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https://doi.org/10.21278/TOF.42Si105
ISSN 1333-1124
eISSN 1849-1391

YIELD AND BIOMASS COMPOSITION OF *MISCANTHUS X GIGANTEUS* IN THE MOUNTAIN AREA OF CROATIA

Summary

Although biomass of *Miscanthus x giganteus* shows a significant potential for production of second-generation biofuels, it is currently mostly used as a combustion fuel. The objective of this paper is to investigate: (I) dry matter yield and yield components; (II) biomass composition; and (III) potential divergences of the investigated parameters from the standard for solid fuels CEN/TS 14961:2005, in relation to two harvest seasons and six fertilizer treatments. The investigation has determined that there is a potential for producing significant quantity of biomass from *M x giganteus* in the investigated agro-ecological conditions of the mountain areas of Croatia. The laboratory analyses indicated the suitability of using biomass in direct combustion.

Key words: *Energy crop, Miscanthus x giganteus, dry matter yield, combustion properties*

1. Introduction

According to the objectives of the Energy Strategy for Europe until 2020, Framework for climate and energy policies until 2030 and the UN Climate Change Conference (Paris Climate Agreement - COP 21), the renewable energy sources emerge as one of the most important element of energy self-sufficiency and for mitigating climate changes [1, 2]. Agricultural biomass as a component of renewable energy sources represents a significant source of different raw materials in the “green energy” production system.

Perennial grasses represent the biomass crops suitable for sustainable bioenergy production. *Miscanthus* is one such perennial grass that has received interest because it displays a number of characteristics that make it a good source of biomass. These characteristics include high yield, cold tolerance, C4 photosynthesis, perenniality and a low requirement for inputs [3]. Yield and its components (number of shoots, height of plants) of

M x giganteus primarily depend on place of plantation, climate and meteorological conditions, type of soil and agro-technical measures applied in cultivation of the grass. In the south European countries full yield is achieved after only two years of plantation, while in north European regions it takes up to five years to achieve full yield [4, 5, 6]. Reported dry matter yields of *M x giganteus* biomass are between 8 and 44.1 t ha^{-1} [7, 8, 9, 10]. In Europe, the plant's shoots can grow over two meters high in the first year of plantation, up to four meters in each year following [11]. The number of shoots per unit of surface increases in the first few years and is the lowest in the year of planting [6].

Nitrogen management is an important consideration in developing sustainable, energy efficient and environmentally benign cropping systems designed for energy production [12]. The literature contains contradictory data about the influence of nitrogen fertilization on the yield of *M x giganteus*. Namely, the authors Danalatos et al. [13], Christian et al. [14], Larsen et al. [15] did not find that fertilization had any significant influence, contrary to what was determined by Acaroglu and Aksoy [16], Arundale et al. [17], Pedroso et al. [18].

M x giganteus can be harvested from November (after early frosts) until the beginning of the following vegetation cycle (March, April). In each climate region it is possible to choose an optimal harvest season taking into account meteorological/climate conditions, current yields, moisture content and other energy properties of the crop. Generally, early harvest will maximize yield per hectare while in late harvests it will be lower [19, 20]. If average moisture content in biomass of *M x giganteus* is below 20%, it is considered that the application of technological drying process is not necessary before storing the crop [21].

Despite the fact that this crop displays a significant potential for production of second-generation biofuels, the current primary energy utilization of *M x giganteus* biomass is in direct combustion [22]. Combustion is used over a wide range of outputs to convert the chemical energy stored in biomass into heat, mechanical power or electricity and various items of process equipment are used in this process [23]. Next to heating value, proximate and ultimate analyses are very important factors in studying of fuel combustion properties of biomass [24].

In 2005 the Swedish Institute issued the standard 14961 for solid fuels (*Solid biofuels – Fuel specifications and classes*). The standard sets out the expected values for various biomasses including *M x giganteus* grass. The standard CEN/TS 14961:2005 [25] is based on the investigations conducted in Sweden, Finland, The Netherlands and Germany. As stated by Vassilev et al. [26], in their investigation, the biomass composition depends on location, climate factors, soil type, plantation age, and applied agro-technical measures. Therefore, relatively large differences in relation to literature data and the CEN/TS 14961:2005 [25] standard for solid biofuels can be expected. Furthermore, in all types of biomass, *M x giganteus* included, CEN/TS 14961:2005 [25] only applies to some combustion properties.

In connection to two harvest seasons and six fertilizer treatments, the aim of this paper is to determine: (I) dry matter yield and yield components (II) biomass composition (III) potential deviations of the investigated parameters from the CEN/TS 14961:2005 standard for solid fuels.

