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ADAPTABILITY *OF Miscanthus x giganteus* TO CLIMATE CHANGE IN SERBIA

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Abstract: Efforts to preserve human health, the environment, natural resources and biodiversity by mitigating the impact of climate change, have marked the current twenty-first century. Extreme weather events worldwide, problems with energy supply, and pollution are some of the reasons that encourage us to turn to renewable energy sources. The use of biomass for energy, construction and transport would help reduce greenhouse gas emissions and further global warming of the Earth. *Miscanthus* x *giganteus* is a species that can not only adapt to changes in environmental conditions caused by climate change in Serbia but also mitigate them. This makes miscanthus one of the most perspective plant species that can be effectively grown in different soil types. The paper presents the results of studying the effects of environmental conditions on biomass yield in eight years and growing seasons.

Keywords*:* biomass; yields; new species; mitigation.

СПОСОБНОСТ АДАПТАЦИЈЕ ВРСТЕ *Miscanthus x giganteus*
НА КЛИМАТСКЕ ПРОМЕНЕ У СРБИЈИ

Извод: Очување здравља људи, животне средине, ресурса и биодиверзитета кроз борбу за ублажавање климатских промена, обележавају текући 21. век. Екстремне временске прилике широм света, проблеми са енергетским снабдевањем и загађењем само су неки од разлога који нас подстичу да више пажње посветимо обновљивим изворима енергије. Употреба биомасе у енергетици, грађевинарству и саобраћају допринела је смањењу емисије гасова са ефектом стаклене баште и даљем глобалном загревању планете Земље. *Miscanthus x giganteus*, биљна врста која је показала могућност адаптабилности на промене услова животне средине настале услед климатских промена у Србији, али и способност ублажавања истих, представља једну од перспективних врста које се могу ефикасно узгајати на различитим типовима земљишта. У раду су приказани резултати истраживања утицаја услова средине на количину приноса током 8 календарских година и вегетативних сезона.

Кључне речи: биомаса, приноси, нове перспективе биљне врсте, ублажавање

1. INTRODUCTION

Climate scenarios developed for Serbia until 2030 show the upcoming further increase in temperature from 0.5 to 1.5°C, while the maximum increase from 4.0 to even 4.3°C can be expected in the last years of the 21st century (Programme of the United Nations in Serbia, 2015). The expected climate change includes primarily changes in the precipitation regime and increasingly frequent extreme weather

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events. The consequences of such changes can increase the sensitivity of agricultural production or change growing conditions, including the beginning and end of the growing season of agricultural and other plant species, whose length fluctuates depending on the location. These changes will further affect the organisation and timing of work in the fields, which in some species may lead to two harvests a year.

Measures of adaptation and mitigation of climate change include the adoption, adaptation and implementation of measures in the political approach to climate change, education of agricultural producers and advisors, selection of more resistant species, and effective irrigation measures with precise modeling of future changes. Additional irrigation can increase the yields of some plant species provided that adaptation measures are implemented on time. According to many studies, migrations of thermophilic insects and other animal species from south to north and from lower to higher altitudes can be expected as a consequence of climate change. Due to changes in the regime of precipitation, temperature and soil moisture, most crops will become more sensitive to pests and parasites.

The implementation of the Kyoto Protocol of 1997 and the Paris Agreement of 2015 encourages the use of renewable energy sources to reduce the impact of climate change. In the current strategies for the mitigation of global warming, renewable energy sources play a significant role in the European Union (Matyka, M., Kus, J., 2016). The cultivation of fast-growing energy crops is being encouraged and the use of biomass is increased, which further help achieve different goals of these strategies (Matyka, M., Kus, J., 2016). The importance of growing crops for energy, such as *Miscanthus x giganteus*, has been recognised by international organisations and national governments (Robertson, A.D. *et al.*, 2017). According to the results of several published papers, the combustion of miscanthus briquettes emits an amount of CO_2 that is almost equal to the amount of CO_2 assimilated during plant growth. It can be interpreted as the so-called CO_2-neutral use of miscanthus for energy purposes (Lewandowski, I. *et al.*, 1995; Felten, D. *et al.*, 2013; Schweinle, J. *et al.*, 2015).

