield of the same clones that were established as dense plantations, by sprouting one shoot per stool after harvesting in the experimental plot at the Institute with the planting space 16667 plants ha$^{-1}$ (1.5 m between rows and 0.4 m within rows). The energy that could be obtained by biomass combustion, on base of wood calorific values for the examined clones has been estimated. It was found that the maximum (annual) weight of biomass, and thus also the energy in SRF plantations, are obtained by the clone 'PE 19/66' – 7.236 tha$^{-1}$, and 134.556 GJha$^{-1}$, respectively. However, clone 'B81', which achieves the maximum values in the SRC plantations (6.617 tha$^{-1}$ and 121.523 GJha$^{-1}$), has the least oscillations in all experiments and is very close to maximum values in SRF plantations.

KEY WORDS: poplar clones, spacing, biomass yield, energy

## Introduction
### Uvod

To mitigate climatic change caused by greenhouse gas emissions, the developed world is working to substitute fossil fuels with renewable energy sources. Short rotation forestry (SRF), i.e. fast-growing tree crops grown in carefully tended plantations for rotations shorter than 15 years have an important role to play, because of their numerous ecological benefits. This special type of forestry is concerned with maximization of wood biomass output per hectare for energy production. Highly productive pioneer species are willow and poplar species as a short rotation coppice (SRC) system. It is assumed that for the SRC system the first harvest takes place after 5 years and subsequently every three years up to an age of 20–25 years (willows), and for poplars 7–10 year rotations apply. Fertilization, annual weeding and mechanical harvesting are assumed. The density of SRC systems is assumed 9000–10000 stools per hectare (Laureysens et al., 2005). The SRIC system (short-rotation intensive culture) as applied in this context involves the establishment of plantations using genetically improved, clonally propagated, plant materials (i.e. willow and poplar species) at a density of ~15000 plants ha$^{-1}$, which are coppiced at the end of the first year and then managed on a three-year rotation (Tharakan et al., 2003). The biomass produced from short rotation coppice (SRC), such as willow and poplar, may have a number of uses: as a fuel for electricity generation plants; for the production of charcoal; as a soil amendment for clay caps; or simply as a carbon sink for atmospheric $CO_2$.

Poplars, which are the focus of this paper, have several characteristics that make them ideal for SRC systems, including high yields that can be obtained in a few years; case of vegetative propagation; a broad genetic base; a short breeding cycle;

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ability to resprout after multiple harvests; and feedstock uniformity. The idea of producing large amounts of wood biomass by the cultivation of fast growing tree species with different rotation periods is a well known approach of research at the Institute (Klašnja et al., 2002; 2002a, 2003, 2006; 2008; 2008a, 2008b, Orlović et al., 2003, 2004).

## Material and methods
### Materijali i metode

The research is done in three field trials situated in the North part of Serbia – Vojvodina Province. Vojvodina is distinguished by continental climate, and is marked by warm and rather dry summers, cold, severe winters and short transitional seasons (spring and autumn). Maximal temperatures in summer exceed 35 °C (to 38 and 39 °C), and absolute minimal ones decline to −25 °C (rarely to −30 °C). The highest amount of rainfall is in May and June (average 57 mm, 75 mm, respectively) while July and August are often very dry, (average 47 mm, 37 mm, respectively). In July and August, the monthly precipitation average is achieved in two to three days, and the periods without rainfall can be longer than two months. During spring (till May) low temperatures (even to −13 °C) might damage flowers and fruit set. Early autumn frost may also occur, though less frequently. Storm and hailstorm are regular phenomena from May until September, with highly irregular frequency.

Major characteristics of five poplar clones (4 clones belong taxonomically to Euramerican poplar and one to Eastern cottonwood) have been presented in Table 1.

**Experimental plot 1:** Experimental plot plantation was established by sprouting one shoot per stool after harvesting in the experimental estate "Kaćka šuma" (N 45°17' 36,7", E 19°52' 56,4"), with five experimental clones: four of Eastern cottonwood *P. deltoides* cl. 'B-229', cl. 'B-81', cl. '182/81' and cl.' PE 19/66', and one clone of Euramerican poplar (*P. × canadensis*) cl. 'Pannonia', with 16667 plants $ha^{-1}$. Experimental plantation was established on fluvisol – sandy soil. The main physical and chemical characteristics of the soil were determined by standard methods, based on which the soil was characterised as very favourable for poplar growing. The experiment was planted as a randomized complete block design with four blocks. Within the block each clone was planted once, in one row, with 50 plants. The spacing was 1.5 m between row and 0.40 m within plants in the row. Diameters and heights were measured on 20 plants per block.

