Productivity and chemical composition of wood tissues of short rotation willow coppice cultivated on arable land

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ABSTRACT

In the period 1996–1999 field trial was performed in Obory near Kwidzyn on heavy textured Fluvisols. The experiment was aimed to determine yield, chemical composition, heat value of wood of six genotypes of willow coppice in relation to cutting frequency and on determining the costs and profitability of willow production on arable land for purposes of energy generation. Yield of wood dry matter in one-year cutting cycle amounted to 14.09 $t.ha^{-1}.year^{-1}$ and significantly increased to 16.05 and 21.55 $t.ha^{-1}.year^{-1}$ when harvesting was performed in two and three years cycle, respectively. The highest yield was found for *Salix viminalis* 082 form cut in three years cycle and it amounted to 26.44 $t.ha^{-1}.year^{-1}$. Stems of *Salix* sp. cut every three years showed the lowest water content (46.05%), high heat value 19.56 $MJ.kg^{-1}$ dry matter and the highest content of cellulose (55.94%), lignins (13.79%) and hemicelluloses (13.96%). High yielding potential of *Salix* sp. and high content of cellulose and lignin in wood make this crop very prosperous as a feedstock for bioenergy production. The highest profit from the willow plantation was obtained in case of harvest every three years at 578.76 $EUR.ha^{-1}.year^{-1}$.

Keywords: arable land; coppice willow; cutting frequency; yield of wood dry matter; heat value; chemical composition; bioenergy; profit

From long-time prognosis of utilization of agricultural land in Poland, it is concluded that Polish agriculture will be source of stock for the energy sector of our economy (Kowalik 1997). Short rotation willow coppice (*Salix* sp.) is an alternative to traditional crops and willow biomass harvested from arable land may be used for biofuel production (Gigler et al. 1999, Johansson and Lundqvist 1999, Randerson et al. 2000) or for chemical processing in order to utilize cellulose and lignin (Mac Adam 1987, Hahn-Hägerdal and Tjerneld 1988, Szczukowski et al. 1998, Cook and Beyea 2000).

Nutrient rates applied for short rotation willow coppice are related to soil properties (i.e. soil pH in the range from 5.5 to 7.5). Before plantation establishment, chemical tests of nutrient availability should be done to match nutrient rates to crop demands. Macpherson (1995) reported that *Salix* sp. could uptake 60–80 kg N, 10 kg P and 35 kg K at the yield level of 10 t of dry matter per 1 ha per year. Sometimes herbicide or mechanical weeding should be applied in the second year of willow growth. However, so far no pesticide application is recommended in plantations of growing willow. Since the third year of growth canopy has been closed and willow is able to compete with weeds. On willow plantations, many natural enemies of insect pests was recorded and therefore insecticides application is not needed. Among plant diseases, the most dangerous is rust willow (*Melampsora* sp.) but there are many tolerant clones available and because on productive plantations planting of mixtures of clones is recommended, fungicides are not usually used.

In year 2000, companies Ballard and Daimler-Benz announced that they are ready to start full-scale serial production of methanol-driven cars with polymer fuel cells (Ciechanowicz 2001). There are some reports, which indicated possibility of methanol production using willow biomass (Larson and Jin 1999, Sethi et al. 1999). In some prognosis, very good perspectives for large market for bioenergy including methanol in the future are mentioned.

In Sweden, 15–18 t of timber dry weight per year per hectare is obtained while the economic profitability is achieved already in case of a harvest at 12 t of timber dry weight per hectare per year (Perttu 1992). Performed studies have shown that in Sweden, production of willow for energy purposes may be almost 6 times more profitable than cultivation of rye and two times more profitable than production of wheat. During the recent years the area of Swedish plantations for energy generation purposes has increased significantly and currently exceeds 25 000 ha while for the year 2010 cultivation on more than 500 000 ha is projected (Wilstrand 1999).

