doi: 10.17221/12/2014-RAE

Yield and fuel characteristics of willows tested for biomass production on agricultural soil

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Abstract

Weger J., Hutla P., Bubeník J. (2016): **Yield and fuel characteristics of willows tested for biomass production on agricultural soil**. Res. Agr. Eng., 62: 155–161.

Short rotation coppice (SRC) plantations of fast growing trees in Czech Republic may be grown on approximately 120,000 ha in future, as indicated in the Czech Action Plan for Biomass. Until now, 2,800 ha of SRC were established using predominantly poplar non-native hybrid clone Max-4. The aim of this experiment and article is evaluation of promising domestic clones of willow species and their natural hybrids, to discover their yield parameters and fuel characteristics in field conditions. The experiment was established in Průhonice in 2005 and it was harvested two times in triennial rotation (2008, 2011). For the test of fuel properties biomass was used from three willow species: common osier (*Salix viminalis*) S-337, Smith's willow (*S.*× *smithiana*) S-218 and white willow (*S. alba*). Mean hectare yield of biomass in oven dry tonnes (o.d.t) of all the observed clones after first harvest was 3.9 o.d.t/ha/year, and after second harvest 10.4 o.d.t/ha/year. Observed willow clones had comparable or better yields as well as selected fuel properties (content of ash, melting point) in comparison with poplar clones used in the experiment.

Keywords: short rotation coppice; emissions; native willow

Planting of short rotation coppice (SRC) of fast-growing trees, especially willow and poplar, on agricultural land is considered as a perspective way of lignocellulose biomass production in the whole world as well as in the Czech Republic (Trnka et al. 2008). Biomass can be then utilized for heat and electricity production as well as for chemical and material use (Labrecque, Teodorescu 2005). According to the present Action Plan for Biomass of the Ministry of Agriculture (MZe 2012), which is a basis for prepared State energy policy, SRCs could be planted on 80,000–110,000 ha in long-term horizon, especially in areas with lower quality of soils, less favourable for food production. Growing of fast growing trees for energy biomass is controlled by agricultural legislation. Production and distribution of planting material belongs to the category of horticulture plants.

Until now, 2,800 ha of SRC were established using predominantly poplar clone Max-4 which is hybrid of non-native species (*Populus nigra* × *P. maximowiczii*). Tree monocultures are potentially more sensitive to large-scale damages caused by extreme climatic conditions or by outbreaks of

Supported by the Ministry of Education, Youth and Sports of the Czech Republic, Project No. 2B06132 (Non-food utilization of biomass).

doi: 10.17221/12/2014-RAE

Table 1. Physical properties and emissive parameters (calculated at 13% O_2) of solid biofuels produced from poplar wood (fast growing woody species)

Fuel description	Moisture	Density (kg/dm^3)	Destructive force (N/mm)	CO (mg/m^3)	NO_x (mg/m^3)
Logs	11.2	0.43	–	4.020	209
Short lump wood	11.9	0.44	–	4.846	150
Shredded wood	10.3	–	–	3.982	177
Hard wood chips	6.4	–	–	3.739	186
Soft wood chips	7.5	–	–	5.828	193
Briquette – hard wood chips	7.6	0.74 (0.69–0.80)	57 (44–67)	2.856	199
Briquette – soft wood chips	8.1	0.71 (0.69–0.75)	35 (23–50)	2.736	152
Briquette – scrap diameter 15 mm	7.1	0.73 (0.71–0.73)	67 (48–83)	2.902	195
Briquette – scrap diameter 8 mm	7.3	0.75 (0.70–0.74)	65 (47–79)	2.720	188
Wood briquette Turbohard	6.7	1.08	73	1.651	89

