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REVITALIZATION OF ABANDONED AGRICULTURAL LANDS IN CROATIA USING THE ENERGY CROP *MISCANTHUS X GIGANTEUS*

REVITALIZACIJA ZAPUŠTENIH POLJOPRIVREDNIH ZEMLJIŠTA SA ENERGETSKOM KULTUROM MISCANTHUS X GIGANTEUS U HRVATSKOJ

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ABSTRACT

The revitalization of marginal agricultural soils poses one of the major challenges to the Croatian agriculture. One of the viable solutions could be the introduction of perennial energy crop Miscanthus x giganteus in the intensive agricultural bioenergy production. Miscanthus is characterized by the possibility of growth under different agro-ecological conditions, featuring low growth requirements and high-yielding biomass production. The purpose of this paper is to determine the possibility of the Miscanthus introduction to currently abandoned and marginal agricultural lands in Croatia. There are more than 600,000 ha of that type of lands, identified as potentially interesting areas for planting various energy crops. Furthermore, it will be determined how much biomass and how many various biofuels can be produced from Miscanthus x giganteus devoted to 5 %, 10 % and 15 % of the potentially available abandoned land.

***Keywords**: Miscanthus x giganteus, abandoned areas, revitalization, biofuel*

REZIME

Revitalizacija zapuštenih poljoprivrednih površina predstavlja jedan od glavnih izazova hrvatske poljoprivrede. Jedno od mogućih rješenja moglo bi biti uvođenje višegodišnje energetske biljke Miscanthus x giganteus u intenzivnu poljoprivrednu proizvodnju za proizvodnju bioenergije. Miskantus karakterizira mogućnost uzgoja u različitim agroekološkim uvjetima, niske potrebe tijekom uzgoja i proizvodnja visokog prinosa biomase. Cilj ovog rada je utvrditi mogućnost uvođenja miskantusa na trenutno napuštene i marginalne poljoprivredne površine u Hrvatskoj. Postoji više od 600.000 ha te vrste poljoprivrednih površina koje su potencijalno zanimljivije za sadnju različitih energetskih usjeva. Nadalje procjena količina biomase i raznih biogoriva koje se može proizvesti iz miskantusa uzgojenih na 5%, 10% i 15% potencijalno dostupnih napuštenih površina.

Na osnovu analize uzgoja Miskantusa na napuštenim područjima Sisačko-moslavačke, Karlovačke i Ličko-senjske županije, može se zaključiti da postoji veliki potencijal za proizvodnju biomase i bioenergije - bioplin, bioetanol i toplinska energija. Proizvodnja biomase može imati direktan utjecaj na smanjenje uvoza fosilne energije i goriva, podsticanje energetske nezavisnosti i smanjenje negativnog uticaja na životnu sredinu i klimatske promjene.

***Ključne riječi**: Miscanthus x giganteus, zapuštene površine, revitalizacija, biogoriva.*

INTRODUCTION

Energy crops show the significant potential for future energy production in the world. A number of studies have reported that energy crops can be used for the economically and environmentally sustainable energy production. Some energy crops can be grown on marginal land with a high biomass yield (Koçar et al., 2013). A very interesting energy crop for biomass production is the grass Miscanthus (Miscanthus x giganteus), which has recently attracted increased attention in both Croatia and the EU. This crop does not require special cultural practices and agroecological conditions because it is exceptionally adaptable to various climatic and pedological environments (Krička, et al., 2007; Voća et al., 2016). Miscanthus improves soil fertility, reduces erosion and positively affects its biodiversity. It is resistant to diseases and pests, whereas fertilization requirements are low (Miguez et al., 2008). However, the positive ecological aspect of Miscanthus production is limited by the first and possibly the second year of cultivation due to herbicide treatments and other cultural paractices. Miscanthus is easy to grow and harvest. It is a perennial herb (growing more than 25 years from the same root) that efficiently utilizes nitrogen and water. It is resistant to diseases and pests, has good dry matter yields and good heating values. These are desirable positive properties for the sustainable Miscanthus production alongside ensuring environmental protection and conserving natural resources through improved soil quality and reduced nitrate leaching (Miguez et al., 2008). Because of all these characteristics, Miscanthus is an ecologically and economically viable raw material for agricultural energy production. At present, Miscanthus is used co-firing with coal and/or their direct incineration for heat and/or electricity production. Using different compressing technologies, biomass is processed by briquetting and pelleting, thus can be used more efficiently in the production of "green energy" (Bilandžija, et al., 2017). Moreover, this crop can be used in combination with other raw materials for improving the anaerobic fermentation in biogas production, as well as the production of other liquid biofuels, especially the second-generation bioethanol (due to high contents of cellulose and hemicellulose). The Miscanthus biomass can significantly preserve fossil fuels: 20 t of the Miscanthus biomass is equivalent to 12 t of coal, wheras 30 t of biomass is equivalent to 12,000 litres of fossil fuel. Miscanthus can also be used for other purposes, such as the paper, plastic, construction material and other biomaterial production. It is also used to improve soil structure, erosion reduction and phytoaccumulation (Jones and Walsh, 2001; Baxter et al., 2013, Bilandžija, 2014).

