Impact of the energy willow planting density on the canopy architecture in 9th and 10th year of cultivation

Janusz Dąbrowski[1,*], and *Leszek* Styszko[1]

[1]Koszalin University of Technology, Faculty of Civil Engineering, Environmental and Geodetic Sciences, Koszalin, Poland

Abstract. The purpose of the present paper was an assessment of the dynamics of the regrowth of the shoots of 10 genotypes of basket willow (*Salix viminalis* L.) in the 9th and 10th year of cultivation on light soil in the Middle Pomerania (16°24'N and 54°8'E) with a diversified planting density of cuttings (15.020, 22.134 and 33.200 pcs.$\cdot$ha^{-1}). The field experiment was established in 2007 with 3 planting densities of willow cuttings, and 10 willow genotypes. In 2016–2017, the regrowth dynamics of willow shoots was assessed separately in the first and second row of the plot. The willow genotype, the planting density of cuttings during the establishment of the plantation, the number of the years of shoot regrowth and variants of shoots mowing had an impact on the willow canopy architecture in the 9th and 10th year. The reaction of genotypes with the individual parameters of the canopy architecture was not identical.

1 Introduction

Biomass harvested for energy purposes constitutes a significant source of renewable energy in Poland and in Europe [3–5, 18]. In the production of willow biomass, snag planting per one hectare in the whole 25-year cycle of its cultivation is important. With a perennial cultivation of willow, snag planting per one hectare diminishes in relation to the original plantings. A reduction of willow snag planting per one hectare has a reducing effect on the crop of the biomass of shoots [1, 2, 10, 13, 16]. Dying out of willow snags in the first 3-year cycle with cultivation on very heavy alluvial soil near Kwidzyn depended on the variety, planting density of cuttings and harvest frequency, yet it did not exceed 10% of planting independently of the experiment variant [10]. Research concerning dynamics of willow biomass growth during years of cultivation are performed in Poland mainly in the first 3–4 year rotation [8, 10–12, 14, 17]. These measurements may serve for the current forecasting of the willow biomass yield [11].

* Corresponding author: janusz.dabrowski@tu.koszalin.pl

The purpose of the paper was to assess the regrowth dynamics of the shoots of 10 genotypes of basket willow (*Salix viminalis* L.) in the 9th and 10th years of cultivation on light soil in the Middle Pomerania (16°24'N and 54°8'E) with a diversified planting density of cuttings (15.020, 22.134 and 33.200 pcs.·ha^{-1}) in the conditions of rainfall-retention water system.

2 Materials and methods

The measurements of height and thickness of willow shoots, of the quantity of live and dead shoots in the snag and of the quantity of live and dead snags on the plot were performed in the experiment realized in the years 2016–2017 on the experiment field of the Koszalin University of Technology in Kościernica (16°24′N and 54°8′E). The soil used in the experiment was light, RIVa–IVb soil quality class, a good rye soil complex, appropriate podsolic – pseudopodsolic with a composition of light loamy sand up to the depth of 100 cm, and deeper: light loam. The humus content in the layer of 0–30 cm of soil was 1.41%. Within the framework of the experiment, three planting densities of willow cuttings were randomized on large plots: (**a**) 15.020 pcs.·ha^{-1}, (**b**) 22.134 pcs.·ha^{-1}, (**c**) 33.200 pcs.·ha^{-1}, and inside the planting densities of cuttings: 10 genotypes of basket willow (*Salix viminalis* L.) – three clones: 1047, 1054 and 1047D and seven varieties: Start, Sprint, Turbo, Ekotur, Olof, Jorr and Tordis. In 2007, the following was planted on the objects: **(a)** 38 cuttings, **(b)** 56 willow cuttings and **(c)** 84 cuttings in two rows on the plot sized 25.3 m^2. In April, in the years 2008–2015, homogeneous mineral fertilisation in a clear component was applied in the whole experiment: N – 120 kg·ha^{-1}, P – 8,7 kg·ha^{-1} and K – 34,9 kg·ha^{-1}. In the first 4-year rotation, the first row was mowed twice (after 3 years and after annual regrowth), and the second row was mowed once (after 4 years of regrowth). In the second 4-year rotation (2012–2015), both rows of the plot were mowed once (after the fourth year of regrowth). In the second 4-year rotation (2012–2015), both rows of the plot were mowed once (after the fourth year of regrowth). For the examined factors, a standard analysis of variance was conducted and the structure of variance components was determined. The significance of the effects was assessed with the F test. Data related to representative weather profile for the Kościernica region were collected from the Meteorology and Water Management Station in Koszalin. Annual rainfall in Koszalin in the willow vegetation period (IV–X) was 575.6 mm in 2012 and 620.9 mm in 2017. The hydrothermal extreme conditions (extremely dry and very dry as well as very wet and extremely wet) indicated by the Sielianinow's coefficient (K) fall within the ranges < 0.7 and > 2.5. In the growing season, this coefficient fluctuated in the range of 1.90 (in 2016) to 2.13 (in 2017). Extremely dry and very dry conditions ($K < 0.7$) occurred in May 2017 and September 2016, and very wet conditions ($K > 2.5$) occurred in July 2016 and 2017 and in October 2016 and 2017.

