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POPLAR BIOMASS OF HIGH DENSITY SHORT ROTATION PLANTATIONS AS RAW MATERIAL FOR ENERGY PRODUCTION

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ABSTRACT

The aim of this study is to present the results of examination of mean annual increment and estimated energy production of plantations with a high number of poplar plants per hectare: seven experimental clones of eastern cottonwood *P. deltoides* cl. B-229, cl. B-81, cl. 129/81, cl. 182/81, cl. 181/81, cl. PE 4/68, cl. 665 and Euramerican black poplar *P. x euramericana* cl. M-1 (16667 plants per hectare). Based on measured parameters of growth elements of mean trees in two plantations, biomass (oven dry) weights per hectare were calculated after one year and two years, and the potential energy obtained by combustion of the total aboveground biomass (stem and branches, without leaves) was estimated. The estimated average energy yield of 64.883 GJ/ha (for all clones) in the first year, is significantly higher in the second year and amounts to 260.741 GJ/ha, which is the increase by about four times, with significant interclonal differences.

KEY WORDS: poplar clones, biomass, heating value, energy

INTRODUCTION

According to the European Commission's White Paper (European Commission 1997), the overall aim is to double the share of renewable energy from 6% (in 1999) to 12% of the total energy consumption in the European Union by 2010. According to the White Paper, the major part of this renewable energy could come from woody biomass. This means that, additionally, over 160 million m^3 of woody biomass per year would be used for energy in Europe (Parikka 2004).

Most projections of global energy use predict that biomass will be an important component of primary energy sources in the coming decades, and that SRC (Short Rotation Coppice) will be a primary source of biomass (Kuiper et al. 1998). In addition to combustion and gasification conversion pathways for power and heat production, SRC represent a uniform, locally available feedstock for the production of bioproducts - liquid fuels, chemicals and advanced materials - currently made from petroleum products. SRC has the potential to become an important source of renewable energy in Europe because of high biomass yields, good combustion quality as solid fuel, ecological advantages and comparatively low biomass production costs (Kauter et al. 2003). In northern temperate areas, SRC development has focused on willow clones (*Salix* spp.) and hybrid poplar (*Populus* spp.), while eucalyptus (*Eucalyptus* spp.) has been a model species in warmer climates. The main barrier for a more common use of biomass from SRC as a renewable energy source is the economic background. As an energy source, wood from SRC has to compete with fossil fuels, residues from agriculture (e.g. straw) and forestry, as well as with other renewable energy sources and, in most cases, it is inferior under the given economic and political frame conditions. Consequently, in order to promote the use of biomass from SRC as an energy source, the costs of its production and use have to be decreased. This can, among other things, be attained by increasing the biomass yield and optimising the fuel quality. Plantations help ease shortage of forestry wood. The establishment of new plantations is assumed to increase between 160 and 235 million ha in 2050 (Whityeman 1999). A substantial increase in the area of short rotation forestry production systems will be required to fill the gap between wood supply and demand by both the traditional timber and wood processing industries and the renewable energy sector.

Among the main conditions of energy forestry at a wider level, the decisive role is that of the available land area. However, the actual production areas in Europe are rather small. For this reason, in many cases, energy plantations compete with agricultural lands or other land uses. To eliminate the competition and its undesirable impacts between energy and agricultural production, numerous analysts propose the reduction of energy production to degraded sites in the developing countries. This will intensify the trend of using marginal lands, abandoned agricultural lands, semi-harvested or unharvested coppice forests of poor quality, land along the roads and water courses, etc.

Under short rotation intensive management, the end product is generally woody biomass (feedstock) and as such, tree size and form are not of particular importance. Management objectives centre on maximizing annual woody biomass yield per unit area. The success of the biomass production concept depends, in part, on the efficient production systems. Agricultural management practices (plant spacing, high density, use of herbicides, short rotation and regular harvests) are applied to fast growing tree species. Poplars, which are the focus of this paper, have several characteristics that make them ideal for SRC system, including high yields that can be obtained in a few years; case of vegetative propagation; a broad genetic base; a short breeding cycle; 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 (Klasnja et al. 2002, 2002a, 2002b, 2002c, 2003, Orlovic et al. 2003, 2004, Fischer et al. 2005, Kauter et al. 2003).