Currently, cultivation of short rotation willow coppice on agricultural land would provide an entirely new agricultural product and a flow of cash to producers of such crops. The potential market for the heat produced seems to be a very large. Additionally, significant reserves of inefficiently used agricultural land and the need for finding new sources of income in agriculture show the necessity for a wider scientific and practical focus on that production in our country.

Our studies were aimed to determine the effects of cutting frequency of selected forms of *Salix* sp. on their yielding capacity, chemical composition of wood and heat wood value and determining the costs and profitability of willow production on arable land for purposes of energy generation in different frequency of cutting.

MATERIAL AND METHODS

In the period 1996–1999 in Obory near Kwidzyn (in Northern Poland) the field experiment was performed on heavy textured Fluvisols. The experiment was performed in four replications in a two factorial design.

The first experimental factor was cutting frequency: every year, every two years, and every three years.

The second factor was clone of *Salix* sp.: Rapp Valne (number in collection 1051), Ulv Valne (1052), Orm Valne (1053), *Salix viminalis* 082 (1054), *Salix viminalis* var. *gigantea* (1047), *Salix viminalis* cv. Piaskówka (1040). First three clones are Swedish origin and remaining were obtained in Poland.

Density of planting amounted to 40 000.ha^{-1} what corresponds to spacing 0.33 m × 0.75 m. Area of each plot amounted to 21.78 m^2 in size of 3 m × 7.26 m.

Content of plant available P in the soil was very high, whereas K and Mg contents were evaluated as medium. In the first year, mineral fertilizers were not applied. In the next seasons the following rates of nutrients were applied just when growth commenced: N – 40, P – 9 and K – 33 kg.ha^{-1} (Table 1). All nutrients were applied once every year at the stage of growth renewal: as ammonium nitrate (N), potassium chloride (K) and superphospate (P).

In the season of willow planting, hand weeding was done twice. In December, all plots were harvested in order to stimulate the coppice and growth of willow in the next seasons.

In the spring of 1997 herbicide Casaron G at the rate of 80 kg.ha^{-1} was applied.

Harvest was performed in first days of January. Then water content in wood (%) tissues was determined and dry matter yield was determined t.ha^{-1}.year^{-1}.

Heat value of willow wood was determined by direct calorimetry (total energy MJ.kg^{-1} dry matter). Crude ash content was determined by Heneberg and Stohman, crude fiber by Heneberg and Stohman method in Lepper's modification. Fiber was fractionated into NDF – neutral detergent fiber, ADF – acid detergent fiber and ADL – acid detergent lignin; hemicelluloses and cellulose were determined according to Van Soest's method (Van Soest and Wine 1967). Analyses were done using Fibertec M apparatus. For given parameters and for wood chemical composition only mean values were given because it would affect size of the publication.

Table 1. Applied nutrients rates and forms

Item	N	P	K
Rates (kg.ha^{-1}.year^{-1})	40	9	33
Forms	ammonium nitrate	superphospate	potasssium chloride

Results were subjected to statistical analysis using STATISTICA® software.

Simplified economical analyses were performed taking into account mean values of yield of wood dry matter obtained from all tested clones. The following stages were identified in analysis: plantation establishment, maintenance, fertilization, harvest of plants with chipping and transport.

The costs of machine operations per unit of production (ton, ha) represent the quotient of operational costs per unit of time (hour) and the operational efficiency W_{07}. The calculation of technical means operational costs was done in line with the methodology proposed by the Division of Economy and Agricultural Machines Operation, of the Institute of Agricultural Construction, Mechanization, and Electrification (IBMER) of Warsaw (Kisiel et al. 1989).

The profitability analysis for cultivation of willow was done on the basis of the difference between total revenues and costs related to that crop. The profits of service providers were not included in the calculations.

RESULTS AND DISCUSSION

Yield of dry matter of *Salix* sp. wood in the experiment amounted to 17.5 t.ha^{-1}.year^{-1} (Table 2). Longer intervals between harvesting resulted in significant yield increase. The highest yield was noted for three years cutting frequency (21.55 t.ha^{-1}.year^{-1}). Genotype of willow also affected yield and the highest was found for *Salix viminalis* 082 (average 21.72 t.ha^{-1}.year^{-1}). Production ability was the highest when the three years cycle of harvesting was applied and yield ranged from 18.55 t.ha^{-1}.year^{-1} *S. viminalis* cv. Piaskówka to 26.44 t.ha^{-1}.year^{-1} for *S. viminalis* 082.