Given the ability to preserve soil fertility, protect water from pollution, recycle nitrogen and remedy soil, efficient yields of a miscanthus plantation can be achieved with minimum water consumption and without mineral fertilisers, pesticides and herbicides (Marišová, E. *et al.*, 2016). Miscanthus can be effectively used in eco-remediation of arable and marginal lands and then as a second-generation energy source (Dražić, G. *et al.*, 2015). It can also be used in the construction sector as a non-structural insulation material (Jelić, I. *et al.*, 2016) or bioconcrete (Šekler, I. *et al.*, 2021). Miscanthus plantations can also be habitats for some wild animal species (Babović, N. *et al.*, 2012) and thus contribute to biodiversity conservation.

Miscanthus x *giganteus* (miscanthus), a fast-growing perennial herb (also known as Chinese sedge and elephant grass), originates from the East Asian region, where it has historically been used as a roofing material for ancillary facilities housing animals and rarely for their diet. According to Monti and Zatta (Monti, A., Zatta, A., 2009), miscanthus has a very shallow root, with almost 95% of total root biomass concentrated at depths of 0 to 35 cm of soil. Even though most of it grows near the surface, the depth to which the root of miscanthus extend is over 2 meters (Neukirchen, D. et al., 1999; Riche, A.B., Christian, D.G., 2001), so it can absorb moisture even during the dry periods of the growing season.

Miscanthus is planted in the spring when the soil temperature is around or slightly above 10°C. It grows during the summer and produces the highest yields in the autumn (Farell, A.D. *et al*., 2006; Dohleman, F.G. *et al*., 2010). Nutrients are absorbed into the rhizosphere after autumn, which provides a good source of nutrients and carbohydrates for plant regrowth in the spring and throughout the next growing season This natural flow of nutrients enables optimal growth of miscanthus without additional fertilisation requirements, as shown by many previously published studies. According to these studies, there is a slight difference in yields with additional treatment and without fertilisers (Haines, S.A., 2011).

After the first growing season, miscanthus reaches a height of 1 to a maximum of 2 meters, which makes it unprofitable for further commercial use. However, the harvest can be done to free up space for the following growing seasons. After the second year, miscanthus stems exceed 2 m in height, while after the third and in the following years, they are over 2.5 m tall or even as tall as 4 m. After the third year, with an estimated exploitation period of up to 20 years, the harvest and further use of biomass is not only possible but also recommended.

2. MATERIAL AND METHODS

2.1. Establishment of a plantation

The establishment of the experimental plantation of *Miscanthus* x *giganteus* included preparatory field activities, planting and application of certain agro-technical measures on the experimental plot of the Faculty of Applied Ecology Futura in the village of Noćaj near Sremska Mitrovica.

Previously, the site had the vegetation typical of a wetland site such as Zasavica, which makes its wider area. The vegetation was removed and the land was then ploughed in late March of 2009, as this type of light soil is ploughed easily in the spring. The rhizomes were hand-planted on a one-hectare plot in April 2009, when the soil temperature exceeded 10°C. The rhizomes used were 6 x 6 cm in size, with a planting density of 1 rhizome per 1 m^2 and at a depth of 10 to 15 cm. Planting density can be increased, in which case, mutual competition can reduce the yield in the following years slightly below average (Beale, C.V., Long, S.P., 1997). In the first year after planting, weed control was performed with the means used in corn production, according to previous experiences published in the paper (Consentino, S.L. *et al*., 2016). Weeds can be removed mechanically to enable ideal conditions for the growth and development of miscanthus, which was done sporadically in the experimental field in the following growing seasons, given that miscanthus grew faster than accompanying weeds and chemical control agents were not necessary.

Additional fertilisers were not added to miscanthus seedlings in the experimental field because we assumed that the amount of litterfall would provide enough nutrients during the winter.

