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IMPACT OF SOIL-CLIMATIC AND HYDROLOGICAL CONDITIONS SOUTHWESTERN SLOVAKIA TO THE PRODUCTION INDICATORS OF FAST GROWING WILLOW SALIX

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ABSTRACT

On the research field base of the Department of Sustainable Development of the Slovak University of Agriculture in Kolíňany, in 2011 the production parameters and biomass production were observed in the case of five Short-Rotation Willow Coppice (SRWC) varieties of Swedish energy crop - willow Salix (Tora, Gudrun, Tordis, Inger and Sven). Within the field experiment performed on a small plot of land with approximately 10 666 subjects per hectare the following indicators were observed: The number of living shoots in individuals, shoot length, shoot thickness, yield of dry biomass for individual and total biomass dry matter (DM) yield in $t.ha^{-1}$. The number of shoots produced by individuals in the fertilized variant ranged from 5.00 to 7.33 shoots and in the unfertilized variant from 5.00 to 7.66 shoots. The average thickness of shoots of fertilized variant ranged from 27.05 mm to 35.91 mm. In the case of the fertilized variant the indicator was lower and varied from 25.66 mm to 30.32 mm. The average length of shoots of fertilized variant ranged from 6.11 m to 7.78 m and the unfertilized 5.22 to 7.46. As for the average yield of biomass (dry) DM in kg, in case of the fertilized variant, the individuals reached values from 6.59 kg to 11.39 kg and the unfertilized variant from 6.16 kg to 8.26 kg. The average yield of biomass DM in $t.ha^{-1}$ in the fertilized variant ranged from 70.28 $t.ha^{-1}$ to 121.48 $t.ha^{-1}$ and in the unfertilized variant from 65.70 $t.ha^{-1}$ to 88.10 $t.ha^{-1}$. Annual production of biomass DM in $t.ha^{-1}$ for individual SRWC varieties and fertilizer in a five-year growing cycle is from13140 $t.ha^{-1}$ to 24297 $t.ha^{-1}$.

KEYWORDS: Biomass, production indicators, energy crops, SRWC, shoots, variety.

INTRODUCTION

It is assumed that in the near future in Slovakia, biomass energy obtained from the fast-growing trees will become an important renewable source of energy along with other major energy sources. In order to reach that the energy use of biomass grown on agricultural land would be economically efficient, the Short Rotation Coppice (SRC) crops, which produce large quantities of biomass, should be used. The energy crop – willow (*Salix* spp.) belongs to this category, what is more, its cultivation in the drier conditions of south-western Slovakia has been a research topic of the Department of Sustainable Development of the Slovak Agricultural University in Nitra for several years.

The first three years results of the experimental research of the department showed that the efficiency of production of energy crop - willow varieties observed in the last year of three-years growing cycle is closely connected to the production indicators of individuals inside the stand. The number of shoots, the thickness of shoots, the shoots height and the shoots weight of individuals had a significant impact on the biomass production (Demo et al. 2011a, b).

The production efficiency of energy crop - willow Salix may be affected also by other factors. In many cases the reduced biomass production can be caused by decreased resistance of individuals to frost (Tahvanainen and Rytkönen 1999). Energy crop productivity per unit of area also depends on the completeness of the crop which can be affected by the percentage of rootedness of cuttings after planting and by the improvement of the genetic potential of new varieties in combination with optimal conditions for growth (Hinckley et al. 1992). Successful energy crop - willow grower must be aware of the biological and physiological processes that regulate the production process, carbon intake and its utilization in the plant (Ericsson et al. 1992).

MATERIAL AND METHODS

On the research unit of the Department of Sustainable Development of the SUA in Kolíňany in 2011, production parameters and biomass production of five varieties of Swedish energy crop - willow Salix (Tora, Gudrun, Tordis, Inger and Sven) were observed in the last year of their five-year growing cycle. Within the three repetition of a field experiment performed on a small parcel calculated per hectare with 10 666 subjects the following parameters were analyzed: the number of the living shoots in individuals, the shoots‘ length, the shoots‘ thickness, dry biomass yield per individual and dry biomass yield in $t.ha^{-1}$.