In the cultivation of lignocellulosic crops, the focus should be put on the utilisation of abandoned agricultural lands. According to the digital CLC database (2012), the total abandoned agricultural land in Croatia amounts to almost 600,000 hectares, which represents a large potential for introducing energy crops without interfering with the current agricultural production. Therefore, the purpose of this paper is to analyse the possibility of introducing the energy crop of Miscanthus to currently abandoned agricultural areas in Croatia and their revitalization for energy production. On the basis of the data obtained, the amount of potentially available biomass generated from Miscanthus on such soils will be calculated, as well as the concomitant quantities of biofuel obtainable by its processing. On the basis of the expected Miscanthus yields for lower quality soils, the Miscanthus biomass potential for biogas, heat energy and ethanol production will be calculated. The calculations will be performed relative to 5 %, 10 % and 15 % of the abandoned agricultural land in Croatia, with the emphasis on the Sisak Moslavina, Karlovac and Lika-Senj counties.

Table 1. Condition of agricultural areas by counties (ha)

County	Land devoted to crops CLC (ha)	Abandoned areas (ha)			
		Total	5% areas	10% areas	15% areas
Bjelovarsko-Bilogora	106,811	20,935	1,047	2,093	3,140
Brod-Posavina	90,179	17,334	866	1,733	2,600
Dubrovnik-Neretva	19,071	19,768	988	1,976	2,965
City of Zagreb	16,470	5,467	273	546	820
Istria	35,826	63,792	3,189	6,379	9,568
Karlovac	47,545	53,273	2,663	5,273	7,990
Koprivnica-Križevci	80,591	12,839	641	1,283	1,925
Krapina-Zagorje	39,433	14,640	732	1,464	2,196
Lika-Senj	34,175	33,299	1,664	3,329	4,994
Međimurje	41,926	6,076	303	607	911
Osijek-Baranja	235,375	23,080	1,154	2,308	3,462
Požega-Slavonia	54,780	16,336	816	1,663	2,450
Primorje-Gorski kotar	7,793	20,557	1,027	2,055	3,083
Sisak-Moslavina	96,572	63,062	3,153	6,306	9,459
Split-Dalmatia	48,053	54,206	2,710	5,420	8,130
Šibenik-Knin	43,997	28,517	1,425	2,851	4,277
Varaždin	47,426	8,809	440	880	1,321
Vukovar-Srijem	144,826	9,770	448	897	1,345
Zadar	49,279	28,399	1,420	2,840	4,260
Zagreb	117,056	32,791	1,419	2,839	4,259

MATERIAL AND METHOD

For the purpose of the present research, the latest data of the Central Bureau of Statistics and the Corine Land Cover (CLC) digital database have been processed. The CLC Croatia base is consistent and homogenized with the land cover data across the European Union. It was developed according to the CORINE (Coordination of Information on the Environment) Coordination Program adopted by the European Union and serves as a fundamental reference data set for territorial and spatial analysis. CLC Croatia is publicly available as a GIS browser (AZO, 2015). Table 1 shows the condition of agricultural land by counties (ha). These areas, which are in the CLC digital database, are placed in the category of grassland and treated as agricultural areas with a significant share of vegetation (abandoned areas or areas with poor processing) that could be relatively quickly converted to intensive agricultural production.

According to Table 1, agricultural areas ideal for the Miscanthus production are located in the following counties in Croatia: Sisak-Moslavina (63,062 ha), Karlovac (53,273 ha) and Lika-Senj (33,299 ha). Those counties will be subjected to further evaluation and research. The Istrian and Split Dalmatia counties, for example, were not involved in this calculation because those areas are primarily used for the intensive production of horticultural crops, featuring unfavourable climatic conditions for energy crops. Furthermore, as the Law on Short Rotation Crops (OG 15/2018) defines areas for cultivating energy crops that are classified as abandoned areas with poor quality such as soils in the Sisak-Moslavina, Karlovac and Lika-Senj counties with no intensive food production. Areas in the Osijek-Baranja and Vukovar Srijem counties are not favourable for the energy crop production as they are devoted to the production of food crops such as cereals and oilseeds, which require high-quality soils. (OG 15/2018). Accordingly, the counties of Sisak-Moslavina, Karlovac and Lika-Senj were chosen based on the following criteria (OG 15/2018): low food-energy crop competition, reduced agricultural potential due to a low population density and satisfactory agro-climatic conditions for cultivating Miscanthus. It is characterized by a significant amount of available abandoned agricultural areas suitable for the cultivation of energy crops, which are not used today in any form of agricultural production. The expected yield of 10 tonnes of dry matter per hectare was used for calculating the Miscanthus biomass energy potential relative to three basic scenarios including 5 %, 10 % and 15 % of the abandoned land under consideration. Thermal energy, biogas and bioethanol potential will be calculated and compared to the literature data.