The aim of this study is to present the results of examination of mean annual increment and estimated energy production with the so-called energy plantations, i.e. plantations with the high number of poplar plants per hectare. Based on measured parameters of growth elements of mean trees in two plantations, biomass (oven dry) weights per hectare were calculated after one year, two years and three years, and the potential energy obtained by combustion of the total aboveground biomass (stem and branches, without leaves) was estimated.

MATERIAL AND METHODS

Experimental field plantations were established by sprouting one shoot per stool after harvesting in the experimental estate "Kacka Suma" (N 45°17' 36,7" E 19°52' 56,4"), with seven experimental clones of eastern cottonwood *P. deltoides* cl. B-229, *P. deltoides* cl. B-81, *P. deltoides* cl. 129/81, *P. deltoides* cl. 182/81, *P. deltoides* cl. 181/81, *P. deltoides* cl. PE 4/68, *P. deltoides* cl. *665* and Euramerican black poplar *P. x euramericana* cl. M-1, planting space with 16667 plants per hectare (1.5 m between rows, and 0.4 m within rows). Experimental plantations were established on two different forms of fluvisol – sandy and loamy (Plantation 1 and Plantation 2). 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.

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 in June, while July and August are often very dry. 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.

After the selection of characteristic sample trees, measured parameters of growth elements were determined. Sample trees were chosen as average plants based on average diameter and height on the experimental plot (three trees per each clone and age, in both plantations). The plants are stump shoots, and plant diameters and heights (mean trees) were measured after the first, the second and the third year of plantation age. Biomass volume per unit area was calculated, as well as volume increment, and biomass weight (aboveground biomass weight) was determined based on bulk density of the analysed clones. The heat which could be produced by full combustion of the aboveground biomass per hectare was calculated based on the calorific value of wood of individual clones.

The specimens, two increment cores (Pressler's increment borer) were taken at breast height (1.30 m) of sample trees. The first increment core was fixed at approximately 45° to the axis of maximum diameter, and the second was moved for 90° in relation to the axis of the first core (Pollanschutz, J., 1963). 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.

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 calorific value was determined for ground air-dried samples. Pellets were made by a special device producing pellets ranging from 0.60g to 0.85g. Samples were combusted in C200 IKA Werke calorimeter. There were three replications for each sample.

RESULTS AND DISCUSSION

Growth elements of the selected trees - average diameters and heights within first and second years, and values of wood densities for examined poplar clones were determined (Tab. 1).

Tab. 1: Average diameters (Ds), heights (Hs), and wood densities in two plantations

Plantation 1									
		PE4/68	B229	665	129/81	B81	182/81	M1	181/81
1st year	Ds, cm	1.2	1.3	1.2	1.2	1.2	1.1	0.9	0.9
	Hs, m	2.4	2.3	2.2	2.4	2.3	2.2	2.1	2.1
2nd year	Ds, cm	4.4	4.2	4.3	4.9	5.6	5.4	4.2	3.4
	Hs, m	8.6	8.2	8	8.9	9.3	8.8	8.3	7.5
Wood density, kgm^{-3}		372	435	378	387	440	441	456	437
Plantation 2									
1st year	Ds, cm	1.5	2.5	1.8	2.0	2.0	1.3	1.2	1.1
	Hs, m	2.8	2.1	1.9	2.5	2.2	2.0	2.1	2.2
2nd year	Ds, cm	3.7	4.5	4.9	4.9	4.1	3.5	4.5	3.0
	Hs, m	6.1	6.1	6.2	6.2	7.0	6.7	7.7	5.5
Wood density, kgm^{-3}		361	429	366	394	445	452	449	425

After one year of shoot growth, average height in both plantations varied between 1.9m and 2.8m, and average diameter was from 0.9cm to 2.5cm. Volume, i.e. volume increment, calculated based on the average value of plant diameters and heights ranged from 3.43 m^3ha^{-1} (cl. 181/81) to 14.87 m^3ha^{-1} (cl. B81). Average wood volume of all clones amounted to 7.75 m^3ha^{-1} in plantation 1, i.e. 9.65 m^3ha^{-1} in plantation 2 (Fig. 1). Clone 181/81 showed the minimal volume increment in both plantations, while clone B81 was considerably better in plantation 2, showing the greatest difference by 9.37 m^3ha^{-1}, which can be related to a somewhat lower number of plants per unit area.