The shoots‘ length was determined as the distance between the soil surface and the top of the shoots. The thickness of the shoots was measured at the heights 1.0 m above the ground. Determination of the dry weight of above ground biomass of individuals was performed using the combustion method. In the case of selected individuals, the field trial was performed in three repetitions when all shoots were cut 50 mm above the ground and then weighted by a hinge digital scale. The production of dry biomass in $t.ha^{-1}$ was expressed as 10.666 individuals per ha. In order to determine the biomass DM of individuals, samples were taken from the shoots with varying thickness. To determine statistical significance between the observed production indicators and the varieties, analysis of variance (ANOVA) was used. The data were tested at the significance level $\alpha = 0.05$ and 0.01.

RESULTS AND DISCUSSION

The average values of the production parameters (listed in the Tab. 1) are significantly different for different varieties and fertilization levels. The average number of living shoots for the fertilized variant ranges from 5 shoots in the variety Tordis and Inger to 7.33 shoots in the variety of Sven and Gudrun. Within the non- fertilized variant the number of shoots varies from 5 shoots at the Tora variety to 7.66 at the variety Gudrun. Considering the number of shoots a significant difference could be seen between varieties in the case of fertilized variant (P value = 0.067 <0.01) as well as varieties in non-fertilized variant (P value 0.13> 0.05). However, the difference in the number of shoots was not significant when taking into account only fertilized or non-fertilized variants (P value = 0.79> 0.05). Used Tukey HSD test showed that statistically significant differences appeared between varieties Gudrun - Inger, Gudrun - Tordis, Inger - Sven and Sven - Tordis.

Tab. 1: The average values of the production parameters of the fast-growing varieties of energy trees Salix in the last year of the five-year growing cycle.

Varieties	**Variant of fertilization with mineral fertilizers**	**Monitored production indicators**			
		The average number of shoots	**The average thickness of shoots (mm)**	**The average length of shoots (m)**	**The average weight of shoots in individuals at Harvest´s moisture. (kg)**
Sven	Fertilization	7.33	30.69	7.08	18.47
	without fertilization	5.33	30.32	7.28	16.15
Gudrun	Fertilization	7.33	27.05	6.11	12.16
	without fertilization	7.66	25.66	5.22	11.82
Tordis	Fertilization	5.00	32.26	7.47	14.62
	without fertilization	6.66	25.81	6.03	11.45
Inger	Fertilization	5.00	35.91	7.78	18.73
	without fertilization	5.33	27.74	6.64	13.45
Tora	Fertilization	6.33	33.27	7.25	21.54
	without fertilization	5.00	27.97	7.46	15.60

The average thickness of the shoots in mm was higher for the fertilized variant and varies between 27.05 mm (variety Gudrun) and 35.91 mm (variety Inger). For the non-fertilized variant, the observed values were from 25.66 mm (variety Inger) to 30.32 mm (variety Sven). As for the thickness of the shoots, there was no statistical difference observed between the fertilized and non-fertilized variants. The P value for the fertilized variant was 0.098 (bigger than 0.05) and for the non-fertilized variant 0.374 (bigger than 0.05)

The average length of the shoots in m for the fertilized variant ranged from 6.11 m (Gudrun variety) to 7.78 m (variety Inger) and for the non-fertilized variant it ranged from 5.22 m (Gudrun) to 7.46 m (Tora). The thickness of the shoots, for the lengths of the shoots there were unlikely statitically significantly different between varieties as well as between fertilized and non-fertilized variants. The fertilized variant's P value was equal to 0.002 what is smaller than 0.05 and for the unfertilized variant the P value was 0.0001 what is also smaller than 0.05.

The average values of dry biomass for individuals on the area of 1 ha are shown in the Tabs. 2-3. The average yield of dry matter for individuals (Tab. 2) reached from 6.59 kg in a variety Gudrun to 11.39 kg at Tora variety for the fertilized variant. For the non-fertilized variant the dry biomass yield was slightly lower in comparison with the fertilized variant, and the values were from 6.16 kg (Tordis variety) to 8.26 kg (Sven variety).

The average yield of dry biomass in the case of 10.666 individuals per ha measured in $t.ha^{-1}$ for different varieties differs in the fertilized variant from 70.28 $t.ha^{-1}$ for the variety Gudrun to 121.48 $t.ha^{-1}$ for the variety Tora (Tab. 3). For the variant without fertilization the lowest yield of dry biomass was achieved for the variety Tordis (65.70 $t.ha^{-1}$) and the highest yield for the variety Sven (88.10 $t.ha^{-1}$). Statistically significant difference was observed between varieties when analyzing the yield of dry biomass in $t.ha^{-1}$ for the fertilized variant.