The plantation was expanded (and reached 10 ha by 2018) by planting rhizomes obtained by macropropagation (i.e., rhizome division) of 2 to 3-year-old seedlings. Rhizome division is cheaper than micropropagation because the available rhizomes are separated during the winter dormancy using a rotary cultivator so that each part (section) of the rhizome has at least 2 to 3 buds. The new rhizomes obtained can be stored in the refrigerator at below 4°C until planting in order to preserve moisture for a maximum of one year (Hansen, J., Kristiansen, K., 1997). The rhizomes we used to expand the plantation were not stored in the refrigerator. They were only stored in the field for a short time, i.e., stacked and covered with moist soil to be planted in early spring and thus take advantage of wet soil. Early spring planting allows the development of larger rhizome systems, which are more tolerant to drought and frost in the coming years (Dražić, G. *et al.*, 2014). Planting can be mechanised by using tuber planters (usually potato planters). Furthermore, a Danish company *Hvidsted Energy* has designed a machine specifically for planting miscanthus. The planter can be calibrated to plant at different densities as required. It plants rhizomes in two rows of shallow furrows and moves the soil back (Dražić, G. *et al.*, 2014). It is not recommended to plant rhizomes in fine tilth where, following rolling, rhizomes would have poor contact with the soil, which would make them prone to drying out and consequently reduce the plantation efficiency (Defra, 2007).

2.2. Monitoring of growth parameters

The growth and development parameters of *Miscanthus* x *giganteus* were monitored three years after the establishment of the plantation since it produced minimal biomass yields in the first two years. The monitored parameters were recorded during the growing season, i.e., from June till the harvest in November 2012 to 2018. The plots were sampled randomly and the following parameters were monitored: tree height, number of leaves, number of green leaves, number of dry leaves, number of aging leaves, length of green leaf portion, leaf width, stem diameter, number of shoots, soil moisture content and soil pH value.

The methodology for monitoring the enumerated parameters included the measurement of:

- the stem height – by selecting and measuring the highest shoot in the shrub (Figure 1);
- the number of leaves – by counting the total number of leaves on one shoot, of which the number of dry and the number of green leaves are recorded separately;
- the number of aging leaves – by counting leaves that are in the drying/aging phase on a selected stem;
- the length of the green leaf portion – by calculating the average length of all green leaves of the selected stem;

– the leaf width – by measuring the average width of the longest leaf on the stem;
– the stem diameter – by measuring the average diameter of the selected highest stem;
– the number of shoots – by counting the total number of shoots in one miscanthus bush and calculating the average value of 5 randomly selected bushes of miscanthus on the plot;
– soil moisture content – by measuring the mass of wet soil sampled at arbitrary depth using a technical scale, air-drying the measured sample for 7 days, and then re-measuring the mass of the dried sample, where the obtained difference refers to the soil moisture;
– soil *pH* - directly using a *pH* meter, by making an aqueous solution of the soil and immersing the electrodes of the *pH* meter into it (*Oakton 610 device, -2-20 pH* was used).

Figure 1 Measuring the height of the selected miscanthus stem
Slika 1. Merenje visine izdvojene stabljike miskantusa

The measured parameters were compared with the climatic characteristics for a given location, which included monitoring the characteristics that affect the growth and development of vegetation:
– the mean annual and monthly air temperature (in °C),
– the amount of precipitation on annual and monthly levels (in mm),
– annual and monthly humidity (%),
– the annual and monthly number of cloudy days,
– the annual and monthly number of sunny hours at the location.

The values of climatic characteristics were obtained from the Meteorological Yearbooks of the Republic Hydrometeorological Institute of Serbia for the Sremska Mitrovica measuring station. The village of Noćaj, in which the experimental field is established, is located in the municipality of Sremska Mitrovica.

3. RESULTS AND DISCUSSION

The paper presents the average annual values of the observed climatic parameters (Table 1) for the period from the third growing season (2012) to 2019. They included: average air temperature (°C), average relative humidity (%), the total number of hours of sunshine per year (h), average rainfall (mm), and the total number of cloudy days.