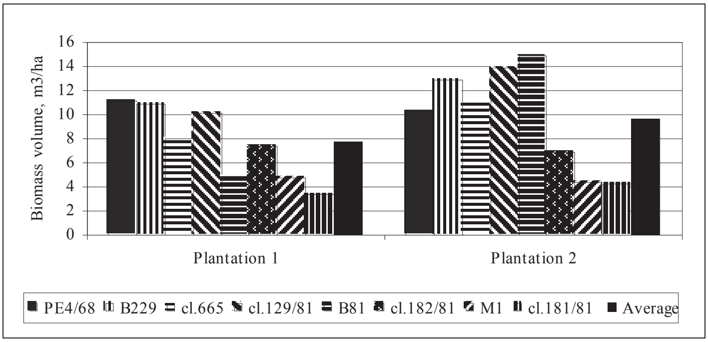

Fig. 1: Biomass volume after the first year

After the second year (cumulative, for two-year old plant), average height ranged between 5.5m and 8.9m, and average diameter varied between 3.0cm and 5.6cm. Biomass volume ranged from 16.65m^3ha^{-1} (minimal for cl.181/81) to 51.71 m^3ha^{-1} (maximal for cl.B229). The yield of most clones is similar in both plantations, except of the clones PE4/68 and B229 which exhibited the differences in biomass volume in different plantations. Average biomass volume of all clones was 34.32 m^3ha^{-1} in plantation 1 and 34.82 m^3ha^{-1} in plantation 2. Although the average values were almost identical, there were significant differences among the clones, clone

181/81 was inferior again (its increment was minimal, like after the first year). The maximal biomass volume was attained by clone B229, which was exceptionally good in both plantations, while the yield of clone PE4/68 was near to maximal only in plantation 1 (Fig. 2).

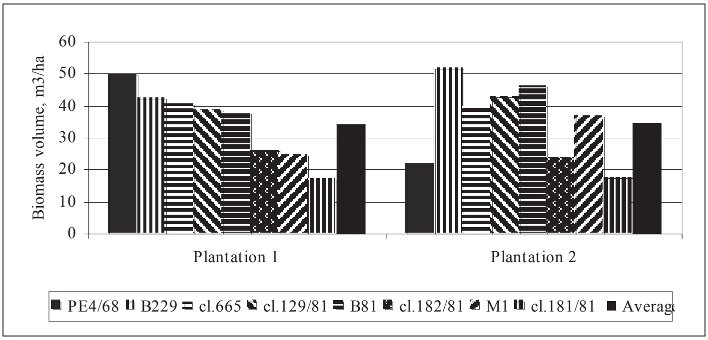

Fig. 2: Biomass volume after the second year

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. Mean values of poplar wood density of examined 7 clones are presented in Tab. 1. The values of basic wood densities varied from 320 kg m $^{-3}$ (min) to 408 kg m $^{-3}$ (max) and from 361 kg m $^{-3}$ to 456 kg m $^{-3}$ (oven dry). This agrees with the values of the specific gravity of wood, being from 0.30 to 0.36 for several poplar clones (Goyal et al. 1999), as well as with the values from 0.343 to 0.371 for *P. balsamifera* L. aged 7 years (Ivkovich, 1996). Our previous research produced similar results for *P. deltoides* wood (aged 4 years) - 456 kg m $^{-3}$ (clone 457 aged 10 years), i.e. 368 kg m $^{-3}$ (Klasnja et al. 1998, Klasnja et al. 2003a).

There is a close relation between biomass dry matter yield and energy yield. In the aim to assess the produced energy of the obtained biomass in different poplar plantations, the mass of oven-dry wood were previously calculated per unit area. Assessment of produced biomass weight after first and second year was on the basis of wood density (Figs. 3, 4).