values in brackets – measured intervals

harmful organisms. This can subsequently cause serious economic losses to entrepreneur and contracting parties (Felton et al. 2010). Large monocultures of intensively grown trees can also decrease biodiversity especially if established on sites with naturally high levels of diversity, e.g. species-rich old grasslands and meadows in conditions of the mild climatic zone (Christian et al. 1994). In practice, new plantations of SRC's are often established on arable soil and their stands are more diverse and less intensive than those of annual crops which they replace (Rowe et al. 2009). Medium and small plantations of SRC grown in short rotations can increase numbers and abundance of many important species including plants, birds of prey, mammals and ground beetles in intensively managed agricultural land (Weih et al. 2003; Nerlich et al. 2012; Weger et al. 2013). Mean size of SRC plantations is 2.1 ha (median 0.9 ha) in the Czech Republic. Therefore, the risk for biodiversity is relatively low from SRC monocultures in local context. Additionally, the number of poplar and willow varieties used in practice is increasing. Establishment of biomass plantations where non-native species are used is restricted by Czech legislation, namely the Act No. 114/1992 Coll., on the Conservation of Nature and Landscape. It is thus important to widen the assortment for SRC, for instance by suitable clones of native willow species.

The material obtained from willow and poplar SRC can be further processed into various forms of solid fuels. The high valorisation can be achieved by production of heating briquettes or pellets. In this manner, it is possible to reach and increase mass and energy density. In case of these products the mechanical properties are important, i.e. volume weight and mechanical solidity. These parameters depend on used material, its structure, water content and compacting pressure. The standard norm, which the findings are based upon, is the ČSN EN 14961–1:2010. According to the standard ČSN EN 14961–2:2011 it is also possible to use the trees without roots for the production of A 2 class pellets. The pellets have the diameter of 6 to 8 mm, ash content up to 1.5%, mechanical resistance higher than 97.5% and powder density higher than 600 kg/m^3.According to the standard ČSN EN 14961–3:2011, for the production of A 2 class briquettes, it is possible to use the whole trees without roots and the required ash content up to 1.5% and density higher than 1 kg/dm^3.

The detailed fuel and energy analyses of fast growing woody species were carried out with energy poplars (Mazancová et al. 2007). From the poplar wood several kinds of solid biofuels were produced, which were subsequently burnt and at the same time the emissions parameters were monitored (Table 1).

The aim of the experiment and article is to evaluate production characteristics of perspective willow species and to discover properties of their wood biomass for heating and eventually to compare the results with properties of poplar wood.

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MATERIAL AND METHODS

Type of SRC field experiment. The experiment was established in 4 repetitions with schematic changing of experimental tree clones variants. It was designed to minimise margin and neighbouring effect and to secure random distribution of tree clones to eliminate influence of changing soil conditions. The experiment was planted using single-row scheme (0.33 × 2.20 m), which is equal to density of plantation of 13,774 pcs/ha. In every experimental variant 15 individuals from the clone or the variety were planted in row blocks. The total area of the experiment was 1,099 m^2 including outer isolating rows. In isolating rows, a mixture of autochthonous woody species (*Rosa canina*, *Corylus avelana*, etc.) was planted.

Site conditions and establishment of the experiment. Michovka experimental site (Průhonice; 49°59'28''N, 14°34'39''E) was arable land used for agriculture food production in past. In 1995, agricultural production stopped on this site and it was converted into grassland. The site is situated in flat land with all cardinal points sun exposition at an altitude of 310 m a.s.l. According to the Czech Republic climate evaluation (Kolektiv 1990) the site belongs to warm, moderately dry climatic region (KR 2), which is characterised with sum of temperatures over 10°C in interval 2,600 to 2,800, annual sum of precipitation 500 to 600 mm and mean annual temperature between 8–9°C. Soil under the experiment was determined as modal brown soil on losses by experts of the Research Institute for Soil and Water Conservation in Prague – Zbraslav (VÚMOP). The evaluated soil-ecological unit of the site is 21100 according to the Czech agricultural soils evaluation (Němec 2001) and it is considered moderately suitable for biomass production of poplar and willow SRC (Havlíčková et al. 2010). Expected average biomass yield is estimated at 8 oven-dry tonnes (o.d.t)/ha/year from SRC plantation in this site according to the above-mentioned typology as well as previous experiments.