Table 1 Summary of the climate parameters for the experimental field location
Tabela 1. Sumirani klimatski parametri na lokaciji oglednog polja

Climate parameters / Posmatrani klimatski parametri	2012	2013	2014	2015	2016	2017	2018	2019
Average air temperature / Prosečna temperatura vazduha (°C)	12.4	12.3	12.7	12.6	12.1	12.2	12.9	12.9
Average rel. humidity / Prosečna relativna vlažnost vazduha (%)	69	75	79	76	78	75	76	73
Total number of sunny hours per year / Ukupan broj sunčanih sati godišnje (h)	2387.1	2088.8	2007.7	2153.8	2019.8	2262.1	2118.6	2155.5
Average rainfall / Prosečna količina padavina (mm)	452.9	620.3	761.1	625.7	614.7	533.2	646.8	662.8
Total number of cloudy days / Ukupan broj oblačnih dana	84	108	98	102	96	82	101	96

The most important climatic parameters that affect plant growth – precipitation and air temperature – were compared with the average stem height and number of leaves in a given year (Figure 2).

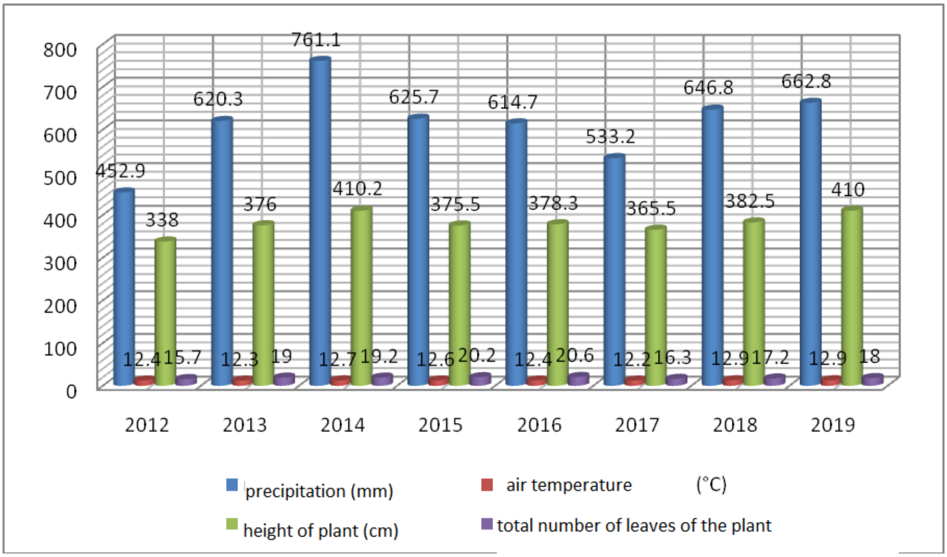

Figure 2 Relationship between climatic parameters and miscanthus height parameters (stem height and number of leaves)

Slika 2. Grafički prikaz odnosa klimatskih parametara i parametara rasta miskantusa (visine stabljike i broja listova)

The average value of annual air temperature for the period from 2012 to 2019 at the measuring station in Sremska Mitrovica was 12.2 - 12.9°C, which indicates that changes in air temperature did not have a significant impact on the growth of miscanthus. In contrast to air temperature, the impact of precipitation on the growth of miscanthus stems in height was evident. The comparison of the weather conditions (precipitation and temperature) with the morphological parameters of miscanthus (stem height and the number of leaves), presented in Figure 2, shows that the highest increase in the growth of miscanthus stems was recorded in the experimental field in 2014 and then in 2019 when the highest amounts of precipitation were recorded. Given that the "zero clone" whose seedlings were planted in the experimental field in the first year (2009) reached a maximum height of 380 cm, the height of 410 cm achieved in 2014 shows that this species can develop above the expected values. In contrast to 2014, 2012 and 2017 were marked as extremely dry or dry years. The miscanthus stems achieved slightly lower growth in these years, but it did not significantly affect the total annual yields. According to these data, it is evident that this species can adapt to climate change. The ability to adapt to water scarcity is shown by biomass yields (Table 2) achieved in years with less precipitation and without additional irrigation.