**Experimental plot 2:** The trial was situated on the territory which is managed by Public Enterprise "Vojvodinašume" Forest Administration "Kupinovo", (N 44° 42' 23.34", E 20° 01' 59.63"), by planting one-year seedlings (1/1) on meadow brown soil on alluvial loess with 278 plants/ha. The experiment was planted as a randomized complete block design with four blocks. Within the block each clone was planted once, in one row, with 50 plants. The spacing was 6 m between row and 6 m between plants in the row. Diameters and heights were measured on 20 plants per block.

**Experimental plot 3:** The trial was situated on the territory which is managed by Public Enterprise "Vojvodinašume" Forest Administration "Višnjićevo", Management Unit "Banov Brod" 18a (N 44° 55'49.67", E 19° 22'57.61") on an area of 5.2 ha, by planting one-year seedlings (1/1) on alluvial semigley soil (humofluvisol), with 278 plants/ha. The experiment was planted in a randomized complete block design with four blocks. Within the block each clone was planted once, in one row, with 50 plants. The spacing was 6 m between row and 6 m between plants in the row. Diameters and heights were measured on 20 plants per block.

The plant diameters and heights were measured after the first and the second year (plants as stump shoots – Experimental plot 1), and after seventh growing season (plants in the plantation established by one-year seedlings – Experimental plots 2 and 3).

Biomass volume per unit area was calculated, as well as volume increment, and biomass weight (aboveground biomass weight, without leaves) was determined based on wood density of the analysed clones.

**Table 1.** Clonal taxonomy and characteristics
Tablica 1. Taksonomske osobine klonova

| Clones/ *Klonovi* | Taxonomy/ *Taksonomija* | Characteristics/ *Karakteristike* | Origin/*Porijeklo* |
|---|---|---|---|
| 'B-229' 'B-81' | *Populus deltoides* Bartr | Fast growth and low susceptibility to *Dothichiza populea, Marssonina brunnea* and *Melampsora* sp./ *Brzi rast i niska osjetljivost na Dothichiza populea, Marssonina brunnea i Melampsora sp.* | Serbia/*Srbija* |
| '182/81' | *(Populus × canadensis) × Populus deltoides* (Dode) Guinier | Fast growth and low susceptibility to *Dothichiza populea, Marssonina brunnea* and medium susceptibility to *Melampsora sp.,* high rooting ability by cuttings / *Brzi rast i niska osjetljivost na Dothichiza populea, Marssonina brunnea i srednja osjetljivost na Melampsora sp., visoka sposobnost ožiljavanja reznica* | Serbia/*Srbija* |
| 'PE 19/66' | *Populus deltoides* Bartr. | Fast growth, resistant to leaf diseases and low susceptibility to *Dothichiza populea*, high rooting ability by cuttings / *Brzi rast, otpornost na bolesti lista i niska osjetljivost na Dothichiza populea, visoka sposobnost ožiljavanja reznica* | Serbia/*Srbija* |
| 'Pannonia' | *Populus x canadensis* (Dode) Guinier | Medium growth potential, low susceptibility to *Dothichiza populea,* and *Marssonina brunea,* high rooting ability by cuttings / *Osrednji potencijal za rast, niska osjetljivost* na Dothichiza populea*, i* Marssonina brunnea *visoka sposobnost ožiljavanja reznica* | Hungary/*Madjarska* |

For the determination of calorific values of wood of the young plants the specimens were increment cores (Pressler's increment borer) taken at breast height (1.30 m) of sample trees (Pollanschutz 1963). For the older plants the specimens were 5 cm thick disks taken at breast height. 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 heat which could be produced by full combustion of the aboveground biomass (without leaves) per hectare was calculated based on the calorific value of wood of individual clones.