3 Results and discussion

The research factors (willow genotypes, the planting densities of cuttings, the variants of shoots mowing in 2008–2011, dates of measurements and years of shoot regrowth) used in the experiment had a significant impact on the canopy architecture (Table 1).

Table 1. Impact of examined factors on the structure of variance components.

Variance component[1]	Number of levels	Percentage structure of variance components in analyses					
		Shoots		Shoots in snag		Snags on the plot	
		height	thickness	live	dead	live	dead
E	10	**47.7*****	**54.6*****	9.5***	3.3***	28.0***	28.0***
D	3	10.2***	4.1***	0.6***	0.2**	**2.5*****	**2.5*****
C	2	9.6***	7.3***	**28.6*****	8.8***	7.3***	7.3***
B	3	4.6***	2.9***	0.0 **n.s.**	0.0 **n.s.**	0.0 **n.s.**	0.0 **n.s.**
A	2	6.5***	1.0***	8.5***	49.2***	6.2***	6.2
Σ A–E		**78.6**	**69.9**	**47.2**	**61.5**	**44.0**	**44.0**
ExD		11.5***	2.9***	5.1***	1.9***	6.9***	9.1***
ExC		0.4***	1.0***	6.5***	2.1***	5.4***	5.3***
DxC		1.0***	0.0 **n.s.**	1.0***	0.5***	1.2***	1.2***
ExB		0.5***	0.8***	0.2*	0.0 **n.s.**	0.0 **n.s.**	0.0 **n.s.**
DxB		0.1***	0.1 **n.s.**	0.2*	0.0 **n.s.**	0.0 **n.s.**	0.0 **n.s.**
CxB		0.1***	0.0 **n.s.**	0.0	0.0 **n.s.**	0.0 **n.s.**	0.0 **n.s.**
ExA		0.6***	7.8***	3.9***	5.1***	6.3***	6.3***
DxA		0.1***	2.0***	0.2**	0.2**	0.4***	0.4***
CxA		0.1***	0.0 **n.s.**	3.1***	9.3***	3.5***	3.5***
BxA		0.0 **n.s.**	0.0 **n.s.**	0.1 **n.s.**	0.2*	0.0 **n.s.**	0.0 **n.s.**
Σ other		7.9	15.5	32.5	19.2	30.0	30.0
Σ interactions		**21.4**	**30.1**	**52.8**	**38.5**	**56.0**	**56.0**

[1]The designation of variance components and significance level is given in Table 2.

The changeability caused by the activity of the main factors ranged from 78.6% with the height of the shoots to 47.2% with the live shoots in the snag. In particular, large effects were demonstrated with interactions: ED (11.5% with the height of the shoots, 9.1% with the dead and 6.9% with the live snags on the plot), EC – with the live shoots in the snag (6.5%), EA – with the thickness of the shoots (7.8%) and CA – with the dead shoots in the snag (9.3%).

The data from the biometric measurements of willow in the years 2016–2017 are presented in Table 2 and the differences between the extreme values and their relative reference to the average of the experiment within the framework of the feature examined are found in Table 3. The data provided in Table 3 confirm that the willow genotypes and the years of regrowth with dead shoots in the snag caused the greatest differences for the parameters of the willow canopy architecture that are characterized by the height and thickness of the shoots, the number of live shoots and the number of live and dead snags on the plot (respectively: 55.8%, 65.2%, 43.4%, 63.4% and 63.4%). In the case of dead shoots in the snag, this was years of regrowth (48.1%). The impact of the planting density of cuttings on the canopy architecture was weaker than that of willow genotypes with the height and thickness of the shoots and with the number of live and dead snags on the plot (respectively: 14.2%, 11.6%, 10.9%, 10.9%); while, with the number of live and dead shoots in the snag and with the number of live and dead snags on the plot, this was additionally smaller than that of shoot mowing variants in the years 2008–2011.

