INSTITUTE OF AGRICULTURAL ECONOMICS, BELGRADE, SERBIA

SUSTAINABLE AGRICULTURE AND RURAL DEVELOPMENT IN TERMS OF THE REPUBLIC OF SERBIA STRATEGIC GOALS REALIZATION WITHIN THE DANUBE REGION

- support programs for the improvement of agricultural and rural development -

Thematic Proceedings

Belgrade, 2018

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Belgrade, 2018

Publisher:

Institute of Agricultural Economics, Belgrade, Serbia

Editors:

Jonel Subić, Ph.D.
Boris Kuzman, Ph.D.
Andrei Jean Vasile, Ph.D.

Technical arrangement and printing:

SAJNOS DOO NOVI SAD
Momčila Tapavice 2
Phone: +381 (0) 21 499 088

Technical preparation and page breaking:

Radojica Sarić, Ph.D., Predrag Vuković, Ph.D.,
Biljana Grujić, Ph.D., Bojana Bekić, B.Sc.

Number of copies:
300

ISBN 978-86-6269-061-6

Publication of Thematic Proceedings was financed with the support of the Ministry of Education, Science and Technological Development of the Republic of Serbia.

INTRODUCTION OF MISCANTHUS IN AGRICULTURAL PRODUCTION IN SERBIA AND THE POTENTIAL FOR USING BIOMASS FOR OBTAINING ALTERNATIVE FUELS

Nenad Djuric[1], *Djordje Glamoclija*[2]

Abstract

According to research results to date on uncultivated agricultural surfaces, as well as on soils under recultivation, best production results were obtained by cultivating the perennial grass species miscanthus. From the ecological point of view, miscanthus is very important, because it can be cultivated in areas with high levels of environmental pollution for the purposes of remediation. The produced plant mass, fresh or dry, represents stored energy that can be used to obtain gas, liquid or solid biofuels, that can replace fossil fuels. The advantage of these fuels results from the fact that they have lower carbon dioxide emissions, and thus a more beneficial effect on reducing global warming caused by the greenhouse effect. In addition to reduced CO_2 *emission, less dependence on import of fossil fuels, primarily oil, has in many countries in the world created much interest in cultivating miscanthus as an energy crop, which is reflected also in the fact that this contributes to the economic development of rural areas. Direct material costs of forming plantations in the first year amount to 262,100 dinars, and full biomass production begins already in the third year.*

Key words: *miscanthus, use, conditions for success, cultivation, costs of forming plantations.*

Introduction

In the Republic of Serbia agricultural areas have been significantly reduced. According to statistical data over 850,000 hectares are uncultivated. The majority of these areas are in rural areas in hilly-mountainous regions of Central Serbia. The increase of uncultivated areas is a consequence of aging

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of rural households and the reduced number of able-bodied family members, who could work in intensive plant production.

The most simple way to reduce these areas is to change planting structures, i.e. cultivation of plant species that due to their manner of use are called energy crops. This group encompasses numerous wild and cultivated annual and perennial species, whose generative and vegetative organs are used to produce biofuel. According to botanical affiliation and the manner of cultivation, energy crops can be field or forest crops (*Jankovic et al.* 2017). In Serbia, for several years already, research is under way about possibilities to cultivate plants whose biomass would be used for obtaining biofuel. In agricultural areas, as well as on soils in recultivation, best production results were achieved by cultivating the perennial grass species miscanthus (*Dzeletovic et al.*, 2009; *Drazic et al*., 2010; *Dzeletovic and Glamoclija*, 2015; *Maksimovic et al*., 2016).