For the determination of moisture content, wood samples were oven dried at 104 °C to a constant weight. All analyses were done in duplicate and the results were expressed on a dry weight basis.

Wood density was determined on the basis of oven-dry weight per green volume of an individual wood specimen. Green volumes were obtained by soaking specimens in water until constant volume was achieved. Excess moisture was removed from the surface of the sample, and each sample's water displacement (volume) was measured. The sample was then oven-dried to constant weight at 104 °C and weighed to determine the dry weight.

The data were subjected to various statistical analyses including: means, calculation of parameter coefficient of variation, analysis of variance (ANOVA) and LSD test.

## Results and discussion
Rezultati istraživanja

### Growth elements – elementi rasta

Growth elements, and values of wood densities for examined poplar clones were determined within first and second years (Table 2 and 2a), and after seventh growing season (Tables 3, 4).

After first year of shoot growth, average height varied between 2.0 m and 2.8 m, and average diameter was from 1.2 cm to 2.5 cm. Volume, i.e. volume increment, calculated based on the average value of plant diameters and heights ranged from 4.32 $m^3ha^{-1}$ (cl. 'Pannonia') to 14.87 $m^3ha^{-1}$ (cl. 'B81'). Average wood volume of all clones amounted to 9.65 $m^3ha^{-1}$.

After the second year (cumulative, for two-year old plant), average height ranged between 6.1 m and 7.7 m, and average diameter varied between 3.5 cm and 4.5 cm. Coefficients of variation (C.V.) for diameters and heights of trees after first and second year were small. Results of ANOVA showed statistically high significant differences between clones ($F = 19.91^{***}$ and $F = 43.21^{***}$). Biomass volume ranged from 24.51 $m^3ha^{-1}$ (cl. '182/81') to 46.86 $m^3ha^{-1}$ (cl. 'B229'). Average biomass volume of all clones was 36.65 $m^3ha^{-1}$.

**Table 2.** Average diameters (Ds) and heights (Hs) after first growing season (Exp. plot 1)
Tablica 2 Srednji promjeri (Ds) i visine (Hs) nakon prve vegetacijske sezone (Pokus 1)

| Clone/ Klon | Ds, cm | C.V. | LSD | Hs, m | C.V. | LSD |
|---|---|---|---|---|---|---|
| 'PE 19/66' | 1.5 | 11.64 | c | 2.8 | 7.57 | a |
| 'B229' | 2.5 | 10.70 | a | 2.1 | 10.63 | b |
| 'B81' | 2.0 | 11.65 | c | 2.2 | 14.72 | b |
| '182/81' | 1.3 | 8.89 | c | 2.0 | 12.42 | b |
| 'Pannonia' | 1.2 | 9.68 | b | 2.1 | 12.19 | b |
| F | $35.61^{***}$ | | | $6.79^{***}$ | | |

*** P< 0,005

**Table 2a.** Average diameters (Ds) and heights (Hs) after second growing season (Exp. plot 1)
Tablica 2 Srednji promjeri (Ds) i visine (Hs) nakon druge vegetacijske sezone (Pokus 1)

| Clone/ *Klon* | Ds, cm | C.V. | LSD | Hs, m | C.V. | LSD | B.W.D[1] $kgm^{-3}$ | O.D.W.D[2] $kgm^{-3}$ |
|---|---|---|---|---|---|---|---|---|
| 'PE 19/66' | 3.7 | 5.94 | c | 6.1 | 4.08 | c | 320 | 361 |
| 'B229' | 4.5 | 4.67 | a | 6.1 | 3.35 | c | 361 | 429 |
| 'B81' | 4.1 | 8.79 | c | 7.0 | 3.70 | b | 387 | 445 |
| '182/81' | 3.5 | 7.69 | ab | 6.7 | 3.34 | a | 364 | 452 |
| 'Pannonia' | 4.5 | 4.15 | b | 7.7 | 3.73 | b | 360 | 449 |
| F | $19.91^{***}$ | | | $43.21^{***}$ | | | | |

[1]B.W.D - **basic wood density** / nominalna zapreminska masa
[2]O.D.W.D – **oven dry wood density** / apsolutno suha zapreminska masa