The highest water content (52.86%) noted for one year cutting frequency decreased to 49.62 and 46.05% for two and three years cutting cycle, respectively (Table 3).

Heat value was relatively less variable but it tended to increase together with longer intervals between harvesting (Table 3). Heat value of wood harvested every year amounted to 18.55 MJ.kg^{-1} dry matter while in three years cycle to 19.56 MJ.kg^{-1} dry matter.

Ash content decreased from 1.89%, when willow was grown in 1 year cycle, to 1.37% and 1.28% for two and three years cycles, respectively.

Content of cellulose was the highest in wood from three years cycle 55.94% and decreased to 48.02% and 45.58%, for two and one year cutting cycle, respectively (Table 4). The highest content of lignin was noted in three years cycle i.e. 13.79%. Hemicellulose content amounted to 13.53% in one year cycle, and 13.96% in three years cycle.

Yield of wood dry matter of willow of short rotation coppice grown on heavy alluvial soil (periodically too wet) harvested in three years cycle was relatively high (average 21.55 t.ha^{-1}.year^{-1}) and ranged from 18.55 to 26.44 t.ha^{-1}.year^{-1}. These data are comparable to reports of willow yield from other countries (Jossart and Ledent 1999, Cook and Beyea 2000, Rosenqvist et al. 2000). Pro-

Table 2. Yield of *Salix* sp. dry matter ($t.ha^{-1}.year^{-1}$)

Botanic name or cultivar (*b*)	Frequency of cutting (*a*)*			
	1 year	2 years	3 years	mean
Rapp Valne (1051)	11.64 ± 0.13	13.92 ± 1.96	19.74 ± 0.68	15.10 ± 1.10
Ulv Valne (1052)	16.88 ± 0.28	16.52 ± 1.67	22.98 ± 0.53	18.79 ± 1.04
Orm Valne (1053)	16.04 ± 1.11	17.50 ± 1.93	22.54 ± 0.31	18.69 ± 1.08
Salix viminalis 082 (1054)	18.19 ± 0.48	20.54 ± 1.95	26.44 ± 0.93	21.72 ± 1.24
S. viminalis var. *gigantea* (1047)	15.68 ± 0.12	14.84 ± 1.32	19.03 ± 0.41	16.52 ± 0.69
S. viminalis cv. Piaskówka (1040)	11.00 ± 0.73	13.00 ± 1.28	18.55 ± 1.11	14.18 ± 1.11
Mean	14.90 ± 0.59	16.05 ± 0.77	21.55 ± 0.63	17.50 ± 0.51

LSD (P = 0.05), a = 1.00, b = 1.42, $a \times b$ = ns
* mean ± standard error (*S.E.*)

ductivity of commercial plantations of short rotation willow coppice in Scandinavian countries was reported from 12 to 18 $t.ha^{-1}.year^{-1}$ wood dry matter (Gigler et al. 1999). In Scandinavian conditions yield at the level of 12 $t.ha^{-1}.year^{-1}$ dry matter is profitable. Recently, in Sweden several cultivars of short rotation willow have been registered – all bred by Svalöf Weibull AB. In this country willow for energy is grown at the area of ca. 20 000 ha of (Larsson 1999). By 2020 is planned increase this area to 600 000 ha of *Salix* sp. plantations. In the Netherlands which occupies 1.8 mln ha of agricultural land in total by 2020 100 000 ha of energy plantations are planned to establish (Vries 2000).

Water content in willow wood was variable and reached 52.86 and 46.05%, during harvesting of one and three years old stems, respectively. Heat value of wood ranged from 18.55 to 19.56 $MJ.kg^{-1}$ dry matter. Ager et al. (1986) studied numerous willow clones and they found water content in the interval of 50.4–61.7%, whereas heat value of wood ranged from 19.0–20.0 $MJ.kg^{-1}$ dry matter.