Table 2. Impact of examined factors on the results of willow measurements in 2016–2017.

Examined factors		**Designation of analyses**					
		Measurements of shoots		Shoots in snag		Snags on the plot	
Factors	Level	height [cm]	thickness [mm]	live [pcs.]	dead [pcs.]	live [%]	dead [%]
Years of shoots regrowth [A]	2016	220.3	12.6	5.5	1.0	77.0	23.0
	2017	265.3	13.5	7.4	7.4	66.5	33.5
	$NIR_{0.05}$	1.3***	0.2***	0.2***	0.2***	0.5***	0.5***
Dates of measurements [B]	30 VI	212.3	11.8	6.5	4.1	71.9	28.1
	30 IX	254.4	13.7	6.5	4.3	71.6	28.4
	10 XI	261.8	13.7	6.4	4.3	71.6	28.4
	$NIR_{0.05}$	1.6***	0.3***	0.2 **n.s.**	0.3 **n.s.**	0.6 **n.s.**	0.6 **n.s.**
Variant of shoots mowing [C][2]	I	215.5	11.9	4.5	2.9	66.0	34.0
	II	270.2	14.3	8.3	5.6	77.4	22.6
	$NIR_{0.05}$	1.3***	0.2***	0.2***	0.2***	0.5***	0.5***
Planting density of cuttings in pcs.·ha^{-1} [D]	15020	196.9	11.6	6.9	4.5	72.0	28.0
	22134	264.2	13.5	6.2	4.1	76.3	23.7
	33200	267.4	14.2	6.3	4.1	66.9	33.1
	$NIR_{0.05}$	1.6***	0.3***	0.2***	0.3**	0.6***	0.6***
Willow genotype [E]	1047	183.2	10.9	7.5	4.8	66.1	33.9
	1054	216.5	10.6	6.4	4.1	78.8	21.2
	1047D	193.8	10.5	8.6	5.7	74.0	26.0
	Start	118.3	7.1	3.7	2.1	34.5	65.5
	Sprint	182.6	10.5	6.3	4.2	65.4	34.6
	Turbo	225.2	10.9	6.3	4.0	82.8	17.2
	Ekotur	365.9	21.7	7.5	5.2	89.3	10.7
	Olof	285.4	15.6	5.1	3.2	66.1	33.9
	Jorr	262.2	12.4	5.0	3.2	72.2	27.8
	Tordis	395.3	20.8	8.1	5.6	88.0	12.0
	$NIR_{0.05}$	2.9***	0.5***	0.4***	0.5***	1.0***	1.0***
Average		242.8	13.1	6.4	4.2	71.7	28.3

[2]Mowing variant in the years 2008–2011: I – mowing after 3-year and 1-year regrowth, II – mowing after 4-year regrowth;
significance level: **n.s.** – no significance, *α = 0.05; **α = 0.01; ***α = 0.001.

Table 4 presents the data for the interaction of willow mowing variants in the years 2008–2011 with the planting density in 2007. The biggest differences between variant II and I of shoots mowing for the height of shoots occurred with the planting density of 22134 cuttings·ha^{-1} and smallest with the planting density of 15020 cuttings·ha^{-1}. While, for the quantity of live and dead shoots in the snag and the percentage share of live and dead snags on the plot the biggest differences between variant II and I of shoots mowing occurred with the planting density of 15020 cuttings·ha^{-1} and smallest with the planting density of 22134 and 33200 cuttings·ha^{-1}.

Table 3. Variability of the examined factors and their reference to an average from experiment.

Main factors		**Measurements of shoots**		**Shoots in snag**		**Snags on the plot**	
Factors[3]	Extreme values	height [cm]	thickness [mm]	live [pcs.]	dead [pcs.]	live [%]	dead [%]
A	difference	45.0	0.9	1.9	6.4	10.5	10.5
	percent	9.0	4.0	16.8	48.1	12.2	12.2
B	difference	49.5	1.9	0.1	0.2	0.3	0.3
	percent	10.0	8.5	0.9	1.5	0.3	0.3
C	difference	54.7	2.4	3.8	2.7	11.4	11.4
	percent	11.0	10.7	33.6	20.3	13.2	13.2
D	difference	70.5	2.6	0.6	0.4	9.4	9.4
	percent	14.2	11.6	5.3	3.0	10.9	10.9
E	difference	277.0	14.6	4.9	3.6	54.8	54.8
	percent	55.8	65.2	43.4	27.1	63.4	63.4
Experiment	Σ	496.7	22.4	11.3	13.3	86.4	86.4
	percent	100.0	100.0	100.0	100.0	100.0	100.0

[3]The designation of main factors is given in Table 2.