**Table 3.** Average diameters (Ds) and heights (Hs) after seventh growing season (Exp. plot 2)
Tablica 3. Srednji promjeri (Ds) i visine (Hs) nakon sedme vegetacijske sezone (Pokus 2)

| Clone/Klon | Ds, cm | C.V. | LSD | Hs, m | C.V. | LSD | Wood volume/ Zapremina drva $m^3ha^{-1}$ |
|---|---|---|---|---|---|---|---|
| 'PE 19/66' | 24.3 | 2.20 | a | 20.5 | 2.74 | a | 116.7 |
| 'B229' | 22.9 | 3.00 | b | 19.4 | 2.94 | ab | 101.4 |
| 'B81' | 23.1 | 4.89 | c | 19.7 | 3.86 | b | 102.8 |
| '182/81' | 20.8 | 3.13 | d | 18.7 | 5.17 | a | 80.6 |
| 'Pannonia' | 19.5 | 2.63 | ab | 20.1 | 3.86 | ab | 79.2 |
| F | $42.72^{***}$ | | | $5.82^{**}$ | | | |

Results of ANOVA for the Experimental plot 2 (Table 3) showed there are not significant differences between replications, but inter – clone differences were significant for diameters and heights ($F = 42.72^{***}$ and $F = 5.82^{***}$).

After seventh year of growth in the Experimental plot 2, average diameter varied between 19.5 cm and 24.3 cm, and average height was from 18.7 m to 20.5 m. This agrees with the

**Table 4:** Average diameters (Ds) and heights (Hs) after seventh growing season (Exp.plot 3)

Tablica 4. Srednji promjeri (Ds) i visine (Hs) nakon sedme vegetacijske sezone (Pokus 3)

| Clone/ *klon* | Ds, cm | C.V. | LSD | Hs, m | C.V. | LSD | Wood volume/ *Zapremina drva* $m^3ha^{-1}$ |
|---|---|---|---|---|---|---|---|
| 'PE 19/66' | 25.9 | 0.69 | a | 20.8 | 3.42 | b | 130.6 |
| 'B229' | 24.6 | 1.17 | b | 18.3 | 3.50 | c | 108.3 |
| 'B81' | 24.8 | 1.16 | c | 21.1 | 2.35 | c | 127.8 |
| '182/81' | 23.5 | 1.74 | c | 17.8 | 3.32 | a | 97.2 |
| 'Pannonia' | 23 | 1.92 | b | 22.1 | 3.61 | ab | 113.9 |
| F | 68.126*** | | | 51.006*** | | | |

values of Laureysens (2005), at 6 years, the DBH averaged over planting densities (500 to 1111 plants $ha^{-1}$) was from 17 cm to 18 cm, and the tree height averaged over planting densities was 16.60m to 18.08m for examined clones. Wood volume, ranged from 79.2 $m^3ha^{-1}$ (cl. 'Pannonia') to 116.7 $m^3ha^{-1}$ (cl. 'PE 19/66'). Average wood volume of all clones amounted to 96.11 $m^3ha^{-1}$.

After seventh year of growth in the Experimental plot 3, average diameter varied between 23.0 cm and 25.9 cm, and average height was from 17.8 m to 22.1 m. Wood volume, ranged from 97.2 $m^3ha^{-1}$ (cl. '182/81') to 130.6 $m^3ha^{-1}$ (cl. 'PE 19/66'). Average wood volume of all clones amounted to 113.89 $m^3ha^{-1}$. We can conclude that in both experiments the maximal yield was obtained by the same clone (cl. 'PE 19/66'), with the annotation that the increasing of around 12 % in the 3rd trial was presumably caused by the differences in soil type. The minimal yield was obtained by the clones '182/81' and 'Pannonia', and the differences attain the amount of 20 %. The value of middle average volume increment for all clones is also for around 18 % higher in the 3rd trial.