Tab. 2: Average values of dry biomass production in kg for individuals from the studied varieties of fast-growing energy trees Salix in the last year of the five-year growing cycle.

Varieties	**Variant of fertilization with mineral fertilizers**	**Repeating**			**The average yield of dry biomass of individuals (kg)**
		1	**2**	**3**	
		Yield of dry biomass of individuals (kg)			
Sven	Fertilization	10.92	8.59	8.82	9.44
	Without fertilization	8.23	8.17	8.38	8.26
Gudrun	Fertilization	7.10	5.14	7.54	6.59
	Without fertilization	7.69	4.99	6.56	6.41
Tordis	Fertilization	6.41	8.59	8.61	7.87
	Without fertilization	5.84	6.59	6.06	6.16
Inger	Fertilization	10.35	7.50	11.42	9.75
	Without fertilization	7.18	5.71	8.12	7.00
Tora	Fertilization	12.06	11.59	10.52	11.39
	without fertilization	10.36	6.41	7.98	8.25

A average values of the dry wood at the harvesting
Sven: -51.16 %, Gudrun: -54.25 %, Tordis: -53.87 %, Inger: 52.10 %, Tora: 52.90 %

(P value = 0.0149> 0.05), however, statistically insignificant difference could be seen for the unfertilized variant (P value = 0.1709> 0.05). A highly significant difference was proven in the case of the yields of dry biomass for individual varieties between fertilized and non-fertilized variant (P value = 0.0093 <0.01).

Tab. 3: Yield of biomass DM in t.ha^{-1} observed in fast-growing varieties of energy trees Salix in the last year of five-year growing cycle.

Varieties	Variant fertilizing with mineral fertilizers	Repeating 1	Repeating 2	Repeating 3	The average yield of biomass DM (t.ha^{-1})	The average annual yield of biomass DM (t.ha^{-1})
		Yield of biomass DM (t.ha^{-1})				
Sven	F	116.472	91.620	94.074	100.687	20.137
	N	87.781	87.141	89.381	88.101	17.620
Gudrun	F	75.728	54.823	80.421	70.288	14.057
	N	82.021	53.223	69.968	68.369	13.673
Tordis	F	68.369	91.620	91.834	83.941	16.788
	N	62.289	70.288	64.635	65.702	13.140
Inger	F	110.393	79.995	121.805	103.993	20.798
	N	76.581	60.902	86.607	74.662	14.932
Tora	F	128.631	123.618	112.206	121.485	24.297
	N	110.499	68.369	85.114	87.994	17.598

• Fertilizing: F – Fertilized, N - Not fertilized

The number of the shoots for individuals sorted by length and thickness are shown in the Tabs. 4 and 5.

Tab. 4: The number of subjects´ shoots sorted according to length (in m) observed in fast-growing varieties of energy crop – willow Salix in the last year of the five-year growing cycle.

Varieties	Variety	Repeating																										
		1									2									3								
		Category length dimensions (m)																										
		Number of shoots	< 3 m	> 3 m	> 4 m	> 5 m	> 6 m	> 7 m	> 8 m	> 9 m	Number of shoots	< 3 m	> 3 m	> 4 m	> 5 m	> 6 m	> 7 m	> 8 m	> 9 m	Number of shoots	< 3 m	> 3 m	> 4 m	> 5 m	> 6 m	> 7 m	> 8 m	> 9 m
Sven	F	7	0	0	1	0	2	0	4	0	7	0	1	2	1	0	2	1	0	7	0	0	0	0	2	1	4	0
	N	5	0	0	0	1	0	2	2	0	5	0	0	1	1	0	1	2	0	6	0	0	0	2	1	1	1	0
Gudrun	F	7	0	3	0	0	3	1	0	0	8	0	1	2	1	3	1	0	0	7	0	0	0	2	5	0	0	0
	N	9	2	1	2	0	3	1	0	0	6	0	1	2	2	1	0	0	0	8	0	0	2	3	2	1	0	0
Tordis	F	6	0	1	0	1	2	0	2	0	4	0	0	0	0	1	0	3	0	5	0	0	0	0	2	0	2	1
	N	5	0	0	2	0	0	1	2	0	9	1	3	1	2	2	0	0	0	6	0	0	1	1	2	0	2	0
Inger	F	5	0	0	0	0	2	0	2	1	4	0	0	0	1	1	0	1	1	6	0	0	0	0	2	1	2	1
	N	5	0	2	0	0	0	0	3	0	5	0	2	0	0	1	0	2	0	6	0	0	2	0	0	0	4	0
Tora	F	7	0	0	0	1	2	0	4	0	6	0	0	0	0	3	0	3	0	6	0	0	0	1	1	2	2	0
	N	6	0	0	0	0	1	3	2	0	4	0	0	0	1	1	0	2	0	5	0	0	0	0	1	2	2	0

