J. Elementol. 2008, 13(4): 655-663

CONTENT OF CARBON, HYDROGEN AND SULPHUR IN BIOMASS OF SOME SHRUB WILLOW SPECIES

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Abstract

Carbon, hydrogen and sulphur were determined in biomass (shoots and roots) of five species of shrub willow: *Salix viminalis*, *Salix dasyclados*, *Salix triandra*, *Salix purpurea* and *Salix alba*. Samples of the biomass collected from a strict experiment were dried to constant weight at 105°C. The content of carbon, hydrogen and sulphur was determined in an automatic determinator ELTRA CHS 500. In addition to the chemical determinations, willow plants were assessed, in the first year of cultivation, in terms of their morphological traits and yields. The results underwent statistical analysis using Excel spreadsheets and Statistica PL software programme.

An average content of carbon in the biomass of the five analysed willow species was 496.33 $g \cdot kg^{-1}$ d.m. Among the five species, the highest carbon content was discovered in the biomass of *Salix purpurea* (501.32 $g \cdot kg^{-1}$ d.m.). An average content of hydrogen in aerial parts of shrub willow was significantly higher than in their roots (507.95 vs 465.88 $kg^{-1} \cdot$ d.m.). The content of hydrogen in all the species of shrub willow was on average 71.11 $g \cdot kg^{-1}$ d.m., with the highest hydrogen amount in biomass attributed to *Salix triandra* (74.98 $g \cdot kg^{-1}$ d.m.). This species, on the other hand, had the lowest concentration of sulphur in its biomass (on average 0.43 $g \cdot kg^{-1}$ d.m.). The average content of sulphur in aerial parts was significantly lower than in roots of willow plants (0.52 vs 0.95 $g \cdot kg^{-1}$ d.m.). This relationship held true for all the five species of willow plants.

An average yield of dry biomass obtained from the five shrub willow species in the year when the experiment was established was 5.81 $Mg \cdot ha^{-1}$. The highest dry biomass yield was produced by *Salix viminalis* (7.22 $Mg \cdot ha^{-1}$).

Key words: shrub willow, productivity, biomass, carbon, hydrogen, sulphur.

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ZAWARTOŚĆ WĘGLA, WODORU I SIARKI W BIOMASIE WYBRANYCH GATUNKÓW WIERZB KRZEWIASTYCH

Abstrakt

W biomasie pięciu gatunków wierzby krzewiastej: *Salix viminalis, Salix dasyclados, Salix triandra, Salix purpurea* oraz *Salix alba*, w pędach i korzeniach oznaczono zawartość węgla, wodoru i siarki. Pobrane ze ścisłego doświadczenia polowego próby biomasy wierzby wysuszono w temp. 105°C do uzyskania stałej masy. Zawartość węgla, wodoru i siarki w biomasie oznaczono w automatycznym analizatorze ELTRA CHS 500. Ponadto określono cechy morfologiczne oraz produktywność roślin *Salix* spp. w pierwszym roku uprawy. Wyniki badań opracowano statystycznie z użyciem arkusza kalkulacyjnego Excel oraz programu komputerowego Statistica PL.

Zawartość węgla w biomasie badanych gatunków wierzby krzewiastej wynosiła średnio 496,33 $g \cdot kg^{-1}$ s.m. Spośród badanych gatunków najwyższą zawartość węgla oznaczono w biomasie *Salix purpurea*, średnio 501,32 $g \cdot kg^{-1}$ s.m. Zawartość węgla w pędach nadziemnych była średnio istotnie wyższa (507,95 $g \cdot kg^{-1}$ s.m.) niż w korzeniach (465,88 $g \cdot kg^{-1}$ s.m.). Zawartość wodoru u badanych gatunków wynosiła średnio 71,11 $g \cdot kg^{-1}$ s.m. Istotnie najwyższą średnią zawartość wodoru w biomasie stwierdzono u gatunku *Salix triandra* (74,98 $g \cdot kg^{-1}$ s.m.). Gatunek *Salix triandra* zawierał istotnie najmniej siarki w biomasie, średnio 0,43 $g \cdot kg^{-1}$ s.m. Średnia zawartość siarki w pędach nadziemnych była istotnie niższa niż w korzeniach, odpowiednio 0,52 $g \cdot kg^{-1}$ s.m. i 0,95 $g \cdot kg^{-1}$ s.m. Zależność tę stwierdzono u wszystkich badanych gatunków wierzb.