The values of wood density were used in the calculation of weight of mean trees, i.e. estimated weight produced biomass per unit area of plantation. The values of basic wood densities varied from 320 $kgm^{-3}$ (min) to 387 $kgm^{-3}$ (max), and oven dry from 361 $kgm^{-3}$ (min) to 452 kg $m^{-3}$ (max). This agrees with the values of the specific gravity of wood, being from 0.30 to 0.36 for several poplar clones (Goyal 1999), as well as with the values from 0.343 to 0.371 for *P. balsamifera* aged 7 years (Ivkovich 1996). Our previous research produced similar results for *P. deltoides* wood (aged 4 years) – 456 $kgm^{-3}$ (clone 457 aged 10 years), i.e. 368 $kgm^{-3}$ (Klašnja et al. 2003).

## Estimated biomass yield – Procijenjen prinos biomase

The weight of the harvested biomass per unit area was calculated based on the data on bulk density of the study clones. The values of average biomass weight after the first and the second year (Fig. 1) behaved similarly to the volume. Namely, the minimal values were measured for clone 'Pannonia' (1.941 DM $tha^{-1}$), while the maximal yield was shown by clone 'B81' (6.617 DM $tha^{-1}$).

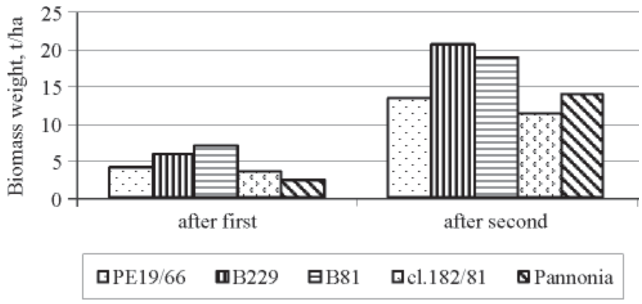


**Figure 1.** Estimated biomass DM yield after the first and the second year (Experimental plot 1)

Slika 1. Procijenjeni prinos biomase (apsolutno suha) nakon prve i druge godine (Pokus 1)

The minimal values of biomass weight after the second year (Fig.1), were measured for clone 182/81 (11.076 DM $tha^{-1}$), while the maximal yield was shown by clone B-229 (20.103 DM $tha^{-1}$).

This agrees with the literature data, because the yields given in the literature for poplars in SRC differ considerably. Mean annual increment (oven dry) lies between 20 $tha^{-1}$ and 35 $tha^{-1}$ (Ciria et al. 1995; Scarascia-Mugnozz a et al. 1997), but other publications report mean annual increment in the range of 2 $tha^{-1}$ to 3 $tha^{-1}$ (Schneider 1995). Average harvestable yields of poplars from SRC in temperate regions of Central Europe and North America range between 10 $tha^{-1}$ and 12 $tha^{-1}$ (Kauter et al. 2003). Riddel-Black (1998) reported that the yield of six poplar clones (16500 plants $ha^{-1}$) after the first growing season was 4.88 $tha^{-1}$to 9.54 $tha^{-1}$.

Regarding the data for the values of DBH, it can be noticed that the trees in the examined plantation (Experiment plots 2 and 3) haven't reached the dimensions needed for the mechanical processing, because the diameters are below 25 cm (except the cl. 'PE 19/66' in the 3rd trial, with a little bit higher value of diameter – 25.9 cm). Therefore, the wood can be used either as raw material for chemical processing (pulp production, mostly), or for producing thermal energy.

The minimum values of biomass weight per unit area (Experiment plot 2) are estimated for the clones Pannonia (28.500 $tha^{-1}$) and '182/81' (29.322 $tha^{-1}$), which fully agrees with the trends in the early stages of growth of examined clones (Experimen-

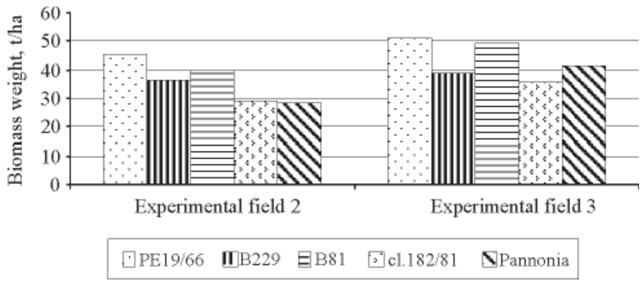


**Figure 2:** Estimated biomass DM yield after the seventh year (Experimental plots 2, 3)

Slika 2. Procijenjeni prinos biomase (apsolutno suha) nakon sedme godine (Pokusi 2 i 3) tal plot 1, Fig. 1). Maximum value of biomass weight was estimated for clone 'PE 19/66' (45.267 tha$^{-1}$). Clones 'B229' and 'B81', which in the case of young plantations with higher number of seedlings per hectare have the maximum values of biomass weight, have similar values, but about 11 % lower (cl. 'B81'), or about 19 % lower (cl. 'B229') from the maximum estimated values in the experiment with older plants.