According to its biological characteristics this is a perennial plant that develops underground perennial and above ground annual organs. After 2-3 years plants achieve full potential with high annual biomass production (*Heaton et al*., 2004; *Djuric et al., 2015; Maksimovic*, 2016). The produced plant mass represents stored energy that can be used for obtaining gaseous, liquid and solid biofuels. The advantage of these fuels lies in the fact that they have lower CO_2 emissions and therefore a beneficial effect on reducing global warming caused by the greenhouse effect. *Lewandowski and Heinz* (2003) state that the option should be to cultivate miscanthus, which, compared to other crops from the grass family has better production characteristics. Miscanthus is sensitive to less favorable ecological conditions, but it can be cultivated on various types of soils, from the most inferior degraded soils, to the most fertile, offering economically profitable biomass yields. As opposed to most grasses, miscanthus uses the C4 route to take in and utilize solar energy producing a raw material with a reduced content of other organic compound and with a significantly higher combustion coefficient. Via combustion, biomass creates less ash which is favorable due to a reduced concentration of harmful gases. In addition to reduced CO_2 emissions, in many countries in the world, less dependence on import of fossil fuels, primarily oil, causes high interest in cultivating energy crops, also reflected in the fact that this contributes to the economic development of rural areas, as emphasized by *Oljaca et al.* (2007). Miscanthus is a good energy crop, because it has the adequate capacity to take in and convert solar energy to biomass with maximum efficiency, minimum inputs, and a favorable effect on the ecosystem. In addition, as pointed out by *Heaton et al*. (2004), costs of production technology need to be lower or at the level of the price of fossil fuels. *Sims et al*. (2006), also give the advantage to miscanthus in comparison with related crops emphasizing that the energy yield of 204 GJ ha^{-1} is higher than for wood mass of softwood, willow and poplar, by approximately 22%, and compared to seeds of oil plants by 7.5 times. The produced biomass can be used in several ways, so that miscanthus is not only an energy crop, but a versatile useful plant.

Economic importance of miscanthus

1. Energy crop. The primary economic importance of cultivation is the use of the produced biomass for obtaining biofuel. Biogas is extracted from the raw material by biological fermentation of organic carbon compounds that are reduced under anaerobic conditions to carbon dioxide and methane with the aid of catalyzing microorganisms. Fresh miscanthus biomass contains significant quantities of sugar and can be used to produce the liquid fuel bioethanol. This energy source is obtained by chemical or biotechnological procedures. Another way of obtaining bioethanol, used more frequently, has three phases. These are raw material preparation, fermentation and separation of the main product and byproducts. Solid biofuel is obtained from air-dried biomass, prepared in several ways, depending on the manner of use in boiler plants. In large boiler plants (thermoelectric power plants), after mowing and drying, dry biomass is formed into round or square bales and placed under overhangs beside the place of use (*Dzeletovic et al.* 2009). If the farmer has special mechanization, dry miscanthus stalks can be harvested using special silo combine harvesters and the obtained biomass used to produce briquettes and pellets (*Michel et al*., 2006). The advantage of using the above ground biomass as solid fuel is in its high energy value (9.2-17.1 MJ kg^{-1}), *Lewandowski et al*. (2003). Combustion of 1 kg of dry biomass produces up to 17.744 MJ of energy. Carbon dioxide, released during combustion was previously fixated by the plants via the process of photosynthesis, therefore its concentration in the atmosphere does not increase. Compared to coal, per kWh^{-1} of produced electrical energy, during combustion miscanthus releases 0.131 kg CO_2, and coal 0.99 kg CO_2 per unit. Thus, as stated by *Styles and Jones*, (2007), miscanthus directly reduces gas emissions that cause the greenhouse effect. The advantage of miscanthus as a source of renewable energy in relation to other plant species is also in the chemical composition of the biomass used for combustion. During harvesting in February-March, dry stalks contain 0.19-0.67% nitrogen, 0.31-1.28% potassium, 0.08-0.14% calcium, 0.1-0.5% chlorine, 0.04-0.19% sulfur, and combustion produces

1.6-4.0% of ash containing less heavy metals than the ash of forest trees (*Hasler et al*., 1998; *Lewandowski and Heinz*., 2003). Agronomic cultivation of miscanthus is economically profitable when costs of production and the obtained product are compared. Results stated by *Ercoli et al*. (1999) show that that the relation between energy yield and energy invested into miscanthus production is 22:1 when intensive agrotechnical measures are utilized, while in a system of sustainable agriculture this is 47:1. With a small investment (without fertilizers and irrigation) energy use is significantly reduced, but biomass yields are also lower. When analyzing dry miscanthus biomass yield from 20 t ha^{-1} and the relationship between energy yield and the energy invested in agrotechnics, *Lewandowski et al*. (2003) concluded that this is between 14:1 and 20:1, depending on agroecological and soil conditions. Mentioned data shows that miscanthus is a valuable energy crop.