The expected yield of the Miscanthus biomass obtained from the low-quality abandoned soils considered was determined according to previous research (Bilandžija et al., 2014) and amounted to 10 t/ha of dry matter. For the calculation of the thermal energy potential, the range of lower heat value of Miscanthus x giganteus (17.60 to 17.91 MJ/kg), from our previous investigations, was used (Bilandžija et al., 2014). The thermal energy potential of the investigated counties expressed in MJ is shown in Table 3.

The average share of ash according to Bilandžija (2014) was calculated according to the formula:

$$aver.ash\ cont. = 1{,}30 \text{ x dry matter yield}/100$$

The obtained average ash content was taken from the dry matter yield in order to obtain the organic dry matter. The above calculation is based on the following formula:

$$org.d.m. = \text{dry biom. yield (t/ha)} - \text{aver. ash con. (t/ha)}$$

An average literature value of 253.3 Nm^3/t of the organic dry matter was used for the calculation of biogas yields (Kiesel and Lewandowski, 2014). The biogas yield results are expressed in m^3 in accordance with the formula (Kaltschmitt and Hofbauer, 2001; Batzias et al., 2005). For the calculation of the bioethanol yield, the average value found in the literature is 361.8 kg/dry matter per ton of biomass produced in soils of low quality (Scordia et al., 2014).

RESULTS AND DISCUSSION

Table 2 shows the potential levels of biomass (based on dry matter) on the abandoned soils under consideration according to three basic scenarios of utilization 5 %, 10 % and 15 %.

Table 2. Total yield expressed in dry matter of the Miscanthus biomass (t) grown on 5 %, 10 %, 15 % of the total abandoned areas under consideration.

County	Yield on 5 % of abandoned areas (t)	Yield on 10 % of abandoned areas (t)	Yield on 15 % of abandoned areas (t)
Karlovac	26,637	53,273	79,910
Lika-Senj	16,650	33,300	49,950
Sisak-Moslavina	31,531	63,063	94,594

The potential for the Miscanthus production on low-quality soils are the most interesting in the Sisak-Moslavina county: 5 %, 10 % and 15 % of the poorer quality areas can yield 31,531 t, 63,063 t and 94,594 t dry biomass, respectively. In the Karlovac county, the results obtained indicate that the potentially generated dry matter content is 26,637 t on 5 % of the abandoned areas, 52,273 t on 10 % and 79,910 t on 15 % of areas with low soil properties and a dry matter yield of the Miscanthus biomass of 10 t/ha. The Lika-Senj county can produce only 16,650 t on 5 % of the abandoned areas, 33,300 t on 10% and 49,950 t at 15% of total abandoned areas with low soil properties.

The following table shows the possibility of producing thermal energy (MJ) from the biomass obtained on soils with low properties. The greatest potential for thermal energy production on low-quality soils was established in the Sisak-Moslavina county, on 5 %, 10 % and 15 % of the poorer quality areas can produce 559,683 MJ, 1,119,366 MJ and 1,679,050 MJ respectively. The Karlovac county follows with 472,798 MJ on 5 %, 945,596 MJ on 10 % and 1,418,394 MJ on 15 % of the abandoned surfaces. The lowest potential was determined in the Lika-Senj county with a total amount of thermal energy of 295,537 MJ on 5%, 591,073 MJ on 10% of the abandoned surface of 886,610 MJ of the potential energy from the Miscanthus biomass on 15 % of the areas under consideration.

