Assessment of the Main Agro-ecological Parameters Effects on the Cultivation of *Miscanthus x giganteus* Grown on Marginal Soils in the Republic of Serbia

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Summary

The aim of this study was to evaluate the influence of climatic parameters, in particular the the precipitation amount and distribution in the vegetation period, then, the type of soil and fertilization on the yield in the first two years of growing *Miscanthus x giganteus* as a test crop. The experiment was performed on two types of soil with limited productive capability - Lessivated Cambisol and Stagnosol, on the experimental fields of Institute of Soil Science, Belgrade, in Mladenovac and Varna. It was implemented the planting density of 2 rhizomes m^{-2}. Miscanthus fertilization was performed in the second vegetative season, using different quantities and types of the NPK fertilizers (50 kg ha^{-1} NPK and 100 kg ha^{-1} NPK – granular fertilizer; 50 kg ha^{-1} NPK - water soluble fertilizer). Unfertilized variant was used as a control. Weather conditions during the monitoring of the experiment were characterized by two extremes: floods in the planting year (year 2014) and the long term drought in the second year (year 2015). On Lessivated cambisol, in the variant treated with 50 kg ha^{-1} of NPK (granular), it was achieved the highest yield of miscanthus, and the lowest - by applying 50 kg ha^{-1} of NPK (water soluble fertilizer). On Stagnosol, the highest yield was recorded in the variant treated with 50 kg ha^{-1} of NPK - water soluble fertilizer, and the lowest - by applying 50 kg ha^{-1} of NPK (granular). The yields of miscanthus on both soil types were not significantly different in relation to control. Concluding, results of the two-year research showed that there were no fertilization and agro-ecological impacts on the yield of miscanthus.

Key words

Miscanthus, yield, Lessivated cambisol, Stagnosol, fertilization

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Introduction

Concerns about worldwide energy supply and national, environmental, and economic security have resulted in a search for alternative energy sources (Maughan et al., 2012; Ikanović et al., 2015; Kresovic et al., 2016). The grand challenge for biomass production is to develop second generation energy crops which have a suite of desirable physical and chemical traits while maximizing biomass yields and minimizing inputs in terms of management of resources (Jones et al., 2015). Agricultural energy crops can be a good source for bioenergy production, and one of such crops is the perennial energy crop *Miscanthus × giganteus* (Bilandžija et al., 2016). Miscanthus has received attention as a biofuel crop because it has relatively high dry matter yields across a range of environmental and soil conditions (Erickson et al., 2008). It is a crop with a low nitrogen requirement showing little biomass yield impact from fertilisation (Himken et al., 1997). The requirement for other micronutrients is also low (Atkinson, 2009).

The mass yield depends on many factors: genotypes, soil types, nutrients used, crop age, bioclimatic location, and the weather during the growing season (Brosse et al., 2012). Following planting, it commonly takes at least 3 years to reach full establishment and biomass production, but soils of low fertility can lengthen the time required to reach full establishment by several growing seasons (Lee et al., 2014).

Miscanthus can grow on a number of soil types, including marginal, as recommended by many authors in order to obtain the profitable production of bioenergy crops. Christian and Haase (2001) concluded that the most suitable soils for miscanthus have an intermediate texture that allows good air movement, a high water holding capacity and high organic matter content. Yields on medium and light textured soils are more predictable than on heavy, clay-textured soils, which have the highest yield potential but also the highest yield uncertainty (Richter et al., 2016).

Although these grasses originate from Asia, they are very well adapted to the climate of Europe (Jezowski et al., 2011). However, the productive potential of miscanthus is limited by its relatively weak abiotic stress tolerance (Yan et al., 2012), which is expressed only in the year of crop establishment. Miscanthus may encounter two types of frost temperatures in Europe: negative temperatures during the winter and late frosts during the spring.

The growing season cycle ranges from 6 to 9 months, depending on the genotype (Zub and Brancourt-Hulmel, 2011). *M.*x *giganteus* not only begins growth in the spring earlier than many other warm-season grasses, but is also able to continue growth into the late summer and early autumn, again past the time when many other C4 grasses have ceased growth for the year (Lee et al., 2014).