2. Raw material for paper production. According to statements by *Cappelletto et al*. (2000) miscanthus stalks have a high content of cellulose and hemicellulose, and obtained pulp is an excellent raw material for paper production.

3. Construction material. Miscanthus stalks are used to cover economic and housing buildings, as *Fowler et al*. (2003). *Acikel* (2011) concludes that if ground miscanthus fibers are added in the production of structural concrete elements, concrete with significantly improved quality is obtained. Ground miscanthus, incorporated into concrete elements increases their resistance to pressure by 4-28%, to compression by 9-25%, to bending 4-9%, and flexibility by 2-6%.

4. Production of biodegradable products. Results of *Fowler et al*. (2003) for production of plant pots show that miscanthus biomass mixed with natural resins in a 70:30 ratio can be used. These pots for cultivating plants are 100% biodegradable. Plastic parts, prepared using this procedure have good quality, and can be biologically degraded after use (*Fowler et al*. (2003).

5. Decorative plant. The introduction of several species of the *Miscanthus* genus into Europe and America, led to the creation of many decorative forms, used for designing decorative areas in parks and in home gardens. Since the plant tolerates air pollution and shade very well, it can also be cultivated in such areas.

6. Soil melioration. Finely cut post-harvest miscanthus remnants can be used as mulch in orchards and for widely spaced farm crops. The goals of mulching is to regulate the water-air and thermal regime of the soil, to curb weeds, improve microbiological activity in the soil, balance nitrogen mineralization and the incorporation of substances assimilated by plants (*Glamoclija et al.*, 2015; *Djuric et al.,* 2015). As a perennial grass that develops a strong and branching root system, miscanthus significantly reduces the risk of soil erosion by wind and water (*Heaton et al*., 2004). According to statements by *Arduini et al*. (2004) miscanthus plants incorporate certain heavy metals that stimulate the growth of above ground biomass, therefore they can be cultivated on soils under recultivation in order to reduce concentrations of heavy metals, for example cadmium.

7. Introducing greenery in nonagricultural areas. Miscanthus can be cultivated on soils under recultivation, along water courses, roads, in hunting areas and other areas not encompassed by agricultural and forestry production.

8. Plant for feed. The above ground miscanthus biomass is rich in carbohydrates and could be used for preparing feed for domestic ruminants (*Burner et al*., 2017). Analyzing the possibilities to use perennial grasses miscanthus, Spanish (giant) reed (*Arundo donax*) and a miscanthus hybrid, obtained by crossing sugarcane and miscanthus (*Saccharum sp* × *Miscanthus sp*.), *Anderson et al*. (2008) conclude that the useful value of biomass depends on conditions for growth success (water regime) and the species.

For several years already experiments concerning the possibility to cultivate miscanthus on various types of agricultural soils, as well as on soils in recultivation are being done in Serbia. Results to date show high annual biomass yield (20 t ha^{-1}) and successful cultivation on lower quality soils and open the possibility to produce miscanthus as an annually renewable raw material for obtaining various biofuels. Compared to other energy crops, miscanthus has advantages, because with lower agrotechnical investments it has higher net energy production per unit area (*Dzeletovic and Glamoclija*, 2015).

Miscanthus biology

The interspecies hybrid *Miscanthus × giganteus* Greef et Deu is a perennial plant with characteristics of an ideal energy crop. It is characterized by a high annual yield, good solar energy to biomass conversion, efficient use of mineral salts and water and satisfactory tolerance to pests and pathogens (MAFF, 2001). Being an infertile interspecies hybrid, miscanthus develops from perennial underground rhizomes, therefore its spread in the environment is very slow and there is no danger of weed forming in adjoining areas. Commercial multiplication is done using rhizome sections with at least two buds, from which spring growth of adventive roots and above ground stalks with leaves begins at temperatures of 10-12°C.