Plon suchej biomasy badanych gatunków wierzb uzyskany w roku założenia doświadczenia wyniósł średnio 5,81 $Mg \cdot ha^{-1}$. Spośród badanych gatunków istotnie najwyższy plon suchej biomasy uzyskano u *Salix viminalis* – 7,22 $Mg \cdot ha^{-1}$.

Słowa kluczowe: wierzba krzewiasta, produktywność, biomasa, węgiel, wodór, siarka.

INTRODUCTION

Poland needs to increase the share of biomass in the total energy balance so as to improve its energy supply safety and enhance conservation of the natural environment. Using plant biomass for production of energy does not add to the warming effect. While growing, plants absorb the same amounts of carbon dioxide during photosynthesis as they release when their biomass is burnt (NALBORCZYK 2002, KISIEL et al. 2006). Production of energy from hardcoal creates a serious burden to the environment, such as elevated emission of carbon dioxide, sulphur dioxide, nitrogen oxides and flying ashes. In contrast to hardcoal combustion, biomass incineration makes it possible to achieve considerable reduction in SO_2 and organic pollutants, including polyaromatic hydrocarbons and flying organic compounds (KUBICA 2001)

Thus, comparison of fossil fuels and energy crops as energy sources should take into account the environmental burden caused by production of such fuels and emission of pollutants during energy generation. The available references lack detailed information concerning the content of carbon and hydrogen atoms in the cellulose and lignin biomass of shrub willows, which largely determine the calorific value of biomass-based solid fuels. The content of sulphur in energy crops should also be investigated, as it conditions the emission of this element to atmosphere while burning biofuels.

MATERIAL AND METHODS

The study was based on a field experiment conducted at the Research Station in Bałdy, the University of Warmia and Mazury in Olsztyn, Poland. The experiment was established in April 2006, on soil classified according to the Polish soil valuation system as defective wheat complex (class III b).

The first factor in the experiment comprised five species of shrub willow: *Salix viminalis*, *Salix dasycladosm*, *Salix triandra*, *Salix purpurea* and *Salix alba*. The second factor consisted of the type of willow biomass: aerial parts (leafless shoots) and underground biomass (roots).

The plants were not fertilised in the first year and the soil reaction was neutral. The grafts were planted in belts: 2 rows in a belt with 0.75 m space between the rows, followed by 0.90 m space between two belts and again 2 rows at 0.75 m spacing. On each plot, grafts were planted in 4 rows. The plants in a row were spaced at 0.25 m, which gave 48 thousand plants per hectare. The area of each plot was 23.1 m^2. The experiment was set up with three replications. At the end of the growing season, in November 2006, the willow plants underwent biometric measurements. The diameter of shoots was measured 50 cm above the ground surface on 10 randomly selected plants from the 2^{nd} and 3^{rd} row on each plot. Height of shoots (in m) was also measured on 10 plants per plot. Samples of biomass was taken for laboratory analyses. For this purpose, one whole plant was harvested from each plot (leafless aerial shoots and roots).

In the laboratory, proper samples of shoots and roots were obtained from the biomass of the five willow species. Biomass samples were dried up to constant weight at 105°C. The per cent contribution of shoots and roots in the dry matter of the *Salix* spp. plants was established. The yield of dry biomass ($Mg \cdot ha^{-1}$) was computed from the yield of fresh biomass of shoots and their moisture content. Dried samples of biomass were ground in an IKA analytic mill, using a 0.25 mm mesh sieve. The ground samples were again dried to constant weight, after which they were subjected to chemical analyses. The content of carbon, hydrogen and sulphur in the biomass of the analysed species of *Salix* spp. was determined in an automatic determinator ELTRA CHS 500.

The results of the study were processed statistically using Excel spreadsheets and Statistical software programme. Arithmetic means were calculated for all the analysed traits. In order to determine the mean concentrations of carbon, hydrogen and sulphur in the biomass (shoots and roots) of each willow species, corresponding weighted averages were computed. Using Duncan's significance test, LSD values at p=0.05 were derived. Finally, simple correlation coefficients for all the tested traits were computed.

RESULTS AND DISCUSSION

In the first growing season, aerial shoots accounted for 72.39% of dry biomass of willow plants, while the roots made up the remaining 27.61% (Figure 1). The lowest contribution of roots to the whole biomass was found for *S. triandra* (20.93%); the highest one – for *S. purpurea* (30.23%).

