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Production Characteristics of Miscanthus (*Mischantus* × *Giganteus* Greef et Deu) under Agroecological Conditions of Serbia †

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Abstract: This paper presents research of production possibilities of miscanthus (*Mischantus* × *giganteus* Greef et Deu) in agroecological conditions of Serbia. For that purpose, an experiment was set up in Srem on the site of Podunavlje village of Surduk. The soil on which the plantation was established in 2012 belongs to the type of carbonate chernozem on a loess plateau, at an altitude of 150 m. Stalk height in the panicle stage and yield of dry miscanthus stalks during five years, from 2015 to 2019, as well as the content of cellulose in dry stalks depending on agroecological conditions and variants of fertilization without top dressing and with spring top dressing of 30 kg ha^{1} of nitrogen fertilizer, were analysed. The highest recorded yield of dry stalks was in 2019 (34.525 kg ha^{1}), and the lowest recorded yield was in the dry year of 2017 (17.980 kg ha^{1}), both in the variant with top-dressing.

Keywords: miscanthus; agroecological conditions; morphological characteristics; dry stalk yield

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1. Introduction

In the last 15 years, several perennial wild grass species have become the subject of interest for biologists and agronomists in Serbia. The research includes grasses that have intensive growth during the growing season and can reach a height of over two meters, while providing a large biomass suitable for different uses. According to results obtained by numerous researchers, including Refs. [1–5] among others, productive organs of these plant species could be used in numerous branches of industry. Miscanthus was originally grown only as an ornamental plant. It is characterized by extremely strong growth and high genetic potential for fertility [6], and is becoming important as an energy crop. As a consequence of its triploidy, miscanthus does not produce fertile seeds, so there is no possibility of the plants spreading outside their plantations and forming weeds in surrounding agricultural areas [7]. Miscanthus is mainly grown for the production of biofuels from aboveground biomass. Fresh plant biomass mown in the panicle forming stage serves as raw material for biogas and bioethanol, while dry stalks are burned directly in large boiler plants or used to produce pellets and briquettes [4,8]. Miscanthus belongs to the group of energy crops, whose role is to release heat by combustion, and reduce the emission of SO_2 and other harmful gases into the atmosphere. CO_2 released during combustion of this biofuel was absorbed by plants from the atmosphere during the year;

therefore, its concentration does not increase [9], and thus, combustion of miscanthus biomass reduces CO_2 emissions. As pointed out [10], the ratio of the equivalent kW h^{-1} of produced electricity and the emission of SO_2 is 0.131 kg, while with coal combustion, that ratio is 7.5 times higher, at 0.990 kg of SO_2. In the temperate continental climate zone, miscanthus is the crop with the highest energy potential per unit area [2]. In the future, fresh miscanthus biomass will be used to obtain gaseous and liquid biofuels, obtained by decomposing cellulose, hemicellulose and lignin. These fuels are relatively cheap and are a good substitute for minerals (shale, oil and natural gas).

The aim of this research was to analyse the influence of agroclimatic conditions of the Srem locality in Serbia on the yield of dry miscanthus plant mass in five different production years, with and without spring fertilization with nitrogen fertilizers.

2. Materials and Methods

The experiment was set up at a site in eastern Srem, in the Danube village of Surduk, in 2012. The land belongs to the type of carbonate chernozem on a loess plateau. It is located at an altitude of 150 m.

A plantation was formed in April 2012 on the 10 m long and 2 m wide experimental plot by planting two rhizomes per square meter, so that 8 elementary plots with two clusters, or a total of 40 clusters, were obtained. To date, every year at the end of March, 30 kg per ha^{-1} of pure nitrogen was added on four plots in a random distribution, while on the other four plots, plants were grown without additional mineral fertilizers. Samples were taken from each elementary plot to determine cellulose content, and the remaining biomass was naturally dried and the yield per cluster was subsequently determined and calculated per unit area. Cellulose content was determined at the Soil Institute in Belgrade using the Fibertec method (ISO 6865/2004).

The total amount of precipitation is presented according to monthly distribution, and also according to the quantities during the vegetation period. Values were obtained from the nearest meteorological station at PKB Agroekonomik Institute, Belgrade (Table 1).

Table 1. Quantities and distribution of precipitation (mm) during 2015–2019.