Annual vegetative growth is simple. In the year of planting, in April, above ground stalks appear from the rhizome and rapidly grow, so that at the end of August they are 2 m high. The plant has maximum daily growth during May and June, when under favorable weather conditions daily growth per plant is 30-35 g of dry mass, i.e. 0.28-0.32 t ha^{-1}. During the fall biomass growth is reduced due to the drying and shedding of leaves. With additional minerals (nitrogen), vegetative growth of plants is prolonged to mid-November. Without additional nutrition this growth ends in mid-October (*Djuric et al.* 2015). Stalks are very similar to bamboo stalks and very rarely form branches. The interior is filled with parenchyma that forms a solid nucleus. At the end of July bottom leaves begin to die out, and the drying process of the entire above ground biomass is accelerated in the fall. Before the winter, products of photosynthesis are moved from above ground organs to rhizomes. Under the influence of winter frosts, dry leaves fall from mature stalks, forming a bed of leaves on the ground. During the winter stalks dry out, and their water content falls to 15-30%

Under agroecological conditions in Serbia, the plant life cycle begins in April, when the soil heats up to 10^oC, and is manifested by the appearance of above ground stalks. The highest influence on the number of stalks that will be formed from buds on rhizomes is exerted by thermal conditions during the winter period. For this reason, at planting it is important to place rhizomes into deeper soil layers. In areas with cold winters and with little snowfall, the bed of fallen leaves is left on the surface (*Greef et al.,* 1997). During the perennial life cycle, plants form a strong cluster from which in every subsequent year numerous underground and above ground stalks will develop. Under favorable conditions maximum yield is obtained in the third year, and lasts 15-20 years if miscanthus is cultivated on a soil with good physical and chemical characteristics and with a favorable water regime (*Lewandowski et al.,* 2003). If plants are cultivated using adequate technological production measures annual biomass yield decreases gradually.

Conditions for successful growth

For high and stable yields of above ground biomass, plants must be provided a favorable water regime, especially in the year when the plantation is formed (*Maksimovic*, 2016). Soils with good water regime are the most favorable for overall plant growth. Good water supply in interaction with nitrogen nutrition in the year of planting very significantly influences plant mass growth and general plant development (*Zub and Brancourt-Humel*, 2010). Plants well developed in their first year will synthesize larger quantities of nutritive substances which enables better overwintering of the rhizome. In subsequent years, plants are supplied with water from deep soil layers owing to the strong and deep root system, but they react favorably to irrigation during critical periods. As emphasized by *Ercoli et al.* (1999), crop irrigation significantly increases the effect of used nitrogen fertilizers. One kilogram of nitrogen used can result in obtaining 37-50 kg of biomass. High levels of winter precipitation after which water lies on the surface have an unfavorable effect on the rhizome.

Thermal conditions during the vegetation period are very important for favorable annual plant growth (*Greef et al.,* 1997; *Drazic et al.*, 2010). Although it originates from cooler and wetter areas, the plant is sensitive to winter frost, especially in the year of planting (*Lewandowski et al.,* 2003). In the first year, plant overwintering depends on the depth of planting. *Clifton-Brown and Lewandowski* (2002) state that shallowly planted rhizomes are especially sensitive, and perish at frosts of -3.5°C. Conclude that deeper planting of larger sections of the rhizome, as well as covering the surface with straw, and in subsequent years with fallen leaves achieves more secure overwintering of plantations.

Miscanthus thrives best on fertile soils with favorable physical characteristics, but gives satisfactory yields on poorer sandy alluvial soils or soils with high contents of organic substances, within the limits of 15-30 t ha^{-1}. It is very tolerant to a broad range of pH, but the optimum is 5.5-7.5 (*Dzeletovic et al.*, 2015). According to research to date, miscanthus should not be cultivated on soils that are too moist during the winter and early spring (*Glamoclija et al.*, 2008). Soil under miscanthus has a higher concentration of organic carbon and total nitrogen, because of high quantities of leaves, roots and rhizomes. And such soil contains significantly increased concentrations of organic sulfur, an uncreased capacity of exchangeable cations and porosity, while moisture and volume mass are reduced (*Kahle et al*., 2001).

Technology of production

All operations related to forming miscanthus plantations in regular agricultural production can be performed using standard agricultural mechanization (*Dzeletovic et al.*, 2015).

Crop rotation. As a perennial plant, miscanthus should be cultivate outside of crop rotation. The best preceding crops for forming plantations are arable species that leave the soil without weeds, with good physical characteristics and enriched in plant assimilation products. This group encompasses annual plants and perennial Papilonaceae, as well as winter wheat. However, miscanthus is most often cultivated on neglected agricultural soils, as well as in areas under recultivation (*Maksimovic*, 2016). In this case, before planting, the field should be cleaned of perennial weed, which is achieved by using total herbicides, for example glyphosates. Once formed, a plantation is used for 15-20 years.