Zub and Brancourt-Hulmel (2011) point out that the temperature range for the growth of miscanthus shoots in a controlled environment between 6°C and 20°C, although the extension rate was lower at 6°C than at 15°C or 20°C.

Achieving the most appropriate conditions for optimal establishment will be critical in regions where spring/summer rainfall is restrictive (Davies et al., 2011). Water supply is necessary to ensure a good establishment rate and a high biomass yield (Zub and Brancourt-Hulmel, 2011).

Miscanthus does not tolerate long-term dry periods, otherwise an accelerated drying of aerial parts, a reduction in leaf and root growth at the expense of the rhizome, might happen (Lewandowski et al, 2000). According to Tuck et al. (2006), a minimum precipitation amount for miscanthus is 600 mm, while Heaton et al. (2010) point out that for the production of 25 t ha^{-1} of dry biomass 500 mm of rainfall in the vegetation period is necessary.

Miscanthus plantation establishment costs are higher compared to other annual crops, and the fact that the invested funds are returned only when the full yield in a few years is achieved, it is necessary to examine the productivity of this species in different environmental conditions (temperature, precipitation and soil). Thus, the aim of this paper was to examine the possibility of miscanthus establishing on two types of soil with limited productive capability (marginal soils) and of achieving satisfactory yields using different quantities and types of NPK fertilizers, under similar weather conditions.

Material and methods

In 2014, the field trials of plant species *M. giganteus* were established on two experimental sites of Institute of Soil Science - in Mladenovac, on Lessivated Cambisol, and in Varna near Šabac, on Stagnosol. The primary tillage was done by plowing at a depth of 25 cm and was carried out in the fall, while the fine pre-sowing preparation was performed immediately prior to planting using the cultivator. Soil sampling for screening the chemical and physical properties of the soil studied was carried out before planting. Description of the miscanthus experimental sites and the main physico-chemical properties of the studied soil types are given in Table 2.

Vital parts of miscanthus rhizomes were planted in the middle of April, in experimental plots of 10 m^2 area. Planting density was 2 rhizome per m^2, since previous studies suggested it as a suitable for achieving the maximum tillering and plant formation in order to achieve the maximum yield. Weeds are suppressed by manual hilling in the first two years of cultivation. Fertilization was performed in the second growing season after miscanthus germination. Treatments were as follows: variant I - control (unfertilized soil); variant II - 50 kg N ha^{-1} + 50 kg P_2O_5 ha^{-1} + 50 kg K_2O ha^{-1} (granular fertilizer); variant III - 100 kg N ha^{-1} + 100 kg P_2O_5 ha^{-1} + 100 kg K_2O ha^{-1} (granular fertilizer); variant IV - 50 kg N ha^{-1} + 50 kg P_2O_5 ha^{-1} + 50 kg K_2O ha^{-1} (water soluble fertilizer). Harvesting of the miscanthus trees was carried out after crops maturing, at a

Table 1. Agro-meteorological parameters of the studied sites for a multi-year period

Agro-meteorological parameters	Sites	
	Mladenovac	Varna
Vegetation period beginning[a]	12 - 15 April	12 - 15 April
Vegetation period end[a]	18 - 21 October	15 - 18 October
Vegetation period duration[a]	over 194 days	189 - 194 days
Effective temperature sum for the vegetation period [a]	over 1500°C	1450°C-1500°C
Total precipitation[a]	650 mm-750 mm	750 mm-850 mm
Precipitation during vegetation period[a]	330 mm-380 mm	380 mm-430 mm
Mean annual temperature[b]	11.7°C	11.6°C
Mean temperature during vegetation period[b]	17.4°C	17.4°C

[a] multi-year average for 1947-2005 (Radičević, 2013);
[b] multi-year average for 1981-2015 (RHMZS)

Table 2. Description of the miscanthus experimental sites and the main properties of the studied soil types