To prepare the experimental the place was deep ploughed and subsequently harrowed with disk harrows. Planting of the experiment was performed on 6 May 2005 with 20 cm long cuttings. First two years it was necessary to weed it one- or two-times per year manually in the rows and by cultivator or disc harrows in the inter-rows. The experiment was fenced to protect it from animal foraging damage and it was not watered or fertilized.

Assortment of woody species. For the experiment 13 poplar and 7 willow clones were chosen which were expected to grow well in given site conditions. The selected assortment was from domestic collections and especially willows included clones of native species and their natural hybrids. Swedish willow variety Tora was chosen as a control clone.

From the whole planted assortment 3 willow clones/varieties were selected for the purposes of this article (evaluation of yield and fuel characteristics): S-218 (*Salix* × *smithiana* Willd.e.g. *S. caprea* L. × *S. viminalis* L.), Tora (*S. viminalis* L. × *S. schwerinii* E.L. Wolf) and S-337 (*S. viminalis* L.).

Evaluation of biomass yields (yield/ha). First harvest was performed in March 2008, three years after the establishment of plantation. Second harvest was performed in January 2011 after sixth year of plantation growth. Harvest of the above-ground biomass (stems of woody plants) was performed according to standard methodology used in Silva Tarouca Research Institute for Landscape and Ornamental Gardening in (VÚKOZ) (Weger et al. 2013).

Evaluation of measured and calculated biometric and yield data was processed by parametric or non-parametric methods of statistical analyses of variance (Analyses of Variance, Kruskal-Wallis analyses) with SW Unistat 5.5 and Statistica 7.1.

Fuel and energy analyses. For the production of solid biofuels which were subsequently tested, the biomass from harvest of two species of willows was available from the experiment: clone S-337 of basket willow (*Salix viminalis*; 180 kg) and clone S-218 of Smith's willow (*Salix smithiana*; 155 kg). Furthermore, biomass sample of white willow (*Salix alba*; 165 kg) was delivered from nearby field experiment in the same locality for comparison.

Fuel and energy analyses were carried out at the samples. Afterwards, various kinds of fuels were

Table 2. Structure of energy chips from poplars produced by wood chipper Tomahawk M-P-350

Size (mm)	Relative quantity (% wt.)
More than 80	0
More than 40	2.4
More than 25	10.9
More than 20	11.2
More than 15	19.4
More than 10	24.6
Less than 10	31.5

doi: 10.17221/12/2014-RAE

produced differing in structure and processing. The stem wood was processed into the form of log wood, short lump wood, shredded wood and wood chips. The wood chips were also processed into the form of heating briquettes. For the production of short lump wood a shredder of wood mass DH 10 S (Rojek, a.s., Častolovice, Czech Republic) was used. The shredder divides trunks into the parts of ca 9 cm. The crushed material is used directly as a fuel in boilers utilizing wood. The fuel in form of shredded wood was prepared by shredder of branches Pirba (Bystroň – Integration, s.r.o.; Jarcová, Czech Republic). The products are parts of wood with size 3–5 cm. In order to obtain the wood chips the wood chipper Tomahawk M-P-350 was used (W+D, s.r.o., Mladoňovice, Czech Republic). Its structure is shown in Table 2. The wood chips were also processed in form of heating briquettes with diameter of 65 mm using a briquetting press HLS 50 (Briklis, s.r.o., Malšice, Czech Republic).

All kinds of fuels were burnt and CO and NO_x emissions were measured. For these purposes heat storage stove SK-2 (Retap s.r.o., Hajniště, Czech Republic) was used. Testo 350 analyser (Testo AG, Lenzkirch, Germany) was used for flue gases. The measured CO and NO_x values were recalculated to 13% oxygen content. For the purpose of comparison the measurement was also carried out with commercially available fuel – wood briquettes Turbohard (Biomac, s.r.o., Brníčko, Czech Republic).

RESULTS AND DISCUSSION

Biomass yields

Two harvests were performed during the observed period of time: in March 2008 and in January 2011, always in winter after third and sixth year of plantation growth, respectively. Mean hectare yield in oven dry tonnes was 3.9 o.d.t/ha/year for all clones and varieties in the first harvest. The best growing willow clone in the first harvest (S-218) also reached the best yields of dry biomass in the whole experiment (Table 3).