The lowest values of biomass weight per unit area in Experimental plot 3 are estimated to clone '182/81' (35.389 tha$^{-1}$) and clone 'B229' (39.108 tha$^{-1}$), which is in complete accordance with the trends in the early stages of growth of examined clones (Experimental plot 1), as well as with the values in the same experiment on another type of soil (Experimental plot 2). Maximum values of weight of biomass were estimated for clone 'PE 19/66' (50.655 tha$^{-1}$). Mutual comparison of results for the yield of biomass in the Experimental plot 2, and 3, it can be concluded that there are differences in all tested clones, and they are reflected in the higher yield of approximately 20 % in the case of average values.

Differences between the maximum yield for clone 'PE 19/66' are about 12 % in favor of Experimental plot 2, which was founded on meadow brown soil on alluvial loess, while the minimum value for the clone '182/81' also differ by about 20 %. The difference in yield is caused by the differences in moistening and content of dust and clay fractions in meadow brown soil and in humofluvisol (Živanov and Ivanišević 1986, Galić 2000). If the annual biomass yields are observed in experimental plot 2, they range from 4.071 tha$^{-1}$ for the clone 'Pannonia' (min), and to the 6.467 tha$^{-1}$ for clone 'PE 19/66'. In experimental plot 3, the annual biomass yields range from 5.055 tha$^{-1}$ for clone '182/81' (min), to 7.236 tha$^{-1}$ for clone 'PE 19/66'.

The data in literature presents that the plantation of 10000 plants ha$^{-1}$ above-ground woody biomass production per year averaged 1.6–9.7 tha$^{-1}$ (Tharakan et al. 2003) at the end of the second rotation. These production levels range within values found in other studies. According to the data given by Fang (1999), for Euramerican clones, the highest biomass, 78.4 tha$^{-1}$ and 71.8 tha$^{-1}$ respectively was achieved under the combination of 1111 plants ha$^{-1}$ with 6 year rotation length. However, at 6 years *P.deltoides* the highest biomass occurred at the combination of 833 plants ha$^{-1}$ with 6 year rotation, i.e. 75.8 tha$^{-1}$. By the end of 6 years, the biomass productivity averaged over four planting densities was from 10.5 tha$^{-1}$ to 11.4 tha$^{-1}$. This large range of biomass yield per hectare, are primarily a reflection of characteristics of poplar clones that were researched and the characteristics of specific habitats on which the experiments were established, and only then the density of plantations, and the possibility of development of plants in defined time periods in dense or rare formations.

## Estimated heating energy yield – Procijenjena količina toplotne energije

The energy yield is a relevant criterion for biomass use as fuel. It can be related to land surface, weight or volume of harvested biomass. The mean energy content related to the dry matter of biomass is therefore a stable feature within a particular type of biomass and more or less independent of external factors. Average heating values of the analysed poplar clones ranged in a very narrow interval from 18.261 MJkg$^{-1}$ (clone '182/81') to 18.656 MJkg$^{-1}$ (clone '129/81'). This agrees fully with the values of our previous research (Klašnja et al. 2006, 2008, 2008a), and the values reported by Ciria (1995) for heating values of SRIC poplar wood (3–5-year old stem and branches) 18.1MJkg$^{-1}$ to 18.3 MJkg$^{-1}$. Benetka (2002), for 1–3 year old poplar clones (wood at breast height and basal part, and branches) reported heating value from 18.60 MJkg$^{-1}$to 19.27 MJkg$^{-1}$.

The values of estimated energy yield per plantation unit area, and plant age (the first or the second year) in Experimental plot 1, are presented in Fig. 3.

Maximal estimated energy which can be produced by the combustion of the total (aboveground) biomass after the first year (without leaves) was 121.523 GJha$^{-1}$ (for clone 'B81') and 3.4 times higher than the minimum for the clone 'M1' (35.579 GJha$^{-1}$).