Soil cultivation. The first operation is autumn deep plowing to a depth of 30 cm with the goal to introduce organic fertilizers which will be distributed in the root system zone, as well as to destroy perennial rhizome weeds (Glamoclija et al., 2015). In the spring the soil should be cleaned of weeds, best with total herbicides, and then prepared for planting using harrows, seed preparing cultivators or rototillers (Djuric et al., 2015).

Plant nutrition. NPK mineral fertilizers are used for additional plant nutrition. Quantities and ratio between specific assimilative substances depend on the natural fertility of the soil. Plants utilize assimilative substances in the NPK very rationally, because of the very pronounced process of displacement of nutritive substances from underground to above ground organs during the vegetative season, as well as their return to the rhizome in ripening phases of the above ground biomass. Compared to other main elements of nutrition, nitrogen plays the most important role in plant nutrition, as emphasized by *Lewandowski et al.* (2003); *Dzeletovic et al.* (2009); *Drazic et al*. (2010) and other researchers. They point out that the issue of rational utilization of mineral fertilizers is current also from the aspect of environmental preservation. According to results of own research, authors point out that before planting, 50 kg ha^{-1} each of nitrogen, phosphorus and potassium should be introduced. Similar results were obtained by *Dzeletovic and Glamoclija* (2015) when studying the effect of increased quantities of nitrogen on product characteristics of miscanthus in the year of planting. The plantation was formed on a carbonate chernozem type soil with s medium level of supply of main nutritive elements (NPK). Mineral fertilizers were introduced before planting, and quantities of phosphorus and potassium in all variants were 50 kg ha^{-1} each, while the level of nitrogen used was 50 kg ha^{-1} in the first, 100 kg ha^{-1} in the second, and 150 kg ha^{-1} in the third variant. During the vegetative period, stalk height was monitored by phenophases (Table 1).

Table 1. *Average height of miscanthus plants in the first year by phenophases, cm*

Treatment/dates	3 July	30 July	30 August	28 September	29 October
N_1 P_1 K_1	88	131	152	154	154
N_2 P_1 K_1	60	111	137	144	143
N_3 P_1 K_1	53	81	127	136	133

Source: *Dzeletovic and Glamoclija* (2015)

Results of this research showed that required quantities of nitrogen for miscanthus plants can be provided with 50 kg ha^{-1} of the active substance. Quantities of nitrogen fertilizers above this level have no effect on the vegetative growth of plants. Under conditions of intensified nutrition with nitrogen, plants formed smaller stalks. However, analysis, by phases of plant growth, of the chemical composition of leaves showed that the increased quantities of nitrogen used in plant nutrition influenced the dynamics of incorporation of this fertilizer and of the synthesis of nitrogen compounds (Table 2).

Table 2. *Average nitrogen content in green miscanthus leaves, %*

Treatment:	30 August	28 September	29 October
N_1 P_1 K_1	1.26±0.05	1.09±0.04	0.89±0.03
N_2 P_1 K_1	1.15±0.14	1.16±0.04	0.76±0.03
N_3 P_1 K_1	1.37±0.23	1.53±0.11	1.26±0.07

Source: *Dzeletovic and Glamoclija* (2015)

In the year of planting a plantation, the entire quantity of mineral fertilizers should be introduced before planting rhizomes, and if the need for additional plant nutrition arises, it is best to use this before above ground stalks appear. Depending on soil fertility, quantities of nitrogen can even be increased, and supplemental feeding in following years can be left out if the effect of this agrotechnical measure is minor. Research by other authors showed that enhancing plant nutrition with nitrogen is of no major importance for the vegetative growth of plants, because owing to their strong roots they utilize the used assimilative substances very well, so that loses by leaching into deeper layers are reduced. *Lewandowski et al*. (2003), also point out that supplemental plant nutrition is specific, especially from the aspect of the use of potassium fertilizers. If used in major quantities, potassium mineral fertilizers have an unfavorable effect on the quality of raw material for combustion by increasing ash content. *Himken et al*. (1997) state that 21-46% nitrogen, 36-50% phosphorus, 14-30% potassium and 27% magnesium is returned from above ground organs into rhizomes. In the spring assimilative substances from rhizomes return to above ground plant organs, which makes miscanthus plants partially independent from supplemental mineral nutrition (*Christian et al*., 2001). If the leaf mass is not removed from the soil surface, its decomposition and humification increases the natural fertility of the soil, which also has a favorable effect on total mineral salt requirements of plants. When miscanthus is cultivated on less fertile soils and on soils in recultivation system, supplemental nutrition should also be provided in subsequent years. The quantity of fertilizers to use should be determined according to the natural fertility of the soil and plant needs, in order to rationalize production costs (*Kahle et al*., 2001; and *Dzeletovic and Glamoclija*, 2015).