2. Materials and methods

2.1 Materials (field test)

<u>*Experimental field*</u> (~ 2000 m^2) was set up on the mountain Medvedica (650 m above sea level, N 45° 55' 37.2", E 15° 58' 24.4") at the end 2011. The planting distance was 1 metre. In the fourth plantation year (spring 2014) the field experiment observing the fertilizer treatment (FT) was set in a randomized block design in three replications. In addition to

control block (0 kg N ha^{-1} – FT1), one block was made up of two levels of mineral fertilization (50 kg N ha^{-1} – FT2; 100 kg N ha^{-1} – FT3) and three levels of solid cow manure fertilization (10 t ha^{-1} – FT4; 20 t ha^{-1} – FT5; 30 t ha^{-1} – FT6).

Yield and its components. The yield components were determined within all investigated fertilizer treatments at the end of the 2014 vegetation season. From each basic plot 10 plants were cut at 5 cm from soil, the length of plant was measured up to sheath of the last leaf and shoots were counted. Green biomass yield was also determined for all fertilizer treatments in two harvest seasons (HS), autumn (10 November 2014 – HS1) and spring (15 April 2015 – HS2). The harvest was carried out by manual cutting of the plants at 5 cm from soil on 18 randomly selected locations 10 m^2 large. The yield was determined by weighting green mass, subsample drying (~1000 g of chopped mass, 48 hours at 60 °C).

2.2 Methods

After drying, samples were ground in a laboratory grinder (IKA Analysentechnik GmbH, Germany). Each sample was analysed three times.

Proximate analysis. The samples were characterized according to standard methods: moisture content (CEN/TS 14774-2:2009) in laboratory oven (INKO ST-40, Croatia). Ash (CEN/TS 14775:2009), fixed carbon (by difference) and volatile matter (CEN/TS 15148:2009) were determined by use of a muffle furnace (Nabertherm Controller B170, Germany).

Ultimate analysis. Total carbon, hydrogen, nitrogen and sulphur were determined by dry combustion in a Vario Macro CHNS analyser (Elementar Analysensysteme GmbH, Germany), according to the protocols (EN 15104:2011) and (EN 15289:2011). The O content was calculated by difference.

Heating value. Heating value was determined by ISO method (EN 14918:2010) using an IKA C200 oxygen bomb calorimeter (IKA Analysentechnik GmbH, Heitersheim, Germany).

Statistical analysis. All data obtained from the samples were analysed according to the GLM procedure in the SAS system package version 8.00 (SAS Institute, 2000).

3. Results and discussion

3.1 Field trials

The height of plant and number of shoots are important components in determination of total yield of *M x giganteus.* Table 1 shows the yield components (at the end of growth) and the yield of the 4-year *M x giganteus* grass plantation pending on different harvest season (HS) and different fertilizer treatments (FT).

Table 1 Yield and components of the investigated biomass

Parameters	*Dry matter yield (t DM ha^{-1})*		*Plant height (m)*	*Number of shoots/m^2*
	HS1	*HS2*		
FT1	*40.09*	*27.06*	*3.45*	*52.30*
FT2	*44.62*	*28.51*	*3.61*	*55.20*
FT3	*39.78*	*21.90*	*3.63*	*51.95*
FT4	*37.88*	*25.24*	*3.61*	*50.90*
FT5	*39.03*	*27.80*	*3.56*	*56.05*
FT6	*37.91*	*24.53*	*3.56*	*52.80*
Significance	*NS*	*NS*	*NS*	*NS*

Values marked with identical letters statistically do not differ significantly with p<0.05
Significance: *** p<0.001; ** p<0.01, * p<0.05 and non-significant (ns)

From the results given in table 1 it is evident that none of the investigated factors (P>0.05) had a significant influence on the yield or yield components. The autumn (maximum) yields in the third and subsequent years were between 18 and 20 t DM ha^{-1} at different locations in Germany, Austria and Switzerland [4, 27]. Clifton–Brown et al. [5], in their investigations determined the autumn yields in the third year of plantation at 37.8 t DM ha^{-1} (Portugal - with irrigation), 29.1 t DM ha^{-1} (Germany), and 18.7 t DM ha^{-1} (England). Christian et al. [14], Borkowska and Molas [28] and Mantineo et al. [29] found that the average yields at the end of the vegetation season in the fourth year of plantation was the following: 12.53 t DM ha^{-1} (England), 14.83 t DM ha^{-1} (Poland) and 26.9 t DM ha^{-1} (Italy - 2 rhizomes m^2), successively.