Mean hectare yield of all clones and varieties was 10.4 o.d.t/ha/year after the second harvest. All measured clones increased biomass yields between the first and second harvest. Clone S-218 was the best growing also in the second harvest. Also, the highest absolute increase in yield was calculated at S-218 clone (from 7.2 to 19.0 o.d.t/ha/year). It is evident from the results presented in Table 3 that statistically significant differences were calculated between yields of planted clones.

Evaluation of fuel and energy analyses

Fuel and energy analyses of energy willow dendromass are shown in Table 4. From this table it is obvious, that the composition of willow wood is practically the same at all species. The important fact is low nitrogen content in comparison with poplar wood (ca. five times lower). The ash content is also lower (compared to poplar ca. three times) and higher is temperature of ash melting (in comparison with poplar by ca. 120 K).

The biofuels were produced from mixture of all three materials in form of log wood (diameter up to 5 cm), short lump wood, shredded wood and wood chips. The wood chips were also processed into the form of heating briquettes. All the fuels produced were burnt and detected emissions are shown in Table 5. Graphical expression of emission values according to the Table 4 is shown in Fig. 1. Fig. 2 shows typical courses of measurements for selected fuels.

Table 3. Hectare yields of oven dry biomass (t/ha/year) of tested clone in the experiment at Michovka site and statistical analyses of the mean yield according to the analyses of variance ANOVA– test, Least Significant Difference (LSD)

Clone code	No. of measurements	1st harvest III/2008	2nd harvest I/2011	LSD test difference between clones	Homogeneous subsets after 2nd harvest
S-337	4	4.9	10.7	S-218–S-337: 0.6095 J-105–S-337: 0.4553	A
Tora	4	3.7	11.9	Tora–S-337: 0.1149	A
S-218	4	7.2	19.0	S-218–Tora: 0.4946 S-218–J-105: 0.1541	B
J-105	4	6.6	14.7	J-105–Tora: 0.3404	B

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Table 4. Fuel and energy parameters of willow wood from selected species of willows and poplars (recalculated to waterless state)

Composition	Unit	Common osier S-337	Smith's willow S-218	White willow	Poplar J-105
Volatile matter	(% wt.)	81.02	80.44	80.51	80.40
Non-volatile matter	(% wt.)	17.63	17.80	18.24	15.30
Ash	(% wt.)	1.35	1.76	1.25	4.31
Carbon	(% wt.)	50.21	51.12	51.02	50.26
Hydrogen	(% wt.)	5.80	5.59	5.68	5.87
Nitrogen	(% wt.)	more than 0.1	more than 0.1	more than 0.1	0.55
Sulphur	(% wt.)	0.034	0.067	0.039	0.03
Oxygen	(% wt.)	38.92	39.02	39.20	38.94
Chlorine	(% wt.)	0.032	0.064	0.036	0.03
Gross calorific value	(MJ/kg)	19.92	19.80	19.90	19.40
Net calorific value	(MJ/kg)	18.66	18.59	18.67	18.12
Ash					
Softening point	(°C)	more than 1,340	more than 1,340	1,290	1,200
Melting point	(°C)	more than 1,340	more than 1,340	more than 1,340	1,210
Flowing point	(°C)	more than 1,340	more than 1,340	more than 1,340	1,220

for comparison, the poplar wood values are shown (Hutla, Jevič 2009)

Yield characteristics

The highest yields in both rotations were reached by domestic clone of Smith's willow S-218, which is a natural hybrid of autochthonous willows – *Salix caprea* and *Salix viminalis*. Its yield was 29% higher than for poplar J-105 (Weger, Bubeník 2012) or 59/77% higher than the best willow cv. Tora and S-337, respectively. S-218 had low losses in selected spacing in the experiment.