Table 4. Impact of the interaction between planting density of cuttings and variants of shoots mowing in 2008–2011 on parameters of willow canopy architecture in 2016–2017.

Planting density of cuttings		**Variant of mowing[4]**	**Measurements of shoots**		**Shoots in snag**		**Snags on the plot**	
[pcs. ·ha^{-1}]	[pcs. in row]		height [cm]	thickness [mm]	live [pcs.]	dead [pcs.]	live [%]	dead [%]
15020	19	I	179.6	10.5	4.6	2.8	63.6	36.4
	19	II	214.2	12.7	9.2	6.2	80.2	19.8
	difference (II-I)		**34.6**	**2.2**	**4.6**	**3.4**	**16.6**	**16.6**
22134	28	I	231.4	12.3	4.6	3.0	71.3	28.7
	28	II	296.9	14.7	7.8	5.1	81.3	18.7
	difference (II-I)		**65.5**	**2.4**	**3.2**	**2.1**	**10.0**	**10.0**
33200	42	I	235.5	12.8	4.5	2.8	63.1	36.9
	42	II	299.4	15.5	8.0	5.3	70.8	29.2
	difference (II-I)		**63.9**	**2.7**	**3.5**	**2.5**	**7.7**	**7.7**
$NIR_{0.05}$			2.2***	**n.s.**	0.3***	0.4***	0.8***	0.8***

[4]The designation of mowing variant and the significance level is given in Table 2.

The arrangement of the varieties from the largest to the smallest reaction to the planting density of cuttings to the parameters of the canopy architecture in 2016–2017 was as follows:
1 – height of the shoots: Olof, Ekotur, 1047, Jorr, Sprint, 1054, Turbo, Start, 1047D, Tordis,
2 – thickness of the shoots: Olof, Jorr, 1047, Sprint, 1054, Ekotur, Start, Turbo, Tordis, 1047D,
3 – live shoots in snags: 1047D, Ekotur, Jorr, Start, 1054, Tordis, 1047, Turbo, Sprint, Olof,
4 – dead shoots in snags: 1047D, Ekotur, Jorr, 1054, Tordis, Start, 1047, Sprint, Turbo, Olof,
5 – live and dead snags on the plot: Jorr, 1054, Sprint, Olof, Turbo, Start, Tordis, 1047D, 1047, Ekotur.

The parameters of the canopy architecture for the interaction of willow genotypes with the planting density of cuttings are provided in Table 5, and the difference between the extreme values of the parameters of the canopy architecture in the years 2016–2017 are provided in Table 6. Owing to the data from Table 6, it was possible to arrange willow genotypes in relation to their reaction to the planting density of cuttings while accepting the assumption that large differences between the extreme values of the parameters of the canopy architecture qualify the genotype to a high sensitivity to the planting density, while small differences qualify it to a small reaction.

Table 5. The impact of interaction between planting density of cuttings in 2007 and willow genotype on parameters of willow canopy architecture in the years 2016–2017.