Table 3. Calculation of the thermal energy from the Miscanthus biomass grown on 5 %, 10 % and 15 % of the total abandoned soil (MJ)

County	Thermal energy (MJ) per 5 % of the total leaked areas	Thermal energy (MJ) per 10 % of the total leaked areas	Thermal energy (MJ) per 15 % of the total leaked areas
Karlovac	472,798	945,596	1,418,394
Lika-Senj	295,537	591,073	886,610
Sisak-Moslavina	559,683	1,119,366	1,679,050

Croatia encourages the production of biogas and domestic production of biogas plants as part of the national energy strategy. The main target is to generate 2.6 PJ of energy from biogas in 2020, i.e. 100 million m^3 of biogas. The abandoned areas in Croatia could be successfully utilized for biogas production in keeping with the established energy strategy. The potential for biogas production from Miscanthus grown on low-quality soils in the counties under consideration are shown in Table 4.

Table 4. Total biogas yield from the Miscanthus biomass grown on 5 %, 10 % and 15 % of total abandoned soil (m3)

County	Biogas (m3) per 5 % of the total abandoned areas	Biogas (m3) per 10 % of the total abandoned areas	Biogas (m3) per 15 % of the total abandoned areas
Karlovac	6,659,439	13,318,628	19,978,067
Lika-Senj	4,162,618	8,325,236	12,487,855
Sisak-Moslavina	7,882,974	15,766,198	23,649,172

Table 4 indicates that the highest biogas yield can be achieved in the Sisak-Moslavina county with 23,649,172 m^3 on 15 % of the abandoned areas, with 15,766,198 m^3 on 10 % and 7,882,974 m^3 on 5 % of the abandoned areas under consideration. The Karlovac county follows with 19,978,067 m^3 on 15 % of the abandoned areas, 13,318,628 m^3 of biogas on 10 % and 6,659,439 m^3 on 5 % of the abandoned areas. Finally, the Lika-Senj county's potential is 12,487,855 m^3 of biogas on 15 % of the abandoned soils, 8,325,236 m^3 of biogas on 10 % and 4,162,618 m^3 of biogas on 5 % of the abandoned areas under consideration. Consequently, it can be concluded that there is considerable potential to reduce natural gas consumption by using cultivated energy crops for biogas production and the production of their own biofuels, thereby achieving energy independence but also contributing to the reduction of greenhouse gas emissions.

Table 5 shows the potential amount of bioethanol on the soils of poorer quality under consideration.

Table 5. Calculating the production of bioethanol from the Miscanthus biomass grown on 5 %, 10 % and 15 % of the abandoned soils under consideration (t)

County	Bioethanol per 5 % of the total abandoned surfaces	Bioethanol per 10 % of the total abandoned surfaces	Bioethanol per 15 % of the total abandoned surfaces
Karlovac	9,637,267	19,274,171	28,911,438
Lika-Senj	6,023,970	12,047,940	18,071,910
Sisak-Moslavina	11,407,916	22,816,193	34,224,109

As seen in Table 5, the greatest potential for bioethanol production on the low-quality soils was determined in the Sisak-Moslavina county with an amount of 34,224,109 t of ethanol produced on 15 % of the abandoned areas, 22,816,193 t ethanol on 10 % of the abandoned areas and 11,407,916 t on 5 % of the abandoned areas. The Karlovac county follows with a potential production of 28,911,438 t of ethanol on 15 % of the abandoned soils, 19,275,171 t on 10 % and 9,637,267 t on 5% of the abandonedareas. The Lika-Senj county exhibited the lowest potential of ethanol production: 18,071,910 t of ethanol on 15 % of the abandoned areas, 12,047,940 t on 10 % of the abandoned areas and 6,023,970 t on 5 % of the abandoned areas.

On the basis of all the considerations mentioned above, it can be concluded that there is considerable potential for reducing

gasoline consumption by using cultivated energy crops and producing liquid biofuels, thus achieving energy independence and reducing greenhouse gas emissions.

CONCLUSION

To achieve the goals set by 2020 and 2030, and in the period thereafter, the European Union (Croatia included) is determined to develop new renewable energy sources. Although renewable sources such as the sun and the wind played a significant role in the energy supply of the European Union during the past 10 years, it has been found that the considerable potential lies in the field of biomass. Croatia has more than 600,000 ha of abandoned lands, identifying the counties of Sisak-Moslavina, Karlovac and Lika-Senj as the potentially most favourable for the Mischantus x giganteus production.

On the basis of the analysis of the Miscanthus cultivation on the abandoned areas in the Sisak-Moslavina, Karlovac and Lika-Senj counties, it can be concluded that there is the great potential for producinf biomass and bioenergy - biogas, bioethanol and thermal energy. Biomass production can have a direct impact on reducing fossil energy and fuel imports, encouraging energy independence and reducing the negative impact on the environment and climate change.

In addition, the use of biomass enables the creation of new and saving the existing jobs in rural areas, increases the local and regional economic activities, and generates additional incomes in agricultural production.

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