After the second year the values for the clones were similar to biomass yield, so the ratio of the maximal energy yield for clone 'B229' (408.843 GJha$^{-1}$), and minimal energy yield 147.243 GJha$^{-1}$ for clone 'PE 19/66' was about 2.8 : 1. If the values of yield are compared, especially the evaluated energy after first and second year of growing, it is evident that the values at the end of second year are significantly higher, for all clones.

Estimated values of energy yield that could be obtained by combustion of biomass of plantations after the seventh year of vegetation in the Experimental plot 2, range from 528.162 GJha$^{-1}$ for clone 'Pannonia' and 535.453 GJha$^{-1}$ for clone '182/81', to 841.688 GJha$^{-1}$ for clone 'PE 19/66' which reaches the maximum value (Fig. 4).

Estimated values of energy yield that could be obtained by combustion of biomass of plantations after the seventh year of vegetation in the Experimental plot 3 range from minimum 646.236 GJha$^{-1}$ for clone '182/81', to 941.889 GJha$^{-1}$ for clone 'PE 19/66' that reaches the maximum value (Fig. 4).

Trend that is noticed considering the average annual yield of biomass per hectare is achieved in terms of energy which could be obtained by combustion. The best results are achieved

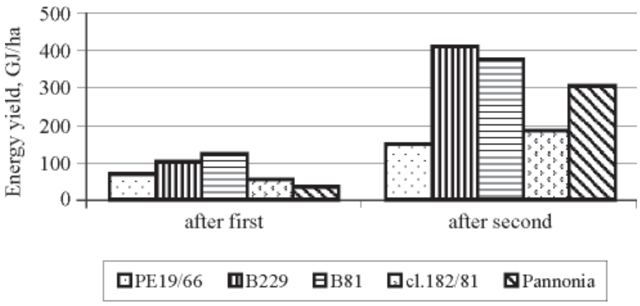


**Figure 3:** Estimated energy yield after the first and the second year (Experimental plot 1)

Slika 3. Procijenjena toplotna energija nakon prve i druge godine (Pokus 1)

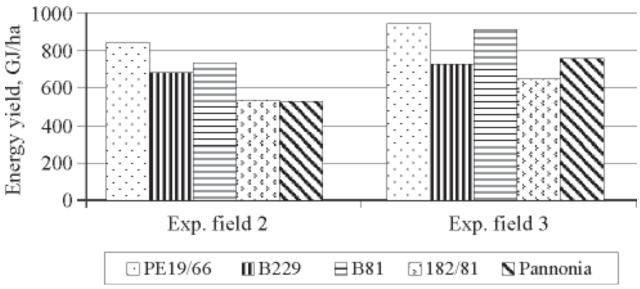


**Figure 4:** Estimated energy yield after the seventh year (Experimental plots 2, 3)

**Slika 4.** Procijenjena toplotna energija nakon sedme godine (Pokusi 2 i 3)

by the clone 'PE 19/66' in the seven-year plantation. It gives the maximum amount of energy of 120.241 $GJha^{-1}$ per year in the Experimental plot 2, and 134.556 $GJha^{-1}$ in the Experimental plot 3. In the SRC plantations this clone is significantly behind in comparison with the 'B81' clone that gives the highest yield of 121.523 $GJha^{-1}$. However, it should be noted that the clone 'B81' behave similarly in all experiments, i. e. that the oscillations of yield and biomass energy are small, and that the seven-year plantation do not show maximum, but they are very close to the maximum values obtained by the clone 'PE 19/66'. The maximum value is achieved at the Experimental plot 3, which is about 12 % higher in comparison to other plantations.

Comparing the minimum values the same trend is recognized – the largest amount of energy by cl. '182/81' of 92.319 $GJha^{-1}$, which is compared with the clone 'Pannonia', which gives the least amount of energy in the SRF, of only 35.579 $GJha^{-1}$. Ratio between the minimum values is 1 : 2.6, which is also found in the analysis of dendromass yield, because the differences between the calorific values of wood of some clones are minor.