The average autumn yield in this investigation was 39.89 t DM ha^{-1}, and if compared with the above literature references, evident is an exceptional potential for production of biomass from *M x giganteus* grass even without irrigation measures. It is interesting to note that, according to available literature, the location of this investigation has one of the highest above-sea altitudes (650 metres) of all experimental fields in Europe.

Postponing harvest from autumn to spring enables natural drying of the plants, but it also causes loss in leaf and inflorescence mass. Expectedly, the yield in this investigation decreased down to average 25.84 t DM ha^{-1} with a 35% biomass loss. Zub et al. [20] investigated in France the yield of *M x giganteus* grass in the third year of plantation and determined, in a late harvest, an average yield of 18.96 tons of dry matter per ha^{-1} (planting distance was 1m x 0.5m) with a 42% biomass loss. On the long term trail, at two locations in Denmark, Larsen et al. [15] found biomass losses of 34% and 42% in late harvests.

In this investigation the average plant height was determined at 3.57 meters, with 53.2 shoots per m^2. Christian et al. [14] determined that the average plant height after the fourth year was 2.14 meters, which is considerably lower compared to this investigations, while Borkowska and Molas [28] received similar results, determining average plant height at 3.12 meters. As for the number of shoots, the relations are similar to those of the plant's height. Christian et al. [14] determined 18.3 shoots per m^2, and Borkowska and Molas [28] 45.4 shoots per m^2.

3.2 Laboratory trials

Proximate and ultimate analysis and lower heating value are considered to be among the essential parameters in evaluation of biomass in the direct combustion process; these values are presented in tables 2 and 3. Moisture content (MC), ash content (AC), volatile matters (VM), nitrogen (N), sulphur (S) and oxygen (O) are undesirable components in biomass, unlike fixed carbon (FC), carbon (C), hydrogen (H) and lower heating value (LHV), whose higher levels improve the quality of biomass when direct combustion is concerned.

3.2.1 Proximate analysis and lower heating value

Table 2 Proximate analyses and lower heating value of the investigated biomass

Parameters	*MC (%)*	*AC (%, db)*	*FC (%, db)*	*VM (%, db)*	*LHV (MJ kg^{-1}, db)*
HS1	*53.282 a ± 9.012*	*1.781 ± 0.245*	*9.663 ± 1.744*	*88.465 ± 1.787*	*17.800 ± 0.235*
HS2	*19.125 b ± 10.141*	*1.714 ± 0.249*	*8.961 ± 1.879*	*89.299 ± 1.832*	*17.718 ± 0.244*
Significance	*****	*NS*	*NS*	*NS*	*NS*
FT1	*36.091 ± 9.021*	*1.599 b ± 0.122*	*10.420 ± 1.169*	*88.014 ± 0.994*	*17.720 ± 0.339*
FT2	*37.023 ± 8.100*	*1.760 ab ± 0.262*	*8.804 ± 1.836*	*89.311 ± 1.582*	*17.819 ± 0.280*
FT3	*36.093 ± 9.013*	*1.862 a ± 0.039*	*8.822 ± 1.943*	*89.324 ± 2.037*	*17.820 ± 0.063*
FT4	*35.005 ± 8.016*	*1.713 ab ± 0.410*	*8.737 ± 2.079*	*89.470 ± 2.435*	*17.776 ± 0.272*
FT5	*36.123 ± 9.168*	*1.816 ab ± 0.133*	*9.896 ± 1.324*	*88.203 ± 1.398*	*17.633 ± 0.077*
FT6	*36.899 ± 9.029*	*1.736 ab ± 0.295*	*9.195 ± 2.259*	*88.969 ± 2.227*	*17.785 ± 0.287*
Significance	*NS*	*****	*NS*	*NS*	*NS*

Values marked with identical letters statistically do not differ significantly with p<0.05
Significance: *** p<0.001, ** p<0.01, * p<0.05 and non-significant (ns)

In general, moisture can vary considerably and represents an undesirable ingredient in any fuel [30]. The statistical analysis indicates that harvest season significantly (P<0.01) influences MC in biomass while it is not the case with the investigated fertilizer treatments (P>0.05). Harvest postponing from autumn to spring influenced the MC content reducing it to 64.11%. The MC content of 19.13% in the spring harvest time indicates the potential for storing the harvested biomass without previously exposing it to additional drying, which is beneficial for energy balance but it also contributes to cost efficiency of the biomass production. In a similar time period, Lewandowski and Heinz [21] determined a moisture loss of 63.64% (from 49.5% to 18.0%), and Borkowska and Molas [28] of 57.43% (from 59.9% to 25.5%).