Planting. As a sterile triploid interspecies hybrid, miscanthus propagates only vegetatively, by macropropagation (rhizomes) or micropropagation (tissue culture), as stated by *Dzeletovic* (2012). In large scale commercial production, the planting material used are sections of the rhizome approximately 10 cm long and with 2-3 buds. Under our agroecological conditions, manual planting is done in the first half of April, or after the danger of spring frosts passes. Planting earlier in the spring has its advantages, because of the better utilization of the favorable soil water regime for accelerated root formation and plant growth. According to results of research in progress, planting in the autumn (October) has advantages over spring planting, because by the spring rhizomes better adapt to environmental conditions, so that spring plant growth begins earlier. Before extraction, rhizomes are cut in the ground using a rotary digger, and then removed using universal harvesters for root-tuberous plants (*Wilkins and Redstone*, 1996). Rhizomes can be planted manually on small surfaces, or using larger planters for potatoes. Today, there are also specially designed planters for miscanthus rhizomes with which this operation can be done very precisely in relation to the depth of planting and the distribution of plants in a row. Before starting mechanical planting, it is necessary to classify the rhizomes, remove large rhizome sections that cannot pass through the tube of the planter, as well as sections without 2-3 developed buds. The miscanthus planter is a two-row machine that plants rhizomes into furrows previously created using plows. According to statements in the MAFF (2001) publication, planters have good performance, so that the efficiency of forming plantations is approximately 92%. The planters whose performance was studied by had a box that could carry up to 5 tons of planting material. By engaging only one worker for 1 hour, it is possible without any major difficulties to plant 0.3-0.5 ha, i.e. approximately 4 hectares daily. The efficient performance of planters can be expected to additionally decrease the costs of forming a plantation (*Lewandowski et al*., 2003). Planting depth plays an important role in the subsequent growth of the root system and above ground stalks, as well as plant tolerance to frost (*Glamoclija et al.*, 2015). Planting is optimal if rhizomes are covered by 10-12 cm of soil, although *Christian and Haase*, (2001) conclude that optimal plant growth in the year of planting is achieved by planting the rhizome at a depth of up to 20 cm. After placing rhizomes in the furrows and covering them using harrows, the field should be rolled using smooth or ribbed rollers, especially if the surface layer is dried out. Rolling compacts the surface layer of soil and provides better contact between the rhizome and the soil (*Dzeletovic*, 2012; *Maksimovic*, 2016). When determining planting density, the spreading of plants during the life of the plantation should be taken into account. Optimal density of a plantation is achieved by planting 10,000-12,000 rhizomes per hectare. If rhizome sections smaller than standard dimensions (10-15 cm) are used for planting the number should be increased to 20,000-25,000 to compensate for poorer sprouting (*Heaton et al*., 2010). Studying the effect of planting density (1-4 rhizomes per m^2) on the yield of miscanthus biomass, *Lewandowski et al*. (2003) concluded that higher plant density offers an advantage only during the initial years of growth, but not later, when plants form strong clusters. Planting at a distance of 76 cm x 76 cm requires 17,200 rhizomes and this vegetative spacing is optimal for plant spreading and the agricultural mechanization used at the University of Illinois, as stated by *Lee et al*. (2014). It is expected that the initial benefit of high density is reduced as soon as the plant reaches maturity, while the maximum production of dry biomass will be the same regardless of initial planting density (*Clifton-Brown and Lewandowski*, 2002). *Lewandowski et al*. (2003) recommend planting density of 2 rhizomes per m^2 as the most appropriate for producing miscanthus as a bioenergy source. Studying the effect of planting density (2 or 3 rhizomes per m^2) on the yield of biomass under our agroecological conditions, *Dzeletovic et al*. (2012) and *Maksimovic* (2016) conclude that planting density is significantly influenced also by soil characteristics. These authors recommend higher planting density on soils rich in organic substances and with a heavier mechanical composition, and less density on lighter, structural soils.