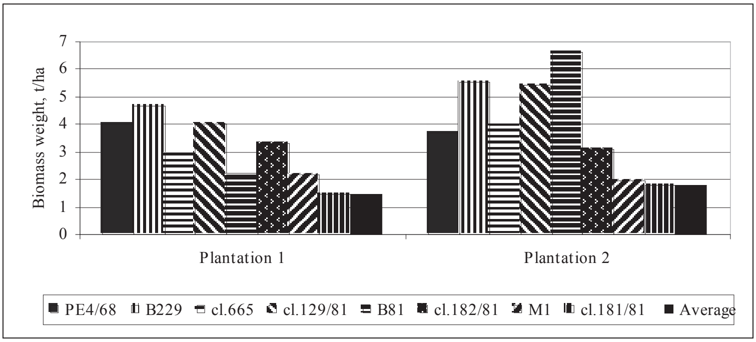

Fig. 3: Estimated biomass yield after the first year

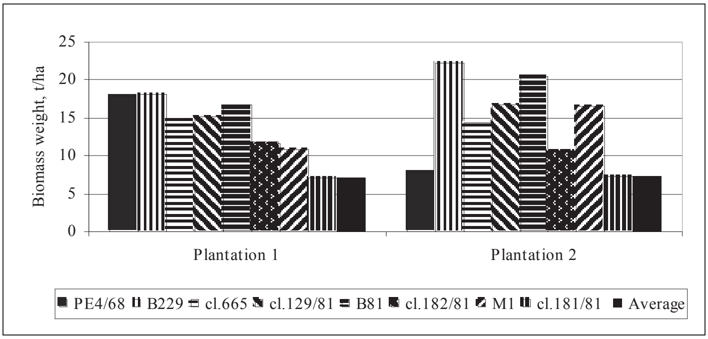

Fig. 4: Estimated biomass yield after the second year

The values of average biomass weight after the first year behaved similarly to the volume. Namely, the minimal values were measured for clone 181/81 (1.458 t ha^{-1} in plantation 1 and 1.781 t ha^{-1} in plantation 2), while the maximal yield was shown by clone B81 in plantation 2 (6.617 t ha^{-1}). As for the average value in both plantations, the best clone was B229, because it attained a high biomass yield on both soil types - average 5.101 t ha^{-1}. Biomass yield after the second year was much more uniform in the study plantations, which means that the effect of soil type was much lower. However, the differences among individual clones were great – e.g., the maximal yield (cl.B229 - 22.183t ha^{-1}) was more than three times higher than the minimal yield (cl.181/81 - 7.076t ha^{-1}). During the second year, the increase in yield (volume increment expressed as biomass weight) was from 5.601t ha^{-1} for clone 181/81 (min), to 15.002t ha^{-1} for clone B229 (max). This agrees with the literature data, because the yields given in the literature for poplars in SRC differ considerably. Maximum yields lie between 20 and 35 o.d.tha^{-1} yr^{-1} mean annual increment (Ciria et al. 1995, Scarascia et al. 1997), but other publications report mean annual increment in the range of 2 - 3 o.d.t ha^{-1} yr^{-1} (Schneider 1995). Average harvestable yields of poplars from SRC in temperate regions of Central Europe and North America range between 10 and 12 o.d.t ha^{-1} yr^{-1} (Kauter et al. 2003). The yield after the first year (18,000 plants ha^{-1}) ranges from 2.2 to 3.6 o.d.t ha^{-1} for poplar clones and 2 to 2.5 o.d.t ha^{-1} year^{-1} for willow clones (Hanson 1991). Riddel-Black et al. (1996) report that the yield of six poplar clones (16,500 plants ha^{-1}) after the first growing season was 4.88 to 9.54 o.d.t ha^{-1}.

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. In relation to harvested biomass, the energy yield is mainly determined by the contents of energy-rich compounds, such as lignin, resin or cellulose. As the share of these components in different fractions of the biomass (bark, wood, twigs) differs, there are differences in the energy concentration of these fractions. 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 value of the analysed poplar clones ranged in a very narrow interval from 17,340 MJ/kg (clone M1) to 18,743 MJ/kg (clone B229). This agrees fully with the values of our previous research (Klasnja et al. 2002, 2006), and the values reported by Ciria et al. (1995) for heating values of 3 – 5-year old SRIC poplar wood (stem and branches) 18.1 – 18.3 MJ/kg. Benetka et al. (2002) for 1-3 year old poplar clones (wood at breast height and basal part, and branches) reported heating value from 18.60 MJ/kg to 19.27 MJ/kg.