Table 2 Summary of the average values of the observed miscanthus height parameters, climate conditions, and biomass yield on the experimental plot from 2012 to 2019
Tabela 2. Sumirane prosečne vrednosti posmatranih parametara rasta miskantusa, temperature vazduha, padavina i ukupnog godišnjeg prinosa suve biomase na oglednom polju u periodu od 2012. do 2019. godine

Parametar / Parameter	2012	2013	2014	2015	2016	2017	2018	2019
Height of plant / Visina stabla (cm)	338	376	410.2	375.5	378.3	365.5	382.5	410
Total number of leaves / Ukupan broj listova	15.7	19	19.2	20.2	20.6	16.3	17.2	18
Air temperature / Temperatura vazduha (°C)	12.4	12.3	12.7	12.6	12.1	12.2	12.9	12.9
Precipitation / Padavine (mm)	452.9	620.3	761.1	625.7	614.7	533.2	646.8	662.8
Total annual yields of dry biomass / Godišnji prinosi suve biomase (t/ha)	16.73	18.2	23	21.1	22.3	24	24	24

The value of annual biomass yields was slightly higher in rainy years, which was related to the greater availability of water for the root system of miscanthus that favours high groundwater levels. This was evident in 2014, when the yield amounted to 23 t/ha, which was 4.8 t/ha more than in the previous 2013 and 1.9 t/ha more than in the following 2015 with an average precipitation amount (Figure 3).

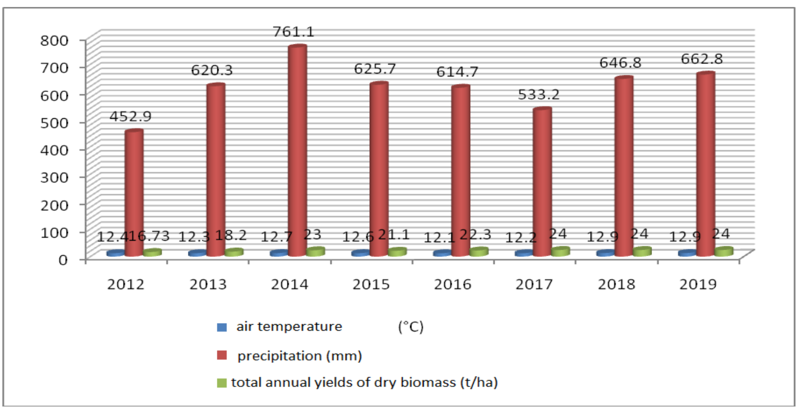

Figure 3 Ratio of air temperature, precipitation and total yield of dry biomass per hectare in the study period 2012 – 2019
Slika 3. Grafički prikaz odnosa temperature vazduha, padavina i ukupnog prinosa suve biomase po hektaru oglednog polja u periodu od 2012. do 2018. godine

Furthermore, following 2014 (the sixth year since the establishment of the plantation), the growth density could be described as “impassable crops” within the field itself (Figure 4).

Figure 4 Impassable miscanthus crops after the sixth growing season
Slika 4. Nemogućnost prolaska kroz useve miskantusa nakon šeste vegetacione sezone

The following years of the study period had yields over 22 t/ha reaching the maximum and stable values of dry biomass yield of 24 t/ha obtained since 2017, which indicated the ability of miscanthus to adapt to changes in environmental factors. The achieved values of yield can be compared with the yields achieved in Mediterranean countries where miscanthus is grown (Spain, Portugal, Italy, Greece) (Dražić, G. et al., 2014; Ji-Hoon, Chung and Do-Soon, Kim, 2012).

To examine the adaptability, the harvest was performed twice during the growing season of 2017, in July and in December. The stems reached the same height in December as in July, while the total amount of harvested biomass in July and December equaled the amount of biomass after one annual harvest. This shows that miscanthus can be harvested twice a year if we want to use it in biogas plants, for instance.