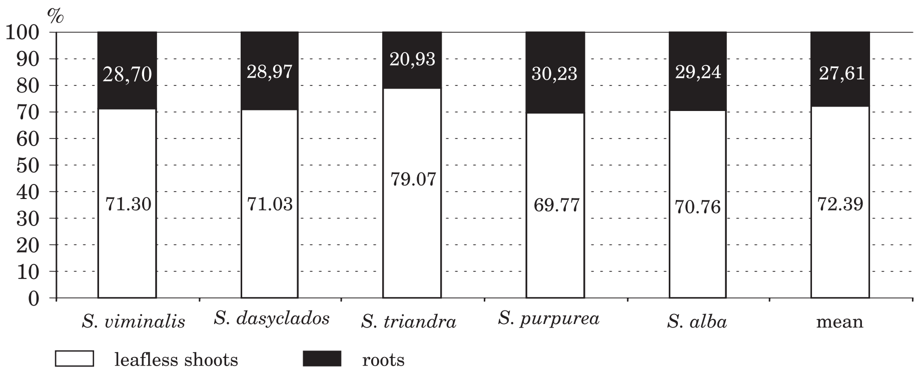

Fig. 1. Contribution of leafless shoots and roots in dry biomass obtained from *Salix* spp. plants

An average height of the shoots grown by the five willow species was 2.19 m (Table 1). Significantly higher shoots were developed by *S. viminalis* (2.70 m). *Salix dasyclados* grew comparably tall shoots, whereas the other willow species produced much lower shoots.

The thickest shoots were grown by *S. dasyclados* (14.73 mm). Similar diameters of shoots were obtained for *S. viminalis* and *S. triandra*. On the other hand, the diameter of shoots grown by *S. purpurea* and *S. alba* was significantly smaller compared to *S. dasyclados*.

The yield of dry aerial biomass obtained in the first growing season was on average 5.81 Mg·ha^{-1}. Among the five tested species of shrub willow, *Salix viminalis* produced the highest dry biomass yield (7.22 Mg·ha^{-1}), with *S. dasyclados* and *S. triandra* yielding on a comparable level. *Salix purpurea*, on the other hand, produced the lowest yields of dry matter (3.95 Mg·ha^{-1}). Yields of aerial biomass obtained in the first growing season being lower than in the consecutive years can be explained by the fact that

Table 1

Height and shoot diameter, yield of dry matter of the five shrub willow species

Species	Height of shoots (m)	Diameter of shoots (mm)	Dry biomass yield ($Mg \cdot ha^{-1}$)
Salix viminalis	2.70	13.27	7.22
Salix dasyclados	2.61	14.73	6.89
Salix triandra	2.02	11.70	6.78
Salix purpurea	1.68	7.70	3.95
Salix alba	1.95	11.50	4.19
Average	2.19	11.78	5.81
$LSD_{0.05}$	0.14	3.13	1.57

the plants needed to develop their root system, to the detriment of the growth and development of aerial parts. KALEMBASA et al. (2006) report that yields of dry matter obtained from leafless shoots produced by *Salix viminalis* in the first growing season range from 3.21 to 6.51 $Mg \cdot ha^{-1}$, depending on fertilization. The analogous yields produced by a hybrid of *S. viminalis* and *S. purpurea* were much lower, from 0.45 to 1.04 $Mg \cdot ha^{-1}$. In the following years (2nd and 3rd growing season), yields of dry matter produced by *Salix viminalis* increased to 30 $Mg \cdot ha^{-1}$. In our own tests, the yielding potential of *Salix* spp. plants in the first year was much lower than in the following seasons (STOLARSKI 2002, SZCZUKOWSKI et al. 2004).

The content of carbon in the biomass of the five willow species was on average 496.33 $g \cdot kg^{-1}$ (Table 2). The highest carbon content was determined in the biomass obtained from *Salix purpurea* (on average 501.32 $g \cdot kg^{-1}$ d.m.).

Table 2

Content of carbon in biomass of the five shrub willow species ($g \cdot g^{-1}$ d.m.)