Plant care and protection. During the first year, the most important measures of care on plantations are cultivation between rows and hilling in order to keep the area between rows loose and free of weeds, followed by irrigation if soil moisture content is under 70% of maximum water capacity. *Lewandowski et al*. (2003) point out that irrigation of plantations in the year of planting improves initial plant growth, which is confirmed also by results stated by *Glamoclija et al.* (2015) emphasizing that plant watering is an important measure of care, especially in periods of lengthy draught. Simultaneously the plantation can be provided supplemental nitrogen if it is assessed that initial plant growth is slowed down. Seasonal variations of growth of above ground biomass are mainly a result of stress caused by draught. Watering can be done using various mobile irrigation systems. Needs for irrigation mainly depend on climate conditions and soil characteristics and significantly increase the production price, but if miscanthus is cultivated on marginal soils or technogenous media (ash landfills), the plantation should be watered every day during the first year. Weed suppression is one of the biggest problems in the first year, especially if the plantation was formed on soil that was not used for intensive agricultural production (*Lesur*, 2012; *Maksimovic et al*., 2016). In addition to mechanical measures for suppressing weeds, herbicides used in the production of maize and other millet type cereals can be used (*Serafin and Ammon,* 1995). In subsequent years plants exhibit strong spring growth, and cover spaces between rows well, so that weeds can be suppressed by tilling the soil between rows using rotocultivators. In its homeland, East Asia, miscanthus is subject to attacks of pests and pathogenic fungi, therefore when importing planting material, it is necessary to implement all quarantine measures. Pathogenic fungi belonging to the *Fusarium* genus can cause diseases if winters are warm and humid. There are few insects that feed on miscanthus biomass, although aphids (*Leptosphaeria* sp.) are sometimes found on plants. However, to date no significant limitation of miscanthus production caused by pathogens or pests has been noted in Europe (*Lewandowski et al*., 2003). Under our agroecological conditions, miscanthus is tolerant to pests and pathogen so that there is no need to use chemical agents to protect plantations (*Glamoclija et al.*, 2015).

Miscanthus harvesting is done using special mowers, but ordinary (roto) or silo-combine harvesters can also be used. Harvesting time depends on how the biomass will be used. Fresh biomass used for obtaining biogas, is mowed in August, while dry stalks for solid biofuel or for other purposes are harvested in the winter, most often in February or March. Moving the time of harvest to the second half of the winter period reduces the yield of above ground biomass, but provides better raw material for biofuel, because all undesirable nutritive substances have been moved to underground plant organs (*Clifton-Brown et al.*, 2002; *Dzeletovic*, 2012;). Although in the first year yields have no major commercial value, stalks should be mowed by the beginning of the next vegetative season. Multiphase harvesting of dry stalks implies mowing, turning over the swath, gathering and bailing, with or without bale compaction. This method permits the crop to dry in swaths, which is faster than the drying of upright stalks (*Lewandowski et al*., 2003). In order to efficiently harvest larger areas, mechanization should be adapted to plant height (2.0-3.5 m) and the hardness of miscanthus stalks. In Western Europe countries specialized mechanization is used to harvest entire stalks and tie them into bundles, if they will be used as construction material, or in the industry of paper and geotextile (*Glamoclija et al.*, 2015).

Product storage. To prevent biomass moistening and spoilage, bales left in the field must be covered with protective, impermeable material, but it is better to store under overhangs. For large bales to be stored in a warehouse, stalk water content should be under 25%. Since drying in warehouses is difficult, stalks should be harvested when the water content drops under 18%. Dried bales can be stored up to three years without any change of raw material quality (*Heaton et al*., 2004). Green miscanthus stalks are stored under anaerobic conditions prepared similarly to maize silage. In addition to storage in bulk, miscanthus biomass is also stored as briquettes and pellets (*Jankovic et al.*, 2016). In years with maximum production, up to 100 t ha^{-1} of raw biomass i.e. 10-25 t ha^{-1} can be obtained (by harvesting in August), and under irrigation even over 30 t ha^{-1} of stalks, containing 15-30% of water (*Maksimovic et al*., 2016). After the harvest approximately 3 t ha^{-1} of leaf mass is also left in the field, which can serve as a protective covering for rhizomes against freezing, or can be used as raw material for preparing artificial manure compost (*Djuric et al.*, 2015).