• Fertilizing: F - fertilized N - not fertilized

The Tab. 4 shows the shoots according to the length in m and it indicates that a substantial part of the shoots in all studied varieties is within the category 6-8 m. The shoots belonging to the 9 m category were observed just in the case of varieties Inger and Tordis. When comparing these length values with the values from the previous year of a three-years long growing cycle it can be seen that in the third year after planting a significant amount of shoots for all varieties can be found within the category 1– 3 m. Only a small number of the shoots reached the length 5 or 6 m.

Tab. 5: The number of subjects' shoots sorted according to the thickness (in mm) observed in fast-growing varieties of energy crop – willow Salix in the last year of the five-year growing cycle.

Varieties	**Variety**	**Repeating**																										
		1									**2**										**3**								
		The diameter size category (mm)																										
		Number of shoots	**< 15**	**> 15**	**> 20**	**> 25**	**> 30**	**> 35**	**> 40**	**> 45**	**Number of shoots**	**< 15**	**> 15**	**> 20**	**> 25**	**> 30**	**> 35**	**> 40**	**> 45**	**Number of shoots**	**< 15**	**> 15**	**> 20**	**> 25**	**> 30**	**> 35**	**> 40**	**> 45**
Sven	H	7	0	0	1	2	0	2	1	1	7	1	2	0	1	1	0	1	1	7	0	1	0	3	0	1	2	0
	F	5	0	1	2	0	0	0	1	1	5	0	2	0	1	0	0	1	1	6	0	2	1	1	0	0	1	1
Gudrun	H	7	1	2	1	1	1	1	0	0	8	3	0	0	0	2	2	1	0	7	1	1	0	1	1	3	0	0
	F	9	2	2	1	2	0	1	1	0	6	1	1	2	1	0	0	1	0	8	0	2	1	2	1	1	1	0
Tordis	H	6	0	2	1	1	1	0	1	0	4	0	0	0	1	1	1	1	0	5	0	1	0	1	0	1	2	0
	F	5	0	2	0	0	2	1	0	0	9	0	4	2	2	0	1	0	0	6	0	1	1	2	2	0	0	0
Inger	H	5	0	0	2	0	0	1	1	1	4	0	0	0	1	1	1	0	1	6	0	0	0	2	0	1	2	1
	F	5	2	0	0	0	0	2	1	0	5	1	1	0	1	2	0	0	0	6	1	1	0	0	2	1	1	0
Tora	H	7	0	1	1	1	0	2	2	0	6	0	0	2	1	0	2	0	1	6	0	0	1	2	0	2	1	0
	F	6	0	0	0	3	1	2	0	0	4	0	0	2	0	1	1	0	0	5	0	0	1	1	1	2	0	0

• Fertilizing: F - fertilized N - not fertilized

The number of the shoots of individuals for each category of thickness is shown in the Tab. 5. As the table shows the thickness of the shoots observed in the majority of varieties can be found within the category 15 to 45 mm. There are only few shoots from the variety Gudrun and Inger belonging to the category below 15 mm. Similarly, only few shoots from the variety Sven and Inger can be found within the category 45 mm. A comparison of these values of the thickness showed that majority of the shoots reached a thickness only 5 to 10 mm in the third growing year.

The increase in length was seen and thickness for the last two years of production has been significant. A similar trend was also reflected in the case of average yield of biomass DM of individuals in kg. In the third growing year biomass DM yields for the individuals of different varieties varied between 3.24 kg (variety Inger) to 4.63 kg (variety Tordis). In the fifth year of growing of the same varieties (Tab. 2) the average yield of biomass DM for individuals ranged from 6.16 kg at the non-fertilized variant (variety Tordis) to 11.39 kg for the fertilized variant (variety Tora).