Overwintering parts of unharvested miscanthus showed the ability to regenerate and straighten dry autumn stems bent by winter snow. They straighten up again in early spring, after frosts and snow, ready to be harvested and utilized or just removed from the field.

Miscanthus is sensitive to pests and diseases typical of the localities of its natural range of distribution (Asia), while there have been no similar data for European countries, as confirmed by our experience.

In the initial phase of growth, miscanthus uses stocks of nutrients stored in rhizomes, while in the later, mature stage, as cited in different literature sources, the plant can absorb 2 kg of nitrogen, 0.1 kg of P_2O_5, 3.5 kg of K_2O and 0.01 kg of MgO from the soil per ton of annual yield (Dražić, G. et al., 2014). Following the data, we used no additional fertiliser in the experimental field.

4. CONCLUSION

Both the tests conducted in Serbia and the experiences of other countries have proven the importance of growing *Miscanthus* x *giganteus* which can play an important role in reducing greenhouse gases, and consequently in mitigating climate change.

By monitoring the growth parameters of miscanthus in the experimental field of the faculty, it was evident that the species is very easy to adapt to the climatic conditions of our areas and to accompanying climatic changes that are increasingly present in our localities. Its growth was favoured by high levels of available water that helped achieve the maximum yields at the site. However, its yields did not decrease significantly in dry years, which can be taken as another indicator of the ability of miscanthus to adapt to the environment.

Growing miscanthus has multiple benefits. Apart from the fact that it does not require large investments and special treatment during its growth, once established, the plantation can be exploited for many years (estimated at up to 20). Planting miscanthus on contaminated sites can enable soil remediation by phytoextraction of pollutants, and prevent the further spread of pollutants by wind, water, or soil erosion. Other benefits include wildlife habitats, the aesthetic value of sites, and the creation of a buffer zone by reducing the runoff and inflow of nitrate-rich waters (after fertilisation of agricultural land) into groundwater. The collected biomass can be later used for:

- energy: production of biofuels (due to its lignocellulosic composition), briquettes and pellets;
- construction (in the production of bioconcrete or insulating materials);
- feeding domestic animals (higher parts of stems and leaves).

According to the RS Energy Development Strategy until 2015 with projections until 2030, the Green Agenda for the Western Balkans, the Glasgow Agreement and all other obligations of Serbia in the process of joining the European Union, the goal set by Serbia is to increase the use of renewable energy sources and reduce greenhouse gas emissions, to which the use of miscanthus could contribute.

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СПОСОБНОСТ АДАПТАЦИЈЕ ВРСТЕ *Miscanthus* x *giganteus* НА КЛИМАТСКЕ ПРОМЕНЕ У СРБИЈИ

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Резиме

Очување здравља људи и животне средине, ресурса и биодиверзитета, кроз борбу против и за ублажавање климатских промена, обележавају текући двадесетпрви век. Екстремне временске прилике широм света, проблеми са енергетском снабдевеношћу, загађење, само су неки од разлога који нас подстичу да више пажње посветимо обновљивим изворима енергије. Употреба биомасе у енергетици, грађевинарству и саобраћају, допринела би смањењу емисије гасова са ефектом стаклене баште и даљем глобалном загревању планете Земље. *Miscanthus* x *giganteus*, врста која која је показала могућност адаптабилности на промене услова животне средине настале услед климатских промена у Србији, али и способност митигације истих, представља једну од перспективних биљних врста које се могу ефикасно узгајати на различитим типовима земљишта у Србији. Најзначајнији услови средине који су незнатно утицали на количину приноса суве биомасе по хектару површине, праћени су у току 8 календарских година и вегетативних сезона. Резултати су показали да мискантус успева да се адаптира на промене у режиму доступносити воде, осунчаности и промене температуре, које представљају кључне климатске факторе за раст биљака, а који се из године у годину значајно мењају због климатских промена које су осетне и на нашим просторима.