Months	Years					Average	Optimum
	2015	2016	2017	2018	2019		
January	49.0	46.0	23.0	39.0	22.0	55	-
February	49.0	41.0	20.0	47.0	34.0	51.0	-
March	97.0	79.0	29.0	58.0	12.0	54.0	50.0
April	25.0	35.0	66.0	35.0	77.0	52.0	55.0
May	88.0	76.0	116.0	81.0	142.0	80.0	85.0
June	20.0	98.0	37.0	85.0	89.0	82.0	90.0
July	5.0	35.0	16.0	97.0	43.0	65.0	100.0
August	69.0	12.0	30.0	77.0	40.0	56.0	80.0
September	86.0	45.0	61.0	53.0	28.0	54.0	55.0
October	68.0	58.0	57.0	37.0	14.0	54.0	35.0
November	51.0	50.0	52.0	49.0	54.0	52.0	-
December	14.0	63.0	37.0	65.0	55.0	45.0	-
III-IX	390.0	380.0	355.0	486.0	431.0	443.0	515.0
I-XII	621.0	632.0	544.0	723.0	610.0	700.0	

Data for the average monthly air temperatures by years and multi-year heat values were taken from the Meteorological Station at PKB Agroeconomic Institute, while heat requirements of plants were taken from the data of Withers (2014) (Table 2).

Table 2. Average air temperatures (°C) during 2015–2019.

Months	Years					Average	Optimum
	2015	2016	2017	2018	2019		
January	3.0	1.0	−5.0	3.0	2.0	1.6	-
February	3.0	7.0	3.0	2.0	6.0	2.1	-
March	7.0	8.0	10.0	5.0	11.0	6.9	10
April	12.0	13.0	12.0	17.0	14.0	13.0	15.0
May	19.0	18.0	18.0	20.0	16.0	18.3	18.0
June	23.0	22.0	23.0	21.0	24.0	22.4	19.0
July	28.0	23.0	25.0	22.0	24.0	24.0	21.0
August	26.0	23.0	25.0	24.0	26.0	23.5	21.0
September	21.0	19.0	18.0	18.0	20.0	18.5	18.0
October	11.0	14.0	13.0	14.0	16.0	11.2	10.0
November	7.0	8.0	7.0	8.0	12.0	7.1	-
December	3.0	3.0	4.0	3.0	6.0	2.4	-
IV-IX	19.4	17.5	18.0	17.6	19.3	17.2	16.5
I-XII	13.6	13.3	12.8	12.9	14.8	13.1	

Agrochemical analysis of the soil was conducted in the laboratory of the Soil Institute in Belgrade. Results are shown in Table 3.

Table 3. Agrochemical analyses of soil (Surduk locality).

Depth	pH (H_2O)	pH (nKCl)	Humus (%)	N (%)	P_2O_5 (mg 100 g^{-1})	K_2O (mg 100 g^{-1})
0–30 cm	7.9	7.1	3.66	0.253	17.4	21.6
30–60 cm	8.2	7.3	3.41	0.219	15.1	19.4
Average	8.1	7.2	3.54	0.236	16.3	20.5

Statistical analyses were performed using IBM SPSS Statistics Version 20 (IBM, New York, NY, USA).

3. Results and Discussion

The average stalk height during the five-year study was 294.1 cm, with very significant variations across the research years. The second treatment with nitrogen supplementation on a multi-year average also influenced this morphological trait of miscanthus (Table 4).

Table 4. Stalk height in the panicle stage (cm) during 2015–2019.

Year/Variant	2015	2016	2017	2018	2019	Average
Control	222	295	235	328	357	287.4
N, 30 kg ha^{-1}	227	318	242	356	361	300.9
Average	224.5	306.5	238.5	342.0	359.0	294.1
LSD *, years	5%	74.474		1%	129.668	
LSD *, N_{30}	5%	15.26		1%	26.57	

* LSD—Least significant difference

In years when the amount of vegetation period precipitation was below 400 mm, plants formed stalks in the height range of 224.5 cm (2015) to 306.5 cm (2016). The average heights of stalks in years with more than 430 mm of vegetation precipitation were 342.0 cm (2018) and 359.0 cm (2019). These values are significantly higher compared to the average height in the first and third years of the study. The impact of nitrogen on stalk height was significant in the five-year average, as well as in the second year, and very significant in the fourth and fifth years. Plants had the tallest stalks in 2019 (359.0 cm), both for the controls (357.0 cm) and in the variant with supplementation (361.0 cm).

The five-year average for stalk yields, obtained by measuring the total dry biomass after mowing and converting to kilograms per hectare, was 25.953 kg ha^{-1}. Significant variations in dry stalk yield in the overall average were influenced by weather conditions, as well as crop fertilization (Table 5).

Table 5. Dry stalk yield (kg ha^{-1}) during 2015–2019.