Site location	Mladenovac	Varna
Grid reference	44°24'N, 20°40'E	44°41'N, 19°39'E
Texture	Clay loam	Loam
Soil type	Lessivated Cambisol	Stagnosol
Chemical properties		
pH in 1M KCl	4.98	4.12
Total N (%)	0.28	0.12
SOM (%)	3.05	2.26
Available P_2O_5 (mg $100g^{-1}$)	7.98	9.42
Available K_2O (mg $100g^{-1}$)	21.8	17.0
Available Ca (mg $100g^{-1}$)	440	195
Available Mg (mg $100g^{-1}$)	58	28
Available Fe (mg kg^{-1})	63	133
Available Mn (mg kg^{-1})	43	90
Available Zu (mg kg^{-1})	2.2	0.7
Available Cu (mg kg^{-1})	4.1	1.7
Available Co (mg kg^{-1})	0.26	0.17

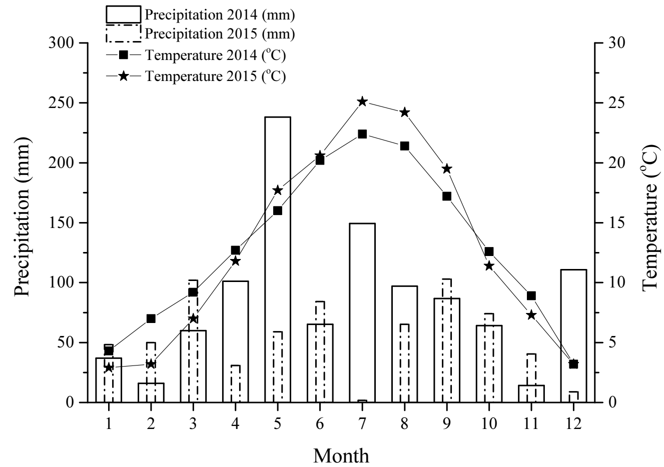

Figure 1. Average monthly air temperature and total precipitation sum at Mladenovac site in period 2014-2015

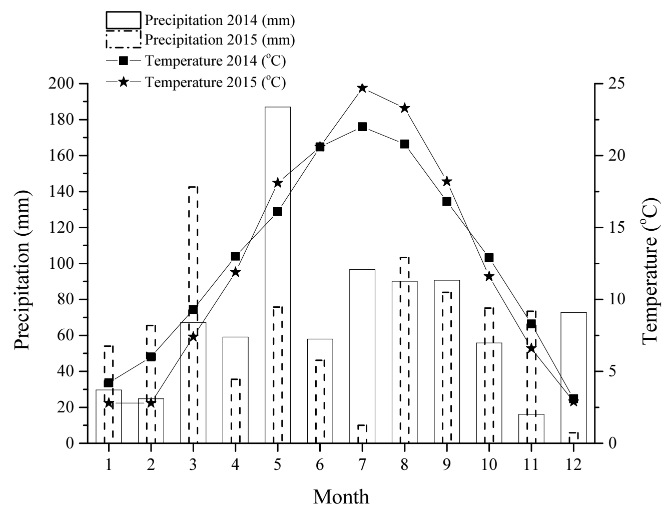

Figure 2. Average monthly air temperature and total precipitation sum at Varna site in period 2014-2015

time when they had the lowest percentage of water, which was in the middle of February each year.

Effects of fertilization and agro-ecological conditions of the studied localities on achieved yield in the second year of miscanthus growing were analyzed using two-factorial analysis of variance in the SPSS statistical program.

On the basis of the sample plots coordinates from available maps (Radičević, 2013), agro-meteorological parameters for a multi-year period were determined (Table 1). Climatic data for the period of study for site Mladenovac were taken from the Smederevska Palanka meteorological station (Figure 1), and for Varna - from the Šabac meteorological station (Figure 2).