Species (a)	Type of biomass (b)		Average
	shoots	roots	
Salix viminalis	506.89	475.09	497.77
Salix dasyclados	503.41	468.48	493.29
Salix triandra	505.86	456.29	495.48
Salix purpurea	514.53	470.84	501.32
Salix alba	509.07	458.68	494.34
Average	507.95	465.88	496.33
$LSD_{0.05}$	a – 5.8	b – 3.6	a × b – 8.2

Similar carbon concentrations were determined in the biomass of *Salix viminalis*. The average content of carbon in aerial parts was significantly higher than in roots (507.95 vs 465.88 $g \cdot kg^{-1}$ d.m.). Significantly more carbon was determined in the biomass obtained from shoots of *Salix purpurea* (514.53 $g \cdot kg^{-1}$ d.m.), whereas the lowest carbon level was found in roots of *Salix triandra* (456.29 $g \cdot kg^{-1}$ d.m.). The content of carbon in the biomass of *Salix* spp. was significantly positively correlated with the content of hydrogen (r=0.43) and significantly negatively correlated with the content of sulphur (r=-0.79), at n=30 (for 30 pairs of replications). Some other own studies showed that one-year shoots of *Salix viminalis* contained 484.1 g carbon per 1 kg^{-1} d.m. (Stolarski et al. 2005). Other chemical analyses carried out on various types of biomass in China by Cuiping et al. (2004) proved that an average content of carbon in willow timber was 467.9 $g \cdot kg^{-1}$ d.m., as compared to 483.2 $g \cdot kg^{-1}$ d.m. in birch wood, 421.1 $g \cdot kg^{-1}$ d.m. wheat straw and 637.8 $g \cdot kg^{-1}$ d.m. bituminous coal. The average content of carbon in the biomass of shrub willow cv. Wodtur (*Salix dasyclados* species) was 518.3 $g \cdot kg^{-1}$ d.m., and of cv. Sprint (*Salix viminalis* species) – 513.2 $g \cdot kg^{-1}$ d.m. (Stolarski et al. 2008). Regarding the above studies, the lowest content of carbon has been determined in biomass of Jerusalem artichoke (430.8 $g \cdot kg^{-1}$ d.m.).

The content of hydrogen in biomass of the analysed species of willow was on average 71.11 $g \cdot kg^{-1}$ d.m. (Table 3). Statistically, the highest significant content of hydrogen in biomass was determined for the species *Salix triandra* (74.98 $g \cdot kg^{-1}$ d.m.). The average content of hydrogen in shoots was significantly higher than that found in roots (71.78 vs 69.33 $g \cdot kg^{-1}$ d.m.). The highest concentration of hydrogen in biomass was found in shoots produced by *Salix triandra* (76.34 g kg^{-1} d.m.), while the lowest one occurred in roots of *Salix dasyclados* (66.40 $g \cdot kg^{-1}$ d.m.). The level of hydrogen in biomass of *Salix* spp. was significantly negatively correlated with the content of sulphur (r=-0.52, n=30). While analysing the relationships between

Table 3

Content of hydrogen in biomass of the five shrub willow species ($g \cdot kg^{-1}$ d.m.)

Species (a)	Type of biomass (b)		Average
	shoots	roots	
Salix viminalis	71.56	70.17	71.16
Salix dasyclados	67.10	66.40	66.90
Salix triandra	76.34	69.84	74.98
Salix purpurea	72.89	69.99	72.01
Salix alba	71.02	70.24	70.79
Average	71.78	69.33	71.11
$LSD_{0.05}$	a – 1.80	b – 1.10	a × b – 2.60

the analysed biometric features and the levels of the particular elements, it was only in one case that a strong negative correlation was established, namely between the diameter of shoots and content of hydrogen, where *r*=-0.56 was calculated for the mathematical model of $y = -0.0433 x + 7.5584$ (*n*=15). The content of hydrogen in one-year shoots of *Salix viminalis* in another experiment carried out by the same authors (STOLARSKI et al. 2005) was 68.7 $g \cdot kg^{-1}$ d.m. Some other tests showed that the concentration of hydrogen in biomass of *Salix* spp. was only slightly varied and ranged between 66.3 $g \cdot kg^{-1}$ d.m.for *Salix viminalis* to 66.8 $g \cdot kg^{-1}$ d.m. for *Salix dasyclados* (STOLARSKI et al. 2008). CUIPING et al. (2004) report that an average content of hydrogen in willow wood was 71.0 $g \cdot kg^{-1}$ d.m., compared to 83.6 $g \cdot kg^{-1}$ d.m. in birch wood, 65.3 $g \cdot kg^{-1}$ d.m.in wheat straw and 39.7 $g \cdot kg^{-1}$ d.m. in bituminous coal, where it was the lowest.