Second highest yielding domestic clone in the experiment was S-337 (*S. viminalis*) with the yields of 4.9 and 10.7 o.d.t/ha/year produced at first and second harvest, respectively. In Polish yield evaluation, varieties of *S. viminalis* produced in two localities of Warmian-Masurian Voivodship region in density of 7,400 plants per hectare 7–7.6 o.d.t/ha/year (variety Turbo), 7.5–8 o.d.t/ha/year (Tur), 12–15 o.d.t/ha/year (clone UWM 043) and 7.7–7.9 o.d.t/ha/year (UWM 046) depending on site (Stolarski et al. 2011). The testing took place in locations of Leginy (53°59'N, 21°08'E) and Kocibórz (54°00'N, 21°10'E) in the experimental station Warmia, University of Warmia and Mazury (year sum of precipitations 650–750 mm, mean year temperature 8°C). Willows were harvested after 4 years of growth.

Fuel and energy aspect

The CO emissions are relatively high in case of materials 1V–4V, it means at all forms of process-

Table 5. Operational measurements of selected gaseous emissions of biofuels produced from energy willows under reference O_2 content = 13%

Fuel	Specification	CO (mg/m^3)	NO_x (mg/m^3)
Logs	1V	4.312	142
Short lump wood	2V	4.208	113
Shredded wood	3V	3.705	91
Wood chips	4V	4.020	111
Briquette	6V	2.783	105
Briquette Turbohard	10	1.651	89

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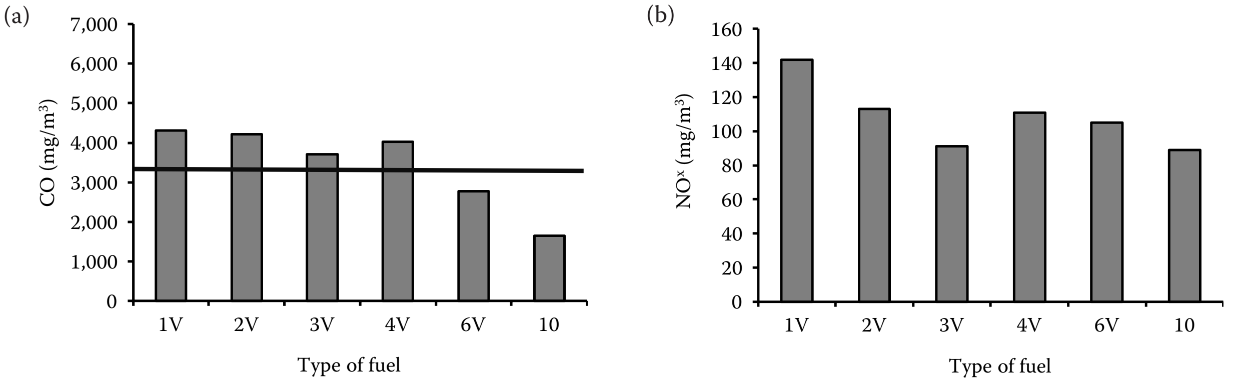

Fig. 1. Average values of gaseous CO (a) and NO_x (b) emissions in flue gases of the tested forms of fuels produced from energy willow under reference O_2 content = 13%; emission limit of class 1 according to the standard ČSN EN 13229:2002 is designed in CO graph (black line)