Year/Variant	2015	2016	2017	2018	2019	Average
Control	20.425	25.320	18.025	30.655	33.373	25.560
N, 30 kg ha^{-1}	21.470	25.550	17.980	32.210	34.525	26.347
Average	20.948	25.435	18.003	31.433	33.949	25.953
LSD, years	5%	6.9855		1%	11.9522	
LSD, N30	5%	756.47		1%	1.31701	

In the most meteorologically unfavourable year (2017), the average yield of dry stalks was the lowest (18.003 kg ha^{-1}). The average yield of dry stalks in the first three years with an unfavourable water regime was 21.462 kg ha^{-1}. Compared to the fourth and fifth years, i.e., with a period of favourable water and heat regime (32.681 kg ha^{-1}), the average yield of dry stalks was 48% lower. Additional crop nutrition had a significant impact on dry stalk yield in the overall five-year average. The higher impact of nitrogen on crop nutrition was influenced by the amount and monthly distribution of precipitation in the miscanthus vegetation period. A comparison of obtained yields with previous studies by numerous authors [4,6,11] suggests the conclusion that yields depend on many factors, including agroecological and applied agrotechnics.

Dry stalks contained a high share of cellulose in all variants and years of research. The average cellulose content was 32.11%, and is presented in Table 6.

Table 6. Stalk cellulose content in (%) during 2015–2019.

Year/Variant	2015	2016	2017	2018	2019	Average
Control	31.95	32.13	32.21	32.09	32.14	32.11
N, 30 kg ha^{-1}	32.01	32.20	32.19	32.01	32.16	32.12
Average	31.98	32.17	32.20	32.05	32.15	32.11
LSD, years	5%	0.253		1%	0.431	
LSD, N30		0.091			0.156	

Analysis of stalk cellulose content by study years showed differences, but they were not statistically significant. Use of nitrogen fertilizers also did not affect cellulose synthesis in the stalks, so there were no differences by years, nor of the multi-year average. Carbohydrate content is about 80% of the air-dried mass of miscanthus stalks, while cellulose content makes up 30–35% [2]. According to the results of numerous authors, including Refs. [3,5] among others, meteorological conditions and applied agrotechnical measures do not have a statistically significant effect on the chemical composition of aboveground biomass, or on cellulose content in stalks. Studies of quality of miscanthus stalks grown in different agroecological conditions in Serbia, Refs. [6,7], concluded that growing conditions and applied agrotechnical measures did not have any major impact on the chemical composition of aboveground biomass, since during the maturation of plants, i.e., stalks, the highest percentage of nutrients is transferred to rhizomes. Two-factor analysis of variance of the examined traits is presented in Table 7.

Table 7. Two-factor analysis of variance of examined traits.

Factors	Stalk Height	Dry Stalk Yield	Cellulose Content
Year (A)	738.3 **	6541.8 **	1.378 ns
Fertilization (B)	42.56 **	105.43 **	0.012 ns
A × B	7.13 **	17.92 **	0.153 ns

** significant at 0.01.

The data in Table 7 show that the year factor had a very high statistical significance for stalk height (738.3 **) and dry stalk yield (6541.8 **); conversely, the year had no statistical significance for cellulose content. The fertilization factor had a very high statistical significance for stalk height (42.56 **) and dry stalk yield (105.43 **); on the other hand, this factor had no statistical significance on cellulose content. The interaction of year and fertilization had a very high statistical significance for stalk height (7.13 **) and dry stalk yield (17.92 **). This interaction had no statistical significance for cellulose content.

4. Conclusions

As presented in the paper, based on research results of the impact of weather and soil conditions on the production of miscanthus on highly productive soil, the following conclusions can be made.

The average value of stalk height during the five-year study was 294.1 cm, with very significant variations throughout the years of research. Nitrogen supplementation on a multi-year average also influenced this morphological trait of miscanthus. The yield of dry stalks for the entire experiment on a five-year average, calculated in kilograms per hectare, was 25.953 kg ha^{-1}. Significant variations of dry stalk yield in the overall average were influenced by weather conditions, as well as by crop nutrition. Dry stalks had a high share of cellulose in all variants and years of research (32.11%). The year factor had very high statistical significance for stalk height (738.3 **) and dry stalk yield (6541.8 **), while having no statistically significant effect on cellulose content. The fertilization factor had a very high statistical significance for stalk height (42.56 **) and dry stalk yield (105.43 **); however, crop fertilization had no statistical significance on cellulose content.

Supplementary Materials: The poster presentation can be downloaded at: https://www.mdpi.com/article/10.3390/IOCAG2022-12287/s1.

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