Cellulose content in wood of all studied genotypes of coppice willow (all classified to *S. viminalis*) increased with the length of cutting cycle. The similar relations were found by others (Prosiński and Surmiński 1961). Abovementioned authors found 47.2, 51.8, and 54.8% of cellulose in stems of *Salix acutifolia* Will. grown in one, two and three years cutting cycle, respectively. In their studies, higher content of lignin was found: 19.6, 21.2, and 28.0% compared to our results.

High yield of *Salix* sp. wood, together with high level of accumulation of cellulose and lignin cause that this wood could be of interest as a stock material to methanol production (Novak et. al 1999, Szczukowski and Tworkowski 2001).

Production of methanol from biomass is relatively intensive because lignin and cellulose in the process of chemical conversion are changed into secondary energetic carriers – gas and liquid fuels (Larson and Jin 1999, Sethi et al. 1999). Efficiency of ethanol production from wood is rather low in the process of biological conver-

Table 3. Some parameters of *Salix* sp. wood (irrespectively of clones)

Item	Frequency of cutting*		
	1 year	2 years	3 years
Water content (%)	52.86 ± 0.57	49.62 ± 0.77	46.05 ± 0.29
Heat value ($MJ.kg^{-1}$ dry matter)	18.55 ± 0.18	19.25 ± 0.20	19.56 ± 0.13
Crude ash (%)	1.89 ± 0.08	1.37 ± 0.06	1.28 ± 0.07

* mean ± standard error (*S.E.*)

Table 4. Chemical composition of *Salix* sp. wood (%) (irrespectively of clones)

Item	Frequency of cutting*		
	1 year	2 years	3 years
Cellulose	45.58 ± 0.98	48.02 ± 0.75	55.94 ± 0.47
Lignin	13.44 ± 0.26	12.38 ± 0.31	13.79 ± 0.39
Hemicelluloses	13.53 ± 0.66	13.39 ± 0.82	13.96 ± 0.95

* mean ± standard error (*S.E.*)

Table 5. Yields of dry matter obtained and willow production profitability in case of different frequency of cutting (irrespectively of clones)

Item	Frequency of cutting		
	1 year	2 years	3 years
Production cost (EUR.ha^{-1})	338.49	726.37	1 216.45
Dry mass yield (t.ha^{-1})	14.90	32.10	64.65
Costs of production per 1 t dry matter (EUR)	22.72	22.63	18.82
Price per 1 t of chips dry matter (EUR)*	45.67	45.67	45.67
Profit per 1 ton dry matter (EUR)	22.96	23.04	26.86
Profit per 1 ha (EUR)	342.03	739.72	1 736.28
Profit per 1 ha.year^{-1} (EUR)	342.03	369.86	578.76

* the price per 1 t dry matter of chips was assumed as equal to price of 1 t of timber wastes

sion because it is not fully converted in the fermentation process due to high content of lignin (Hahn-Hägerdal and Tjerneld 1988).

Data given by Ciechanowicz (2001) show that from 2.6 tons of dry wood 1 tone of methanol could be obtained and efficacy of chemical conversion is 38.5%. According to many authors (Novak et al. 1999, Ciechanowicz 2001) methanol produced from biomass obtained from arable land will be dominant on future fuel market.

The willow production costs and profitability on arable land for different frequency of cutting are presented in Table 5. When yield was obtained in one year cutting cycle production cost amounted to 338.49 EUR and longer cutting cycles resulted in increase of cost to 726.37 and 1 216.45 EUR for two and three years cutting frequency, respectively. In the light of our calculation, it may be concluded that from the point of production profitability the best solution is to harvest *Salix* sp. in three years cycle with direct chipping. The profit per 1 ha per year of operation in that case was at 578.76 EUR. When plants were harvested in two years cycles, the profit per 1 ha per year of plantation operation amounted to 369.86 EUR while in case of yearly harvest 342.03 EUR.