The values of estimated energy yield per plantation unit area, depending on the soil type (locality), and plant age (the first or the second year) are presented in Fig. 5 and 6.

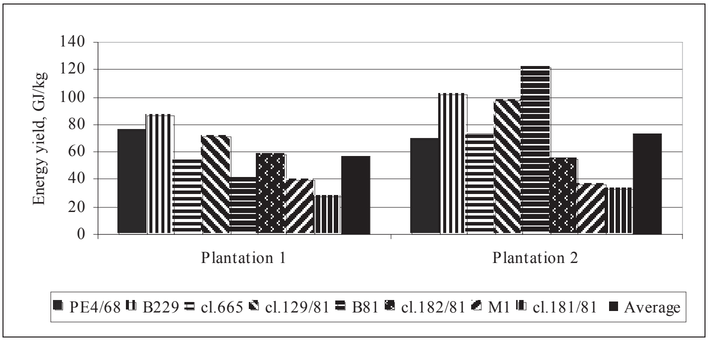

Fig. 5: Estimated energy yield after the first year

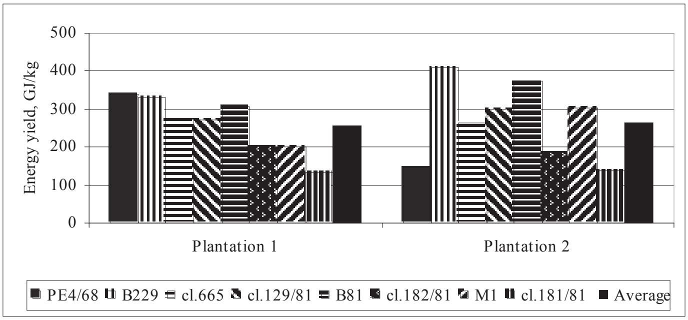

Fig. 6: Estimated energy yield after the second year

If average estimated energy which can be produced by the combustion of the total (aboveground) biomass (without leaves) is observed independent of localities, as it had already been inferred that the effect of soil type on the yield was eliminated after the second year, it can be concluded that the significant increase in biomass yield also conditioned the great increase in the estimated energy per hectare of plantation. Namely, the average of 64.883 GJ ha^{-1} (for all clones) after the first year, is significantly higher in second year and amounts to 260.741 GJ ha^{-1}, which is the increase by about four times. The ratios between the clones were similar to biomass yield, so the ratio of the maximal energy yield (max. clone B229), and minimal energy yield (min. clone 181/81) was about 3:1.

Ii is interesting to analyse biomass increment during the second year, because it was a great deal higher for all clones than in the first year. Namely, the average biomass increment weight in the first year was only about 3.5t/ha, because of the relatively small sizes of plants which sprouted on the stump. The yield in the second year was significantly higher, and it was average 10.706 t ha^{-1} (annual increment), i.e. depending on the clone, it ranged between 5.601 t ha^{-1} (min cl.181/81), to 15.002 t ha^{-1} (max cl.B229). It should be noted that in plantation 2, the plants were left on the stumps also during the third year. The measurements show a very low biomass increment in the third year. Average weight of annual increment was only 1.319 t ha^{-1}, and it ranged from 0.590 t ha^{-1} (min cl.181/81), to 2.118 t ha^{-1} (max cl. B81). The cause of such a sharp decline of biomass increment should be the fact that the optimal rotation for planting space (1.50 x 0.40m) is two years. This is indicated by the increment of both plant height and diameter, because the ratio of diameter increase in the second year and the first year is 2:1, and the ratio of height as much as 3:1. The significant decrease in volume increment in the third year could also be the fact that in such a dense plantation, as individual sprouts were left on each stump, the plants do not have sufficient living space, which leads to a significant growth stagnation.