Results and discussion

Meteorological data. At both sites studied temperate continental climate prevails, with hot summers and relatively mild winters, with continental regime of precipitations that are higher in the warmer part of the year. The miscanthus growth after planting the rhizomes in 2014 started in May, and the vegetation period duration continued and during October (Table 1). In 2015, at both sites the germination of miscanthus began in the first week of April. Earlier beginning of the vegetation period (eight days earlier than the multi-year average) also stated Radičević (2013). Meteorological conditions are variable (Popović, 2015). Weather conditions during the monitoring of the experiment were characterized by two extremes: floods in the planting year (year 2014) and the long-term drought in the second year (year 2015).

Compared with multi-year average (Table 1) for both sites, 2014 was with significantly higher precipitation in relation to the multi-year average. At Mladenovac site (Figure 1), during the vegetation period, it has fallen 125.86% more precipitation compared to the multi-year average, while at Varna site (Figure 2) there was 57.36% more precipitation. Regarding the total precipitation amount, at Mladenovac site it was registered more than 48.5% of precipitation in relation to the multi-year average, and at Varna site - 5.9%. In 2015, at Mladenovac site there was 17.7% more precipitation in relation to the multi-year average and at Varna site - 6.1%. Total annual precipitations were 4.9% lower in relation to the multi-year average at the Mladenovac site, and 3.7% - at Varna site.

At both sites it was recorded higher annual mean temperature and the vegetation period temperature in relation to the multi-year average (Table 1). In 2014, the annual average temperatures were 1.3°C higher (Mladenovac) and 1.2°C higher (Varna) than multi-year average. Similar deviations were in 2015 (1.2°C for Mladenovac and 1.1°C for Varna). The temperatures during the vegetation period in 2014 slightly deviated from the multi-year average (0.1°C for both Mladenovac and Varna), while in 2015 the deviations increased (1.2°C for Mladenovac and 1.0°C for Varna).

Soil conditions. The soil conditions for the both sites studied in this trial are summarized in Table 2. Both soils have a very low phosphorus and medium potassium content, with acid to very acid reaction, and medium provided with organic matter. They are very highly provided with available forms of iron and manganese, while Lessivated Cambisol is very highly provided with copper. According to the textural composition, Lessivated Cambisol is a clay loam and has a relatively favorable particle size distribution for the cultivation of miscanthus, while Stagnosol is a loam in the surface horizon, with an impermeable subsurface clay horizon, which prevents normal infiltration, and without the use of complex amelioration measures, it is limited for most plant species cultivation (Glamočlija et al., 2012, 2015).

Yield of the miscanthus biomass. In the first year a total yield of aboveground biomass is low and has no commercial value (Glamočlija et al., 2012; Živanović et al., 2014). At the site of Mladenovac (Lessivated Cambisol) achieved biomass yields are in the range from 0.26 to 0.58 t ha^{-1}, while at the Varna site (Stagnosol) the observed yields are significantly lower, almost negligible (0.07 to 0.3 t ha^{-1}), which is in the size of the lowest yield at the Mladenovac site (Figure 3). Christian (1994) suggested that yields were low because of the short growing period in the first season. Unlike the yield achieved in our ecological conditions, at different sites in America the yields in the first growing season range from 1 to 5.1 t ha^{-1}

Studied factors (agro-ecological conditions of the site and fertilization) did not have a statistically significant effect on the yield of miscanthus biomass in the second year of cultivation. Biomass yield of miscanthus, achieved in the second year at the site Mladenovac, was the highest in the fertilization variant II (2.95 t ha^{-1}) and the lowest - in fertilization variant IV (2.1 t ha^{-1}), whereas at the site of Varna the situation is opposite. The lowest yield was obtained in the variant II (1.68 t ha^{-1}), and the highest - in variant IV (2.3 t ha^{-1}). The yields of miscanthus in control are slightly higher on Lessivated Cambisol (2.75 t ha^{-1}) as compared to the yield obtained on Stagnosol (2.23 t ha^{-1}). On average, at the Mladenovac site it was achieved a higher yield (2.7 t ha^{-1}) as compared to Varna site (2.1 t ha^{-1}).