Goor et al. (1999) stated that the difference between total revenues and costs (direct and indirect) related to cultivation of willow during the years 1996/1997 in the Walloon region (Belgium) was, in average 684.6 EUR.ha^{-1}.

Danfors et al. (1998) reported that case of the average harvest of ca. 10 t dry weight.ha^{-1}, the average year gross profit was 429 EUR per ha.

Our results suggest that some soils, especially alluvial, are very suitable for growing of short rotation willow and utilization of obtained biomass for bioenergy production.

Comparing the results of the conducted economic analyses for the experiment with the studies from other European countries, the production and economic conditions as well as the status of agriculture related to them should be taken into consideration. It can, however, be concluded that the results obtained from the conducted experiment are compatible to the data quoted in the literature.

REFERENCES

Ager A., Rönnberg-Wästlijung A.C, Torsèn J., Sirèn G. (1986): Genetic improvement of willows for energy forestry in Sweden. Swed. Univ. Agric. Sci. Sect. Energ. Forest. Rep., *43*: 1–47.

Ciechanowicz W. (2001): Bioenergy. Aura, *4*: 8–10. (In Polish)

Cook J., Beyea J. (2000): Bioenergy in the United States: progress and possibilities. Biomass Bioenerg., *18*: 441–455.

Danfors B., Ledin S., Rosenqvist H. (1998): Short-rotation willow coppice growers' manual. Swed. Inst. Agric. Engin. Uppsala, 40.

Gigler J.K., Meerdink G., Hendrix E.M.T. (1999): Willow supply strategies to energy plants. Biomass Bioenerg., *17*: 185–198.

Goor F. J.-M. Jossart, Ledent J.F. (1999): Willow short rotation coppice profitability assesment. A case study in Belgium. In: Overend R.P., Chornet E. (eds.): Proc. 4th Biomass Conf. Amer. Pergamon: 31–37.

Hahn-Hägerdal B., Tjerneld F. (1988): Production of ethanol from lignocellulosic materials. Anim. Feed Sci. Technol., *21*: 175–182.

Johansson J., Lundqvist U. (1999): Estimating Swedish biomass energy supply. Biomass Bioenerg., *17*: 85–93.

Jossart J.M., Ledent J.F. (1999): Short rotation coppice of willow and shelterbelt effect. Biomass a growth opportunity in green energy and value-added products. In: Overend R.P., Chornet E. (eds.): Proc. 4th Biomass Conf. Amer. Pergamon: 47–53.

Kisiel R., Kaliszewicz D., Kucka E. (1989): Normative calculation of potato growing cost. Acta Acad Agric. Techn. Olst. Oec., *24*: 35–45. (In Polish)

Kowalik P. (1997): World tendencies of using biomass for heat, electricity and fuel production. Gospod. Paliw. Energ., *1*: 1–5. (In Polish)

Larson E.D., Jin H. (1999): Biomass conversion to Fischer-Tropsch liquids: preliminary energy balances. In: Biomass – a growth opportunity in green energy and value-added products. In: Overend R.P., Chornet E. (eds.): Proc. 4th Biomass Conf. Amer. Pergamon: 843–846.

Larsson S. (1999): Plant breeding of willow, now and in the near future. J. Swed. Seed Assoc., *2*: 107–111.

Mac Adam J.H. (1987): The pulp potential and paper properties of willows with reference to *Salix viminalis.* Irish Forest., *44*: 32–42.

Macpherson G. (1995): Home – grown energy from short-rotation coppice. Farming Press North America.

Novak C.A., Volk T.A., Ballard B., Abrahamson L.P., Filhart R.C., Kopp R.F., Bickelhaupt D., White E.H. (1999): The role and process of monitoring willow biomass plantations. In: Overend R.P., Chornet E. (eds.): Proc. 4th Biomass Conf. Amer. Pergamon: 25–29.