CONCLUSIONS

Eight poplar clones (7 clones of eastern cottonwood, and one clone of black poplar), which are in the phase of selection at the Institute of Lowland Forestry and Environment, were researched. Wood density and higher heating value of wood were determined in the aim to estimate the energy which could be produced by full combustion of the total aboveground biomass in the plantation with 16,667 plants per hectare. The plantations were established from stool shoots (one per stump), at two localities (two soil types), and heights and diameters of mean plants were measured after the first and after the second vegetation. The volume was calculated and then the weight of the produced biomass in both plantations, and the energy per unit area of plantation was estimated.

The above results indicate that the selected clones with relatively high values of wood density and high volume increment, such as the clones PE4/68, B229, B81, and also all other clones included in the research, can reach significant biomass yield if the plantations are established by resprouting from stump after harvest, in the period of two years. The values of average biomass weight after the first year behaved similarly to the volume and they differ significantly between the clones. Namely, the minimal values were measured for clone 181/81 (1.458 t ha^{-1}), while the maximal yield was shown by clone B81 (6.617 t ha^{-1}). As for the average value in both plantations, the best clone was B229, because it attained a high biomass yield on both soil types - average 5.101 t ha^{-1}. Biomass yield after the second year was much more uniform in the study plantations, which means that the effect of soil type was much lower. Volume increment (expressed as biomass weight) in the second year was from 5.601 t ha^{-1} for clone 181/81 (min), to 15.002 t/ ha^{-1} for clone B229 (max). Calculated into energy, this makes the average of 64.883 GJ ha^{-1} (for all clones) after the first year, and significantly more after the second year, average 260.741 GJ ha^{-1}, which is the increase by about four times.

After a two-year rotation, plant development decreased sharply and also biomass yield decreased significantly. In the above analyses cl.181/81 was inferior regarding biomass increment. As it is a poplar clone which has a high value of wood density, just as the other analysed clones, the future research should avoid the limitations which could affect the plant growth in such an experiment. In this way, the potential of the analysed clones could be utilised to a much higher extent.

REFERENCES

1. Benetka, V., Bartakova, I., Mottl, J., 2002: Productivity of *Populus nigra* L., ssp.*nigra* under short-rotation culture in marginal areas. Biomass and Bioenergy 23(5): 327-336
2. Ciria, M.P., Mazón, P., Carrasco, J., Fernandez, J., 1995: Effect of rotation age on the productivity of poplar grown at high plantation density. Biomass for energy, environment, agriculture and industry, Vienna, Austria Proceedings of the Eighth European Biomass Conference: Pp. 489–494
3. European Commission., 1997: Energy for the future, renewable sources of energy. White Paper for a Community Strategy and Action Plan Communication from the commission, FOR/086/97, Brussel
4. Fischer, G., Prieler, S., Van Veltuizen, H., 2005: Biomass potentials of miscanthus, willow and poplar: results and policy implications for Eastern Europe, Northern and Central Asia. Biomass and Bioenergy 28(2): 119-132
5. Goyal, G.C., Fisher, J.J., Krohn, M.J., Packood, R.E., Olson, J.R., 1999: Variability in pulping and fiber characteristics of hybrid poplar trees due to their genetic makeup, environmental factors, and tree age. TAPPI 82(5): 141-147
6. Hanson, E.A., 1991: Poplar woody biomass yields; a look to the future. Biomass and Bioenergy: Pp. 1-7
7. Ivkovich, M., 1996: Genetic variation of wood properties in balsam poplar (*Populus balsamifera* L.). Silvae Genetica 45(2-3): 119-124
8. Kauter, D., Lewandowski I., Claupein, W., 2003: Quantity and quality of harvestable biomass from *Populus* short rotation coppice for solid fuel use - a review of the physiological basis and management influences. Biomass and Bioenergy 24(6): 411-427
9. Klasnja, B., Kopitovic, S., Poljakovic Pajnik, L., 1998: Yield and properties of NSSC semichemical pulp obtained from microbiologically degraded poplar and willow wood. Topola 161/162: 17-30
10. Klasnja, B., Orlovic. S., Galic, Z., Pilipovic, A., Markovic, M., 2002: Short rotation and high plant density poplar plantations for energy production. Biomass for Energy, Industry and Climate Protection, Amsterdam, The Netherlands, Conference Proceedings: Pp. 223-226
11. Klasnja, B., Roncevic, S., Andrasev, S., Galic, Z., 2002a: Short rotation plantations of fast growing broadleaf tree species as the source of renewable energy raw material. 6th International Symposium on Interdisciplinary Regional Research – Hungary, Romania, Yugoslavia, Novi Sad, Yugoslavia, CD
12. Klasnja, B., Kopitovic, S., Orlovic, S., 2002b: Wood and bark of some poplar and willow clones as fuelwood. Biomass and Bioenergy 23: 427-432
13. Klašnja, B., Orlović, S., Drekić, M., Pekeč, S., 2002c: Wood of broadleaves species as raw material for fibre and energy production (in serbian). Radovi -Works. Institut za topolarstvo 27: 39-50
14. Klašnja, B., Kopitović, Š., Orlović, S., 2003a: Variability of some wood properties of Eastern Cottonwood (*Populus deltoides* Bartr.) clones. Wood Science and Technology 37(3-4): 331-337
15. Klasnja, B., Orlovic, S., Drekic, M., Markovic, M., 2003: Energy production from short rotation poplar plantations. 7th International Symposium on Interdisciplinary Regional Research – Hungary, Serbia & Montenegro, Romania, Hunedoara, Romania, CD: Pp. 353-358