Willow genotype	**Planting density of cuttings [pcs.·ha^{-1}]**	**Measurements of shoots**		**Shoots in snag**		**Snags on the plot**	
		height [cm]	thickness [mm]	live [pcs.]	dead [pcs.]	live [%]	dead [%]
1047	15020	**126.1**	**8.8**	7.3	4.8	69.3	30.7
	22134	183.8	10.7	**7.2**	**4.3**	**71.6**	**28.4**
	33200	**239.7**	**13.4**	**7.9**	**5.4**	**57.5**	**42.5**
1054	15020	**169.4**	**9.2**	**7.4**	**5.1**	**88.2**	**11.8**
	22134	**253.1**	**11.4**	6.3	4.1	84.2	15.8
	33200	226.9	11.2	**5.5**	**3.2**	**64.1**	**35.9**
1047D	15020	**174.1**	**10.0**	**11.1**	**7.6**	76.1	24.3
	22134	189.6	**10.8**	8.2	5.2	**80.4**	**19.6**
	33200	**217.7**	10.6	**6.6**	**4.4**	**65.6**	**34.4**
Start	15020	129.4	7.4	3.4	1.7	**45.2**	**54.8**
	22134	**82.0**	**5.8**	**2.5**	**1.6**	**27.7**	**72.3**
	33200	**143.5**	**7.9**	**5.1**	**2.9**	30.6	69.4
Sprint	15020	**133.8**	**8.7**	6.4	4.3	**75.2**	**24.8**
	22134	189.7	10.7	**6.1**	**3.7**	**56.1**	**43.9**
	33200	**224.4**	**11.9**	**6.4**	**4.8**	64.8	35.2
Turbo	15020	**183.4**	**10.1**	6.5	**3.6**	**74.8**	**25.2**
	22134	**246.6**	**11.6**	**6.5**	**4.6**	**93.2**	**6.8**
	33200	245.6	11.2	**5.8**	3.8	80.5	19.5
Ekotur	15020	**299.8**	**20.3**	**8.8**	**6.3**	90.2	9.8
	22134	**441.9**	22.1	7.7	5.2	**92.9**	**7.1**
	33200	355.8	**22.5**	**5.9**	**4.0**	**84.8**	**15.2**
Olof	15020	**152.4**	**12.3**	**5.0**	3.2	**57.2**	**42.8**
	22134	341.5	16.7	5.1	**3.0**	**76.0**	**24.0**
	33200	**362.3**	**17.8**	**5.2**	**3.4**	65.0	35.0
Jorr	15020	**198.5**	**9.3**	**3.7**	**2.0**	**55.0**	**45.0**
	22134	**309.4**	13.7	4.7	3.6	**85.4**	**14.6**
	33200	278.8	**14.2**	**6.5**	**4.0**	76.2	23.8
Tordis	15020	402.0	**20.1**	**9.2**	**6.7**	88.3	11.7
	22134	**404.2**	**21.5**	**7.4**	5.5	**95.1**	**4.9**
	33200	**379.8**	20.8	7.6	**4.8**	**80.2**	**19.8**
$NIR_{0.05}$		5.0***	0.9***	0.7***	0.9***	1.8***	1.8***

Significance level is given in Table 2.

Table 6. Impact of the interaction between planting density of cuttings in 2007 and willow genotype on differences between the extreme values of parameters of willow canopy architecture in the years 2016–2017.

Willow genotype	Measurements of shoots		Shoots in snag		Snags on the plot	
	height [cm]	thickness [mm]	live [pcs.]	dead [pcs.]	live [%]	dead [%]
1047	113.6	4.6	0.7	1.1	14.1	14.1
1054	83.7	2.2	1.9	1.9	24.1	24.1
1047D	43.6	0.8	4.5	3.2	14.8	14.8
Start	61.5	2.1	2.6	1.3	17.5	17.5
Sprint	90.6	3.2	0.3	1.1	19.1	19.1
Turbo	63.2	1.5	0.7	1.0	18.4	18.4
Ekotur	142.1	2.2	2.9	2.3	8.1	8.1
Olof	209.9	5.5	0.2	0.4	18.8	18.8
Jorr	110.9	4.9	2.8	2.0	30.4	30.4
Tordis	24.4	1.4	1.8	1.9	14.9	14.9
$NIR_{0.05}$	5.0***	0.9***	0.7***	0.9***	1.8***	1.8***

Significance level is given in Table 2.

The arrangement of the genotypes in relation to the reaction to the planting density of cuttings provides an indication as to the technology of willow cultivation for energy purposes. The reaction of the varieties is not identical with the individual parameters of the canopy architecture. The Olof variety demonstrated the greatest reaction to the planting density of cuttings with the height and thickness of shoots, and the smallest reaction was demonstrated by the Tordis variety and the 1047D clone; with live and dead shoots in the snag, the largest reaction occurred in the 1047D clone and the smallest reaction with the Olof variety, and with live and dead snags on the plot, the biggest reaction was with the Jorr variety and the smallest with the Ekotur variety. The author's research showed that during multi-year willow cultivation, there are changes in the canopy architecture resulting from the impact of shoot regrowth years, the mowing method, the planting density of cuttings and the varietal features of the willow. Polish domestic literature shows that these effects were documented mainly in relation to the first 2–4-year rotation [8–12, 14, 15]. In the investigations performed in the Middle Pomerania in the years 2007–2014, with 10 varieties of willow in relation to dying out of willow snags, the following had a great impact: the age of cultivation, the planting density of cuttings and their interaction. The varieties and frequency of shoot mowing in the first 4-year rotation demonstrated the smallest impact [13]. In this study, 10 varieties were classified in relation to the tendency of snags to die out. In foreign literature, there are reports stating that willow gives a higher yield of biomass in further rotations than in the first rotation [6, 7]. The measurements of dynamics of willow shoots increase during vegetation may be used for predicting biomass yield. An example of prognostic equations for an average yield of fresh biomass from 9 willow clones obtained from light soil, fertilized with compost from municipal sewage sludge and with different nitrogen doses was developed by Styszko et al. [11]. In these equations, data was taken into account from the following biometric measurements: the length and thickness of shoots and the number of shoots in the snag on four dates of measurements as well as an interaction between the length and thickness of shoots with fixed planting density of 34.782 cuttings per hectare. In the literature, there is still a shortage of similar analyses in the years of cultivation for different planting densities of willow varieties and clones.