An opposite trend in comparison with the length and thickness of the shoots could be seen in the number of the shoots. While in the third growing year the average number of live shoots in the observed varieties ranged from 14.0 (variety Tora) to 20.3 (variety Gudrun), in the fifth growing year of there has been a significant reduction in the number of living shoots observed mainly in the length category up to 3 m and the thickness category up to 5 mm. Within two years, the shoots of such length and thickness parameters died and only longer and thicker shoots in the number from 5 to 9 shoots remained.

When comparing the results obtained from the experimental field in Kolíňany with the results from other experimental field in Selice it can be concluded, that within the three-year growing cycle, the average annual production of biomass DM in Selice with 20.000 individuals per ha with different varieties varied from 17.13 t.ha^{-1} to 39.27 t.ha^{-1}. In case of Kolíňany with the five years growing cycle and 10.666 individuals per ha for the same varieties the values were from 13.140 t.ha^{-1} to 24.297 t.ha^{-1}.

It is important to point out that in Selice the possibility of maximal utilization of the production field with high number of tree individuals was verified. This method is suitable for small-scale growers of energy crop - willow, who all the work related to planting, harvesting crops and treatments perform manually, without machinery. For large plantations of willows, where all the cultivation is done by machines, the most suitable organization of the coppice is 10.000 to 12.000 individuals per ha, as it is at the base in Kolíňany.

In the northern Slovakia at the research unit Krivá in the Orava region, the annual production of biomass DM per hectare for five varieties of willow (Sven, Gudrun, Tora, Sherwood, ULV) ranged from 11.1 to 15.2 t.ha^{-1} (Daniel, Medvecký 2010). On highlands of Wales an annual production of biomass DM after five years of producing of the energy willow was 6 t.ha^{-1} yearly (Heaton et al. 1999). According to Lindegaarda (2001) economics of cultivating the energy willow *Salix* requires an average annual production of biomass DM from 10 to 12 t ha^{-1}. This fact also depends on the costs of input and prices for harvested woody biomass.

CONCLUSIONS

Based on evaluation of the production parameters and biomass production in five Swedish varieties of fast growing willow *Salix* in the last year of a five-years growing cycle under the soil, climate and hydrological conditions of south-western Slovakia following conclusions can be made:

- There is a very significant difference in the number of shoots between varieties in fertilized and unfertilized variant. Statistically significant differences could be seen between varieties Gudrun - Inger, Gudrun - Tordis, Inger - Sven, Sven - Tordis.
- There are no statistically significant differences in the thickness of the shoots in mm between varieties and fertilization levels. The thickness of the shoots for the majority of varieties can be found within the category 15 to 45 mm.
- Contrary to the thickness of the shoots, the shoots' length in m showed statistically significant differences in the fertilized and unfertilized variation between varieties. A decent part of the shoots for all studied varieties belongs to the category 6-8 m.
- As for the yields of biomass DM in t.ha^{-1} there is a statistically significant difference between varieties in the fertilized variant, however, statistically significant difference were not observed between varieties in the non-fertilized variant. The highest yield of biomass DM in t.ha^{-1} for the fertilized variant was achieved by a variety Tora 121.48 t. ha^{-1}, the lowest by a variety Gudrun 70.28 t.ha^{-1}. For the non-fertilized variant the highest yield of biomass DM were achieved with the variety Sven 88.10 t.ha^{-1} and the lowest with the variety Tordis 65.70 t.ha^{-1}.

- The average yield of biomass DM weight for individuals from the studied varieties reached values within the range from 6.59 to 11.39 kg for the fertilized variant and from 6.16 to 8.26 kg for the non-fertilized variant.
- In the five-year growing cycle with 10.666 individuals per ha, the average annual production of biomass DM in $t.ha^{-1}$ for the studied varieties and for the fertilized variants ranged from 13.14 $t.ha^{-1}$ in a variety Tordis to 24.29 $t.ha^{-1}$ for a variety Tora.
- Based on the results obtained it can be concluded that the yields of biomass DM for individuals in $t.ha^{-1}$ were affected by the combination of all production parameters of studied varieties.

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