The non-combustible content of biomass is referred to as AC. High AC leads to fouling problems, especially if the ash is high in metal halides. Biomass fuels, especially agricultural crops/residues tend to have a higher AC [31]. The statistical analysis determined that harvest season has no significant effect on AC (P>0.05), unlike fertilizer treatments (P<0.01). Lewandowski and Heinz [21] determined that harvest postponing from autumn to spring leads to reduction of ash content: This was not found in this investigation. Fertilizer treatment FT1 influenced the production of biomass with the lowest ash content, which is in line with the investigations by Hodgson et al. [32] and Baxer et al. [33]. These authors also concluded that the control fertilizer treatment (N_0) results in production of higher quality biomass with a lower AC. The solid fuels standard CEN/TS 14961:2005 [25] states that the differences in ash content in *M x giganteus* biomass may be expected to be between 1% and 6%, while the literature indicates that AC is between 1.4% and 9.6% [34, 35]. The average AC in this work was determined at 1.74%. Parallel to the above mentioned literature data, it can be observed that the investigated biomass has a quality which is significantly more suitable for the combustion process. In terms of the solid fuels standard, the investigated biomass has the AC within the lower expected value range.

The FC content is the mass which remains after release of volatiles, excluding ash and moisture. Further, it produces char and burns as a solid material in the combustion systems [36, 37]. The statistical analysis has determined that FC is not significantly influenced by either harvest season (P>0.05) or fertilizer treatment (P>0.05), and that the average value of this parameter is 9.312%. On the basis of the literature data it has been established that FC in *M x giganteus* biomass is between 9.5% and 14.0% [26, 38]. The values obtained in this investigation show that FC content is somewhat lower in relation to literature data, while CEN/TS 14961:2005 [25] does not state the typical values for FC.

The concept of VM refers to the components released when fuel is heated at a high temperature, without counting moisture, being part combustible gases and part incombustible [33]. Biomass generally has a very high VM, with typical biomass values about 75%, but they can increase up to 90% [39]. VM content does not display statistically significant dependence (P>0.05) in relation to other factors observed in the experiment, and the average value of volatile matter in this investigation amounts to 88.88%. When compared to the literature, the analysed data show minor differences within the upper limits. Namely, Khodier et al. [37] and Nhuchhen and Salam [40] determined the VM content in *M x giganteus* biomass at 70.7% to 87.2%. CEN/TS 14961:2005 [25] does not state the typical VM values in *M x giganteus*.

The latent heat contained in the water vapour cannot be used effectively and, therefore, LHV is the appropriate value to use for the energy available for subsequent use [36]. LHV is one of the essential parameters for evaluating the potential of agricultural biomass. As in the case of FC and VM contents, harvest season and fertilizer treatment statistically do not show significant influence (P>0.05) on this parameter, the average value of which is 17.759 MJ kg^{-1}. According to the literature data the LHV values are between 16.0 MJ kg^{-1} [41] and 17.2 MJ kg^{-1} [42], while the expected value in CEN/TS 14961:2005 [24] is 18.4 MJ kg^{-1}. Despite certain divergence from the CEN/TS 14961:2005 [24] standard, the analysed biomass can be characterised as a valuable energy raw material, suitable for use in the combustion process.

3.2.2 Ultimate analysis

Table 3 Ultimate analysis of the investigated biomass

Parameters	*C (%, db)*	*H (%, db)*	*O (%, db)*	*N (%, db)*	*S (%, db)*
HS1	*48.596 b ± 0.412*	*4.004 a ± 0.243*	*46.828 a ± 0.432*	*0.487 a ± 0.071*	*0.086 a ± 0.009*
HS2	*49.496 a ± 0.156*	*3.965 b ± 0.069*	*46.159 b ± 0.196*	*0.303 b ± 0.052*	*0.076 b ± 0.006*
Significance	***	***	***	***	***
FT1	*49.161 a ± 0.479*	*4.001 a ± 0.022*	*46.414 b ± 0.444*	*0.349 b ± 0.052*	*0.076 b ± 0.004*
FT2	*49.267 a ± 0.415*	*4.002 a ± 0.010*	*46.270 b ± 0.388*	*0.384 ab ± 0.029*	*0.077 b ± 0.005*
FT3	*49.022 ab ± 0.663*	*3.925 b ± 0.113*	*46.497 b ± 0.429*	*0.471 a ± 0.125*	*0.084 ab ± 0.004*
FT4	*49.134 a ± 0.349*	*4.005 a ± 0.013*	*46.352 b ± 0.232*	*0.420 ab ± 0.101*	*0.090 a ± 0.015*
FT5	*49.116 a ± 0.143*	*4.004 a ± 0.029*	*46.394 b ± 0.043*	*0.405 ab ± 0.148*	*0.081 b ± 0.007*
FT6	*48.575 b ± 0.839*	*3.971 ab ± 0.006*	*47.035 a ± 0.696*	*0.341 b ± 0.136*	*0.078 b ± 0.009*
Significance	***	***	***	***	***