The content of sulphur in biomass of the five analysed species of shrub willow was on average 0.64 $g \cdot kg^{-1}$ d.m. (Table 4). The species called *Salix triandra* had the smallest, statistically confirmed, levels of sulphur in biomass (on average 0.43 $g \cdot kg^{-1}$ d.m.). The average content of sulphur in aerial shoots was significantly lower than in roots (0.52 versus 0.95 $g \cdot kg^{-1}$ d.m.).

Table 4

Content of sulphur in biomass of the five shrub willow species ($g \cdot kg^{-1}$ d.m.)

Species (a)	Type of biomass (b)		Average
	shoots	roots	
Salix viminalis	0.56	0.92	0.66
Salix dasyclados	0.56	1.06	0.70
Salix triandra	0.35	0.72	0.43
Salix purpurea	0.57	0.85	0.66
Salix alba	0.57	1.20	0.75
Average	0.52	0.95	0.64
$LSD_{0.05}$	a – 0.03	b – 0.02	a × b – 0.05

This tendency held true for all the analysed willow species. The lowest amounts of sulphur were determined in shoots of *Salix triandra* (0.35 $g \cdot kg^{-1}$ d.m.), whereas the highest ones appeared in roots of *Salix alba* (1.20 $g \cdot kg^{-1}$ d.m.). Some other experiments showed that the content of sulphur in one-year shoots of *Salix viminalis* was 0.43 $g \cdot kg^{-1}$ d.m. (STOLARSKI et al. 2005). KALEMBASA et al. (2005) observed that the total amount of sulphur in biomass of maiden grass (*Miscanthus* spp.) decreased as the grass continued to grow, with 1.67 g sulphur 1 kg^{-1} d.m. in 1st decade of June declining down to 0.50 g S kg^{-1} d.m. in 1st decade of September. The average content of sulphur for all the clones analysed in the above trial, irrespective of the date of sampling, was 0.91 g·kg^{-1} d.m. The amount of sulphur in the biomass of shrub willow *Salix dasyclados* was 0.44 g·kg^{-1} d.m., and in that of *Salix viminalis* – 0.40 g·kg^{-1} d.m. (STOLARSKI et al. 2008). By comparison, the content of sulphur in biomass of *Miscanthus* grasses was 0.48 g·kg^{-1} d.m. in *Miscanthus giganteus* and 0.58 g·kg^{-1} d.m. in *Miscanthus sacchariflorus.* The highest amount of sulphur determined in the above experiments was found in the biomass of prairie cordgrass (1.34 g·kg^{-1} d.m.). The content of sulphur in hardcoal is in general higher than in biomass of energy crops. According to ZAWISTOWSKI (2003), the content of sulphur in hardcoal is varied, ranging from 2.5 to 13.5 g·kg^{-1} d.m. When comparing the emission of sulphur during combustion of fuels, KUBICA (2001) suggested that that it was 20-fold higher for hardcoal than for timber.

CONCLUSIONS

1. The species *Salix purpurea* was characterised by the highest content of carbon in biomass (on average 501.32 g·kg^{-1} d.m.). The content of carbon in shoots produced by this species was significantly the highest among the analysed types of biomass. On the other hand, the lowest content of carbon was determined in roots of *Salix triandra*.

2. The content of hydrogen in biomass of shrub willow ranged within 66.90 (*S. dasyclados*) to 74.98 g·kg^{-1} d.m. (*S. triandra*).

3. Among the five tested species of shrub willow, the highest average content of sulphur was found in the biomass of *S. triandra*; the lowest – in biomass produced by *S. alba*.

4. Aerial shoots of all the tested species were characterised by higher concentrations of carbon, hydrogen and lower amounts of sulphur than the roots.

5. Relatively high amounts of carbon and hydrogen along with the low content of sulphur in the biomass of shrub willow mean that the plant can be treated as an energy source alternative to hardcoal.

6. The yield of dry biomass of the five tested species of shrub willow obtained in the first growing season was 3.95 (*Salix purpurea*) to 7.22 g·kg^{-1} d.m. (*Salix viminalis*).

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