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Original Research

Influence of Soil Quality for Yielding and Biometric Features of *Miscanthus x Giganteus*

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Abstract

In recent years renewable energy sources (RES) have played a key role in current strategies to mitigate the impacts of global warming and independence on foreign energy sources. Miscanthus (*Miscanthus x giganteus*) is one of perennial grass which was identified as among best choices for low input bioenergy production. Our paper presents the relationship between the quality of soil and yielding as well as the biometrics features of miscanthus (*Miscanthus x giganteus*). Following this study Miscanthus x giganteus has best yields on soils of average quality, not too heavy. Obtained results can also conclude that achieving *Miscanthus x giganteus* yield at 2-4 kg DM $(m^2)^{-1}$ is possible in the case of plants which grow from 30 to 60 shoots for stump with a diameter of 7-9 mm and a height exceeding 2.5 m.

Keywords: miscanthus, biomass, yielding, biometric features, soil quality

Introduction

Increases in oil price and growing concerns about the national security implications of national dependence on foreign energy sources together with concerns about the threat of global climate change caused by fossil fuel use have created a momentum for developing domestic, renewable energy sources [1-3]. Also, in the European Union (EU) renewable energy sources (RES) play a key role in current strategies to mitigate the impacts of global warming. Their exploitation is important for the attainment of different goals like the reduction of greenhouse gas emissions, the partial replacement of fossil fuels, the reduction of external energy supplies, and adherence to commitments made during the International Conference of Kyoto [4-7]. One of the most important renewable energy sources is biomass, especially from agriculture. In recent years interest in biomass energy has increased considerably worldwide. There are several reasons for this: biomass is widely available and it has the potential to produce modern energy carriers such as electricity and liquid transport fuels that are clean, convenient, and easily used in the present energy supply system. Biomass energy can also be produced in a carbon-neutral way and can contribute to (local) socio-economic development [8-10].

Miscanthus (*Miscanthus x giganteus*) is one of the perennial grasses identified as among the best choices for low-input bioenergy production in the U.S. and Europe [2, 11-14]. Miscanthus is a perennial rhizomatous C_4 plant native to Southeast Asia that was imported to Europe as an ornamental plant. Plants that utilize C_4 photosynthesis in comparison to C_3 photosynthesis have higher conversion efficiencies of intercepted solar radiation into biomass,

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higher nitrogen efficiency use, and increased water usage efficiency. Since the early 1970s miscanthus has been generating increasing research interest mainly as a non-food crop for energy production and as a fibre for building materials, geotextiles, and paper. A single genotype is generally used for commercial production, including *Miscanthus x giganteus* [15, 16].

The growth and yield of miscanthus and other crops in a given habitat is controlled by the soil and weather conditions as the main environmental factors [17, 18].

Our paper presents the relationship between the quality of soil and yield as well as the biometrics features of miscanthus (*Miscanthus x giganteus*).

Materials and Methods

The one-factor experiment was established in 2007, which was treated as the year of compensatory and obtained yield was used for mulching carp, which serve to protect against the frost in winter, and the presented results are from 2008-14. The long-term experiment was located in the IUNG-PIB experimental station in Puławy (51°24′46,64"N; 21°57′56,43"E), the quantitative experimental factor was the differing soil conditions.

In the experiment we considered the following soils:

A – fen brown soil with mechanical composition of ordinary dust
B – brown soil, light sandy loam on poorly sandy loam
C – brown soil generated from loess
D – brown soil, light sandy loam on heavy loam
E – brown soil, light loam on heavy loam
F – black soil, medium loam on heavy loam

Miscanthus x giganteus crops in the number of 3 pieces were planted on microplots 1.5 m^2 and 1.5 m deep, of which the bottom was of the local bedrock (Fig. 1). Microplots were filled in 1973-74 with soils collected by levels from natural soil. Layers of soil to fill the microplots were removed and collected separately from the individual levels. During filling the plots preserved the natural arrangement of soil layers [19]. Each of the soils

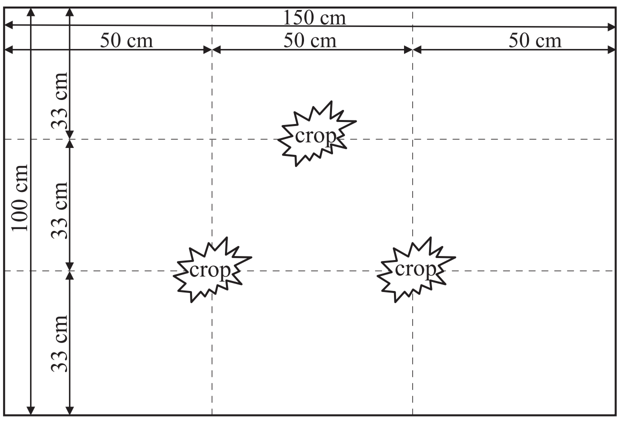

Fig. 1. Scheme of *Miscanthus x giganteus* crop arrangement on microplots.

considered in the experiment were founded in triplicate (3 x 1.5 m^2). In the years preceding the establishment of the experiment, the *Miscanthus x giganteus* object was used to research typical agricultural crops, mainly cereals.