Values marked with identical letters statistically do not differ significantly with p<0.05
Significance: *** p<0.001, ** p<0.01, * p<0.05 and non-significant (ns)

C and H become oxidised during combustion by exothermic reactions (formation of CO_2 and water) and therefore influence the gross calorific value of the fuel. The organically bound O provides a part of the O necessary for the combustion process, additional O must be supplied by air injection [29]. Higher C and H contents lead to a higher HHV. Fuel-bound nitrogen is responsible for most NOx emissions produced by biomass combustion. Lower nitrogen content in the fuel should lead to lower NOx emissions [30]. The S content in biomass largely depends on the macromolecular composition. SOx are formed during combustion and contribute significantly to particulate matter pollution and acid rain. Also S may indirectly contribute to increased corrosion [43, 31].

The statistical analysis determined that all parameters shown in table 3 are significantly affected (P<0.01) by harvest season and fertilizer treatment. Postponing the harvest season from autumn to spring had a positive influence on the quality of biomass due to increased C content and lower O, N and S contents. A higher C content in the late harvests was determined by Baxter et al. [33] as well. Lewandowski and Heinz [21] also determined a positive influence of the spring harvest on reducing the N and S contents. Negative influence of the spring harvests can be observed in a reduced H content compared to the autumn harvests. In terms of the investigated fertilizer treatments and ultimate analyses, the fertilizer treatments FT6 and FT3 had negative influence on the combustion properties of biomass because of the lowest determined C and H contents. Also, evident is a negative effect of the fertilizer treatments FT6, FT3 and FT4 in relation to O, N and S contents, successively. The investigations by Baxter et al. [33] have also shown that the quality of biomass is lowered because of enhanced nitrogen fertilization.

The determined average values in this work are: 49.046% C, 3.985% H, 46.494% O, 0.395% N and 0.081% S. A comparison of the presented data with the literature references for *M x giganteus* biomass for C content of 43.59% and 49.20% [26, 37], H 4.80% to 6.30% [35, 37], O 35.52% to 46.80% [37, 44], N 0.1% to 2.14% [35, 41] and S 0.06% to 0.2% [38, 44], makes it evident that, apart from H, all the elements are in accordance with literature values. The established N content is lower than the literature values, which enhances the quality of biomass in terms of its use for combustion processes. Parallel to the values of the CEN/TS 14961:2005 standard (C 49.0%, H 6.4%, O 44.0%, N 0.7% and S 0.2%) some differences can be observed, as expected.

4. Conclusion

The conducted investigations allow determining the potential for production of substantial quantities of biomass from cultivation of *Miscanthus x giganteus* in the agro-ecological conditions of the mountain areas of Croatia. Although the investigated fertilizer treatments did not significantly influence the yield, it would be useful to introduce at least a minimum amount of nitrogen in order to avoid long-term soil depletion. Postponing harvests from autumn to spring season can result in a significant loss of biomass, but it also resulted in considerable reduction of moisture. The average moisture determined in the late harvest season indicates the possibility to directly store the harvested biomass, which is not the case with the average moisture values in the early harvest season. The analysed ash contents are significantly influenced by fertilisation. It is important to note that the average ash content is within the lower limits in relation to the available literature references, but also to the standard for solid fuels CEN/TS 14961:2005. The applied fertilizer treatments and harvest seasons did not have significant influence on fixed carbon and heating values, but they did influence nitrogen, carbon, hydrogen, oxygen, and sulphur contents. All these parameters show the conformity to or minor deviations from the standard CEN/TS 14961:2005.

Acknowledgment

This research was financially supported by the Croatian Science Foundation (HRZZ) within the project No.3328 „Converting waste agricultural biomass and dedicated crops into energy and added value products – bio-oil and biochar production".

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Submitted: 04.5.2017

Accepted: 15.02.2018

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