4 Conclusions

1. The willow genotype, the planting density of cuttings during the establishment of the plantation, the number of the years of shoot regrowth and variants of shoots mowing had an impact on the willow canopy architecture in the 9th and 10th year, described by the length and thickness of shoots, the quantity of live and dead shoots in the snag and the quantity of live and dead snags on the plot.
2. The willow genotypes differ in the reaction to the shoots growth dynamics in terms of length and thickness, the quantity of live and dead shoots in the snag and the quantity of live and dead snags on the plot in the years of cultivation depending on the planting density and variant of mowing, and their reaction is not the same.
3. The reactions to the planting density of cuttings was as follows: the Olof variety demonstrated the greatest reaction with the height and thickness of the shoots, while the Tordis variety and 1047D clone demonstrated the smallest reaction; with live and dead shoots in the snag, the largest reaction occurred with the 1047D clone and the smallest reaction with the Olof variety and with live and dead snags on the plot, the strongest reaction occurred with the Jorr variety and the smallest reaction occurred with the Ekotur variety.

The authors would like thank the Lillohus AB Company; 291 61 Kristianstad in Sweden for handing over Olof, Jorr and Tordis varieties for the tests free of charge and Mr. Przemysław Dobrzaniecki from Agrobränsle AB in Poznan for intermediation in this donation.

References

1. M.J. Bullard, S.J. Mustil, S.D. McMillan, P.M.I. Nixon, P. Carver, C.P. Britt, Biomass Bioenergy **22**, 15–25 (2002)
2. B. Caslin J. Finnan, A. McCracken, *Short Rotation Coppice Willow Best Practice Guidelines* (Teagas AFBI, Belfast, 2010)
3. EurObserv'ER, 15th EurObserv'ER Report, **103** (2015)
4. Z. Grudziński, Rocznik Ochrona Środowiska **15**, 2249–2266 (2013)
5. GUS, *Energia ze źródeł odnawialnych w Polsce w 2015 r*. (GUS Warszawa, 2016)
6. M. Labrecque, T. Teodorescu, Biomass Bioenergy **25**, 135–146 (2003)
7. W. Nissim, F. Pitre, T. Teodorescu, M. Labrecque, Biomass Bioenergy **56**, 361–369 (2013)
8. W. Nowak, J. Sowiński, A.A. Jama, Fragm. Agron. **28**, 2, 55–62 (2011)
9. M. Stolarski, S. Szczukowski, J. Tworkowski, Fragm. Agron. **19**, 2, 39–51 (2002)
10. M. Stolarski, *Agrotechniczne i ekonomiczne aspekty produkcji biomasy wierzby krzewiastej (Salix spp.) jako surowca energetycznego* (Wyd. UW-M, Olsztyn, 2009)
11. L. Styszko, D. Fijałkowska, M. Sztyma-Horwat, M. Ignatowicz, PAK **5**, 512–515 (2010)
12. L. Styszko, D. Fijałkowska, M. Sztyma-Horwat, ROŚ **12**, 339–350 (2010)
13. L. Styszko, D. Fijałkowska, Progress in Plant Protection **55**, 4, 488–493 (2015)
14. L. Styszko, M. Ignatowicz, A. Borzymowska, Zesz. Probl. Post. Nauk Rol. **564**, 237–245 (2011)
15. S. Szczukowski, J. Tworkowski, M. Stolarski, W. Fortuna, Fragm. Agron. **26**, 3 (2009)
16. S. Szczukowski, J. Tworkowski, Post. Nauk Rol. **2**, 29–38 (2001)
17. J. Tworkowski, S. Szczukowski, M. Stolarski, Fragm. Agron. **27**, 4, 135–146 (2010)
18. A. Uliasz-Bocheńczyk, E. Mokrzycki, Rocznik Ochrona Środowiska **17**, 900–913 (2015)