## Conclusions
### Zaključci

The research was carried out in three plot experiments established in the North part of Serbia – Vojvodina Province. Results presented for biomass production of five poplar clones in the testing phase: *P. deltoides* cl. 'B-229', *P. deltoides* cl. 'B-81', *P. deltoides* cl. '182/81', *P. deltoides* cl. 'PE 19/66', and Euramerican poplar *P. × canadensis* cl. 'Pannonia', in plantations of seven years with spacing of 6 × 6 m (278 plants $ha^{-1}$, Experimental plots 2, 3) on two soil types. Also, the analysis of the biomass production of the same clones that were established as dense planting distance has been done, by the sprouting one shoot per stool after harvesting in the Experimental plot 1, at planting space with 16667 plants $ha^{-1}$. The energy that could be obtained by biomass combustion, on base of calorific (heating) values for the examined tree clones has been estimated.

In the SRF plantations in Experimental plot 3, is achieved the highest yield of both biomass and energy. It is in the range of minimum 646.236 $GJha^{-1}$ for clone '182/81', to 941.889 $GJha^{-1}$ for clone 'PE 19/66' that reaches the maximum value. This clone is the best in the Experimental plot 2, too. In the SRC plantations the maximum is achieved by clone 'B81', and it has the least fluctuations in all experiments and it is very close to maximum values in SRF plantations. Maximum annual energy yield for all experimental plots were in narrow spacing density from 120.241 $GJha^{-1}$ (cl. 'PE 19/66', Exp. plot 2) to 134.556 $GJha^{-1}$ (cl. 'PE 19/66', Exp. plot 3).

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## Sažetak

U radu su prikazani rezultati koji se odnose na produkciju biomase pet klonova topola u fazi testiranja: *P. deltoides* cl. ‚B-229', *P. deltoides* cl. 'B-81', *P. deltoides* cl. '182/81', *P. deltoides* cl. 'PE 19/66', i euroameričke topole *P. × canadensis* cl. 'Pannonia', u pokusnim plantažama starosti sedam godina, u razmaku sadnje 6 × 6 m (278 biljaka po jedinici površine) na dva tipa tla. Također je izvršena analiza produkcije biomase istih klonova u gustim plantažama, u razmaku sadnje biljaka 1,5 × 0,4 m (16667 biljaka po jedinici površine). Na osnovi vrijednosti volumne mase drveta ispitanih klonova, određena je masa suhe tvari drveta po jedinici površine, a zatim na bazi kalorijske vrijednosti drva za ispitivane klonove procijenjena je energija koja bi se mogla dobiti sagorijevanjem biomase. Rezultati su pokazali da maksimalnu godišnju biomasu u pokusu 1 postiže klon 'B81' (6,617 DM tha$^{-1}$) nakon prve godine, i klon 'B-229' (20,103 tha$^{-1}$) nakon druge godine (slika 1), što je u potpunosti suglasno s literaturnim navodima. Utvrđeno je da se maksimalna godišnja biomasa u plantažama kratkih ophodnji od 7,236 tha$^{-1}$ biomase dobiva za klon 'PE 19/66' (pokus 2, slika 2). Važno je napomenuti da klonovi 'B-229' i 'B81'koji u nasadima s velikim brojem biljaka po hektaru (slika 1) imaju maksimalne produkcije sličnih vrijednosti, za 11 %, odnosno za 19 % niže od postignutog maksimuma u pokusu 2. Razlike u vrijednostima produkcije u pokusima 2 i 3 posljedica su utjecaja tla na biomasu svih klonova (slika 2). Procijenjene vrijednosti toplinske energije (slike 3 i 4) imaju isti trend kao i biomasa. Maksimalne vrijednosti u plantažama kratkih ophodnji postiže klon ‚PE 19/66' i to 134,556 GJha$^{-1}$ (slika 4), na oba tipa tla. Međutim, klon ‚B-81', koji postiže maksimalne vrijednosti u kulturama kratkih ophodnji od 121,523 GJha$^{-1}$ (slika 4, pokus 2 i 3), ima najmanje oscilacije u svim pokusima i vrlo je blizu maksimalne vrijednosti u SRF plantažama.

Ključne riječi: klonovi topola, razmaci sadnje, biomasa, energija