Economics of miscanthus cultivation

Direct material costs of forming a plantation in the first year amount to 262,100 dinars (Table 3).

Table 3. *Analytical calculation for forming a miscanthus plantation*

Elements	Quantity	Price	Value, rsd
Production costs			
1. Material costs			
- NPK mineral fertilizer	300 kg ha^{-1}	35 rsd	10.500
- rhizomes	22.000 ha^{-1}	10 rsd	220.00
- herbicides (Glyphosate)	4 l ha^{-1}	400 rsd	1.600
2. Machines			
- plowing	10.000 rsd		10.500
- soil preparation	2.000 rsd		2.000
- planting	4.000 rsd		4.000
- cultivation between rows	2.500 rsd		2.500
- hilling	6.000 rsd		6.000
- irrigation	5.000 rsd		5.000
Total costs			**262.100**

Source: *Own research (Djuric and Glamoclija)*

In the first year dry biomass yield can reach 1-1.5 t ha^{-1}. This quantity of biomass does not have adequate quality or commercial value, and does not cover production costs. If the crop is adequately cared for, the yield in the second year can be 4-7 t ha^{-1}, and under optimal water regime conditions even up to 20 t ha^{-1} (*Bilandzija*, 2014). Depending on soil type, yield realized in the third year, by applying necessary agrotechnical measures, was 1.35-18.6 t ha^{-1}, (*Maksimovic, et al.*, 2016), although in experiments without irrigation *Dzeletovic et al.* (2015) obtained 20.22 t ha^{-1} of biomass. According to these results it can be pointed out that full biomasse production begins already in the third year.

Conclusion

Results of own research compared with results of other authors permit following conclusions:

- From the agronomic point of view, miscanthus is an important plant species that can be cultivated using standard agricultural mechanization;
- The possibility of cultivation under different agroecological conditions and on different types of soil offers the potential to better use agricultural resources in general;
- The relatively simple production technology and the possibility to finalize the product within the household enables a higher level of employment for household members, as well as the development of small facilities for producing all types of biofuel;

- Miscanthus enables large agricultural producers to better utilize soil in the system of recultivation and to secure larger quantities of energy raw materials to construct small facilities to produce electricity;
- From the ecological point of view, miscanthus is very important because it can be cultivated in areas with high environmental pollution for the purposes of remediation;
- High initial investments to form plantations should be alleviated via adequate subsidies. This enables better economy of available forest resources and a decreased dependence on overuse of fossil fuels.

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CIP - Каталогизација у публикацији -
Народна библиотека Србије, Београд

631(082)
338.434(497)(082)
502.131.1(082)
338.23:631(082)

SUSTAINABLE Agriculture and Rural Development in Terms of the Republic of Serbia Strategic Goals Realization within the Danube Region : support programs for the improvement of agricultural and rural development : thematic proceedings / [editors Jonel Subić, Boris Kuzman, Andrei Jean Vasile]. - Belgrade : Institute of Agricultural Economics, 2018 (Novi Sad :
Sajnos). - X, 644 str. ; 24 cm : graf. prikazi, tabele

"Thematic Proceedings includes selected papers presented at the International Scientific Conference - Sustainable agriculture and rural development in terms of the Republic of Serbia strategic goals realization within the Danube region: Support programs for the improvement of agricultural and rural development, which was hold in Belgrade on 14-15th December 2017." --> preface. - "The Thematic Proceedings was prepared as the result of the scientific research on the integrated and interdisciplinary project no. III 46006: Sustainable agriculture and rural development in terms of the Republic of Serbia strategic goals realization within the Danube region." --> preface. - Tiraž 300. - Napomene i bibliografske reference uz tekst. - Bibliografija uz svaki rad.

ISBN 978-86-6269-061-6

a) Рурални развој - Зборници b) Пољопривреда - Одрживи развој - Зборници c) Аграрна политика - Зборници COBISS.SR-ID 257428748