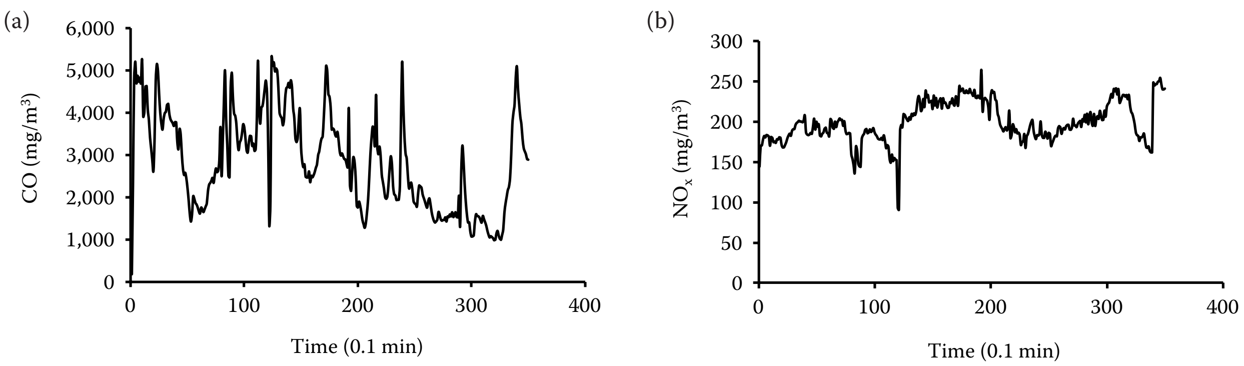

Fig. 2. Course of CO (a) and NO_x (b) emissions during the combustion of briquettes from energy willows

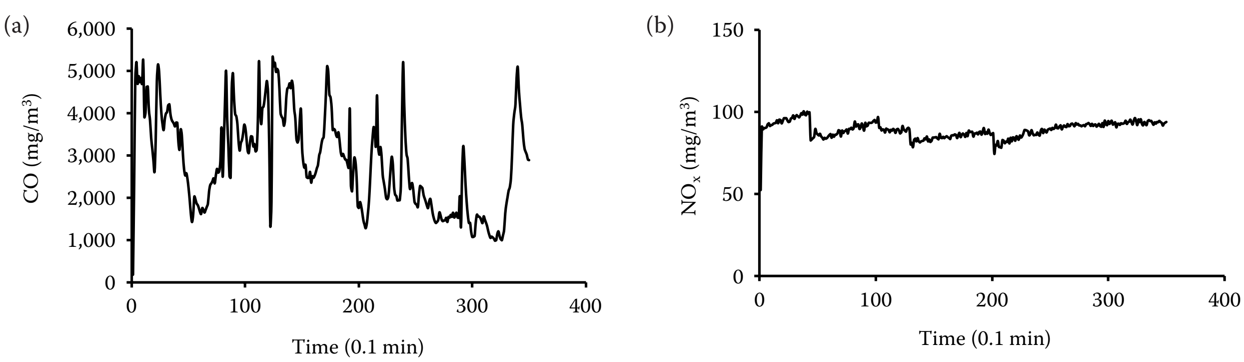

Fig. 3. Course of CO and NO_x emissions during the combustion of wood briquettes Turbohard

ing with exception of briquettes. The emissions from briquettes fulfil the requirements of class 1 according to the standard ČSN EN 13229:2002.

In case of NO_x emissions it is possible to compare the measured values with the Directive of the Ministry of Environment No. 13/2006:2006, which defines the demands necessary to the grant of trademark „Environmentally friendly products" for warm-water boilers destined for biomass combustion with heat output up to 200 kW. The directive determines the emission limit for NO_x content (250 mg/m^3) at 11% of oxygen content. After recalculation to 13% oxygen content, this limit value makes 200 mg/m^3 N. This value was not exceeded in case of the evaluated fuels, which can be probably due to the low content of organically bound nitrogen in the material. The CO emissions in case of all fuels produced from willow wood are higher than in case of briquettes Turbohard. The reason is probably a considerable fluctuation of this value, as it is possible to detect

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at comparison of graphs in Figs 2 and 3. It can be also explained by unstable release of volatile matter in the course of combustion process.

CONCLUSION

From the results of the field experiment in Michovka and from the evaluation of fuel and energy characteristics the following conclusions were made:

– Selected willow clones and varieties had comparable or rather better yields when compared with J-105, the most commonly used SRC poplar clone in the Czech Republic. In our study, the yields of 19.0 o.d.t/ha/year were obtained for *Salix* × *smithiana* clone S-218, which is 29% more than for J-105 clone in the same location.
– The used clones and varieties of willows have better fuel-energetic properties in the content of ash and temperature of ash melting when compared with poplar wood. These properties are probably related to bark content in the studied matter and would manifest when pellets from this wood material are burnt.
– When briquettes from willow or poplar wood are burnt, emission parameters are similar. These values depend especially on mechanical procession of material into suitable form of fuel.

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Received for publication April 30, 2014
Accepted after corrections April 1, 2016

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