In trials in England, Christian et al. (2008) obtained an average yield of 1.6 t ha^{-1} in the first, and 7.47 t ha^{-1} in the second year of growing, and fertilization with different quantities of nitrogen showed no statistically significant effect on the yield in the next years of vegetation periods of miscanthus plantation. In the climatic conditions of Lithuania, on soil with lighter mechanical composition and favorable chemical properties and in the second vegetative year, Kadžiulienė et al. (2014) achieved a biomass yield of miscanthus of 6 t ha^{-1}, which was significantly higher than those realized in our climatic and soil conditions. Their results also indicated that nitrogen fertilization had an impact on increasing yields only in the second year of cultivation.

Maximum yields should be obtained within three years on fertile soils, but may require 4 to 5 years on poor soils (Pyter et al., 2007). According to Zub and Brancourt-Hulmel (2011), yields in the autumn of the first and second year are a good indicator of those for the third year. Also, soil texture, colour and pH value can also affect miscanthus growth rate (El Bassam, 2010). The same author does not suggest the miscanthus plantation establishment on very acid soils, while Śliż-Szkliniarz (2013) does not recommend cold and wet clay and loam soils.

According to the results of obtained yield of miscanthus in the first and second growing year, we can assume that at the tested sites, by growing micanthus on marginal soils, for the full establishment and achievement of maximum yields it will take more than three years. Also, on these soils we can not expect a full yield potential of *M. giganteus* species, as it was also reported by Hoogwijk et al. (2003) that consider that energy crop yields on such soils were estimated to range from 1 to 10 t ha^{-1} per year. Živanović et al. (2014) reported by the number of leaves was increased by increasing nitrogen amounts, so in both years it was the largest at the maximum applied nitrogen amount of 100 kg ha^{-1}. In first year, the effect of nitrogen was stronger (η2 =0.288) on the number of leaves per stem. Authors state that it is optimal biomass increment was obtained with 100 kg per ha^{-1} of nitrogen under favorable water regime.

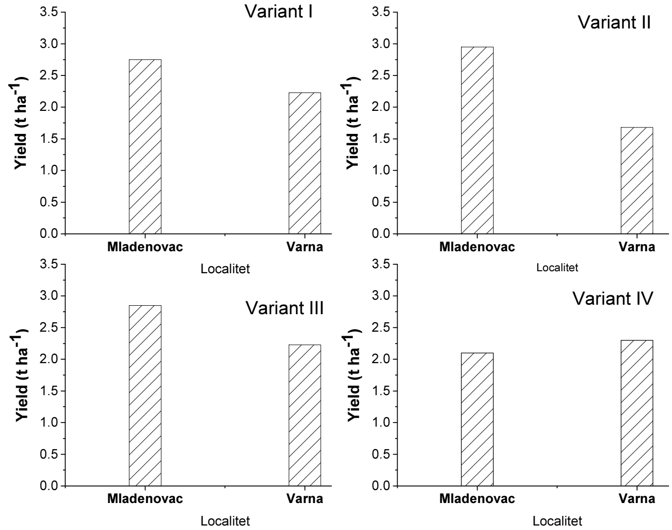

Figure 3. Average biomass yield of miscanthus in the second growing year (t ha^{-1})

Conclusion

Results of the two-year research showed that there was no fertilization and agro-ecological impacts on the yield of miscanthus. Biomass yield of miscanthus, achieved in the second year at the site Mladenovac, was the highest in the fertilization variant II, 50 kg N ha^{-1} + 50 kg P_2O_5 ha^{-1} + 50 kg K_2O ha^{-1} (granular fertilizer), 2.95 t ha^{-1} whereas at the site of Varna the highest - in variant IV, 50 kg N ha^{-1} + 50 kg P_2O_5 ha^{-1} + 50 kg K_2O ha^{-1} (water soluble fertilizer), 2.3 t ha^{-1}. Low yields in the first two years are common for the type of soil on which the trials were established. For a complete plantation it will take more than three years, which will be shown in further researches, because on the yield that can be expected, despite the impact of soil, there will be significantly more effects of weather conditions during the multi-year period since the trials are on site with an unstable climate.

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