16. Klašnja, B., Orlović, S., Galić, Z., Drekic, M., 2006: Poplar biomass of short rotation plantations as renewable energy raw material, in "Biomass and Bioenergy New Research", (ed.F. Columbus), Pp. 35-66, Nova Science Publishers, INC. New York, USA
17. Kuiper, L.C., Sikkema, R., Stolp, J.A.N., 1998: Establishment needs for short rotation forestry in the EU to meet the goals of the commission's White Paper on renewable energy (November 1997). Biomass and Bioenergy 15 (6): 451-456
18. Orlović, S., Klašnja, B., Pilipović, A., Radosavljević, N., Marković, M., 2003: A possibility of early selection of black poplars (*Section Aigeiros* DUBY) for biomass production on the basis of anatomical and physiological properties (in serbian). Topola-Poplar 171-172: 35-44
19. Orlovic, S., Klasnja, B., Ivanisević, P., Galic, Z., Radosavljevic, N., 2004: Selection of black poplar clones for biomass production. Second World Biomass Conference, Rome, Italy. Conference Proceedings, vol. I: 434-437
20. Parikka, M., 2004: Global biomass fuel resources. Biomass and Bioenergy 27(6): 613-620
21. Pollanschutz, J., 1963: Zuwachsmessungen und Bohrkemanalysen- Messmethoden und Genauigkeit, Inform. Dienst. Forstl. Bundesversuchanstalt Mariabrunn in Shobrunn, 1 Teil 71, Folge 2, Teil 72
22. Riddel-Black, D.M., Rowlands, C., Snelson, A., 1996: Short rotation forest productivity using sewage sludge as a nutrient. Biomass for Energy and the Environment, Copenhagen, Denmark. Conference Proceedings, vol. 1: 103-108
23. Scarascia-Mugnozza, G.E., Ceulemans, R., Heilman, P.H., Isebrands, J.G., Stettler, R.F., Hinckley, T.M., 1997: Production physiology and morphology of *Populus* species and their hybrids grown under short rotation. II. Biomass components and harvest index of hybrid and parental species clones. Canadian Journal of Forest Research 27: 285–294
24. Schneider, I., 1995: Statusbericht, Praxisversuch, Energieproduktion und -verwertung. Bewirtschaftung, Ernte und Verwertung von Pappel- und Weiden-Niederwäldern in Kurzumtrieb. Freiburg: Forstliche Versuchs- und Forschungsanstalt Baden- Württemberg, Abteilung Arbeitswirtschaft und Forstbenutzung, 35 pp.
25. Whityeman, A., Brown, C., 1999: The potential role of forest plantations in meeting future demands for industrial wood products. International Forestry Review, 1(3)

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