Perttu K.L. (1992): Energetical crops. Production of energy and detoxication of waste water and sewage sludge. Aura, *3*: 10–11. (In Polish)

Prosiński S., Surmiński J. (1961): Chemical properties of wood from 1, 2 or 3 old willow stems of *Salix acutifolia* Will. Roczn. WSR Poznań, *XI*: 3–8. (In Polish)

Randerson P.F., Heaton R.J., Slater F.M. (2000): Economic prospects for short rotation coppice in Wales: The need for subsidy in a new agricultural industry. 7th Polish-Danish Worksh., Biomass for Energy, Starbienino, Poland: 135–142.

Rosenqvist H., Roos A., Ling E., Hektor B. (2000): Willow growers in Sweden. Biomass Bioenerg., *18*: 137–145.

Sethi P., Chaundry S., Unnash S. (1999): Methanol production from biomass using the hynol process. In: Biomass – a growth opportunity in green energy and value-added products. In: Overend R.P., Chornet E. (eds.): Proc. 4th Biomass Conf. Amer. Pergamon: 833–836.

Szczukowski S., Tworkowski J. (2001): Productivity nad energetical value of coppice willow wood grown on different soils in Vistula river valley. Postęp. Nauk Roln., *2*: 29–38. (In Polish)

Szczukowski S., Tworkowski J., Kwiatkowski J. (1998): Potential of willow biomass utilization as ecological fuel and raw material for cellulose and building materials. Postęp. Nauk Roln., *2*: 53–63. (In Polish)

Van Soest P.J., Wine R.H. (1967): Use of detergents in the analysis of fibrous feeds. Preparation of fibre residues of low nitrogen content. Determination of cell-wall consituents. J. Assoc. Off. Anal. Chem., *50*: 50–55.

Vries E. De (2000): Biomass energy trying to get a firmer footing in the Netherlands. New Energ., *3*: 36–38.

Wilstrand M. (1999): Salix – Establishment and harvesting. J. Swed. Seed Assoc., *109*: 97–103.

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ABSTRAKT

Výnos a chemické složení dřeva rychle rostoucích křovinatých vrb pěstovaných na orné půdě

V letech 1996 až 1999 proběhl polní pokus v obci Obory u Kwidzyna na těžké nivní půdě. Cílem pokusu bylo stanovení výnosů, chemického složení a kalorické hodnoty dřeva šesti genotypů křovinatých vrb v závislosti na frekvenci sklizně a také stanovení nákladů a rentability produkce křovinaté vrby pěstované na orné půdě k energetickým účelům. Výnos suchého dřeva *Salix* sp. sklizené v jednoročním cyklu činil v průměru 14,9 t.ha^{-1}.rok^{-1}. Výrazný nárůst nastal při sklizni proutí v cyklu dvouletém (16,05 t.ha^{-1}.rok^{-1} sušiny) a tříletém (21,55 t.ha^{-1}.rok^{-1} sušiny). Nejvyšší výnos suchého dřeva byl stanoven u odrůdy vrba košíkářská (*Salix viminalis* 082) sklizené v tříletém cyklu (26,44 t.ha^{-1}.rok^{-1}). Pruty *Salix* sp. sklizené každé tři roky měly v průměru nejnižší vlhkost (46,05 %), vysokou energetickou hodnotu (19,56 MJ.kg^{-1} sušiny) a nejvyšší obsah vlákniny (55,94 %), ligninu (13,79 %) a hemicelulózy (13,96 %). Vysoká užitkovost *Salix* sp. spolu s vysokým obsahem vlákniny a buničiny v dřevě dává dobrý předpoklad, že tyto rostliny mohou být velmi zajímavou surovinou pro výrobu bioenergie. Nejvyššího zisku z plantáže křovinaté vrby bylo dosaženo při sklizni rostlin každé tři roky (578.76 EUR.ha^{-1}.rok^{-1}).

Klíčová slova: zemědělská půda; křovinaté vrby; cyklus sklizně; výnos suchého dřeva (sušiny); energetická hodnota; chemické složení; bioenergie; zisk

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