In the first year of growth, plants were weeded by hand, and during all growing seasons we did not use chemical pesticides, which was possible because of the low risk posed by pests, diseases, and weeds. In the experiment we used the following doses of mineral fertilizers: N–120 $kg \cdot ha^{-1}$, P–30 $kg \cdot ha^{-1}$, K-80 $kg \cdot ha^{-1}$, Mg-5 $kg \cdot ha^{-1}$, and S-10 $kg \cdot ha^{-1}$. Harvest of plants and sampling for analysis was carried out after the growing season during one-day depending on the year in the months of November-December. The yield level, biometric features, and share of dry matter were described for all harvested plants individually.

The years of the experiment were characterized by varying weather conditions (Table 1).

Statistical analysis of results was performed using Statistica 9.0 software. During preparation of the database for analysis we removed the outliers and extremes data, and the level of significance adopted for analysis was $p = 0.05$. To determine the significance of differences we used the analysis of variance for a single factor, detailed by NIR test performed post hoc. Assumptions of normality and homogeneity of variance were compiled. Cluster analysis was performed using the method of k-means, and the regression equation was performed using the "backwards step" method. Variables in the cluster analysis and the regression equation were the yield of dry matter (dependent variable in the regression analysis), number of shoots for the plant, plant height, shoot diameter, share of leaves in dry matter yield, and the share of dry mass. Modeling of yield depending on the selected *Miscanthus x giganteus* biometric features was made using neural networks, which are part of a new statistic method known as "data mining."

Results and Discussion

Yield

Obtained results showed that *Miscanthus x giganteus* yields have a high range of variation both between years and soils (Fig. 2, Table 2, Table 3). In the analyzed years, the highest yields were obtained in the brown soil building forms of light sandy loam on heavy loam (D), slightly lower in the fen with brown soil mechanical composition of the ordinary dust (A) and brown soil generated from loess (C). Lowest yields were obtained in brown soil building from light loam on heavy loam (E) and brown soil building from light sandy loam on poorly sandy loam (B). However, the lowest yields were acquired in black soil building from medium loam on heavy loam (F). Also, cluster analysis performed for the soils, taking into account the obtained yield confirms this division (Table 5). The analysis showed *Miscantus x giganteus* yielding less on poor soil (B) and on soils of good quality, but too heavy (E, F). In the case of soil B, the low level of

Table 1. Weather conditions of experimental on the background of long-term average.

Month	I	II	III	IV	V	VI	VII	VIII	IX	X	XI	XII	Average for year
Temperature													
2008	0.9	2.6	3.9	9.4	13.5	18.2	18.8	18.6	12.5	9.9	5.1	1.4	9.6
2009	-2.6	-0.7	2.2	11.0	13.7	16.6	20.1	18.4	14.8	6.8	5.3	-1.1	8.7
2010	-8.4	-2.0	3.2	9.3	14.3	18.3	22.1	20.2	12.2	5.5	6.5	-4.6	8.1
2011	-0,5	-3,7	3,3	11,0	14,3	19,0	18,3	18,9	15,1	8,1	2,8	2,2	9,1
2012	-1,3	-6,5	4,9	9,9	15,6	17,7	21,4	19,0	15,0	8,3	5,7	-3,1	8,9
2013	-3,4	-0,6	-1,5	8,7	15,6	18,7	19,8	19,7	12,1	10,3	5,8	2,0	8,9
2014	-2,2	1,9	6,7	10,8	14,3	16,4	20,9	18,3	14,6	9,5	4,9	0,6	9,7
Average for years 1871-2008	-3.3	-2.3	1.6	7.8	13.5	16.8	18.5	17.4	13.3	8.0	2.8	-1.3	7.7
Rainfall in mm													
2008	43	16	52	46	95	77	92	82	69	44	21	41	679
2009	24	38	67	1	71	119	67	73	27	88	47	55	676
2010	29	35	25	17	107	58	54	89	113	14	66	32	638
2011	25	13	12	24	60	51	210	41	6	21	0	29	492
2012	31	16	20	32	35	69	114	84	19	72	28	21	541
2013	40	29	34	37	85	82	31	7	48	5	45	11	454
2014	39	19	31	58	172	95	66	117	14	22	21	36	690
Average for years 1871-2008	31	30	30	40	57	70	84	75	51	43	39	37	587

obtained yields can be explained by low ability for water retention, which is one of the most important yield factors. Soils E and F are characterized by a large share of floating fraction, which can also negatively influence the soil air-water relationship, especially in periods of high intensity of rainfall. Moreover, these soils during the spring, due to the "albedo" effect, warm up slowly, which delays the start of vegetation. In light of the obtained results it should be noted that the most suitable for *Miscanthus x giganteus* cultivation is soil of better quality but not too heavy.

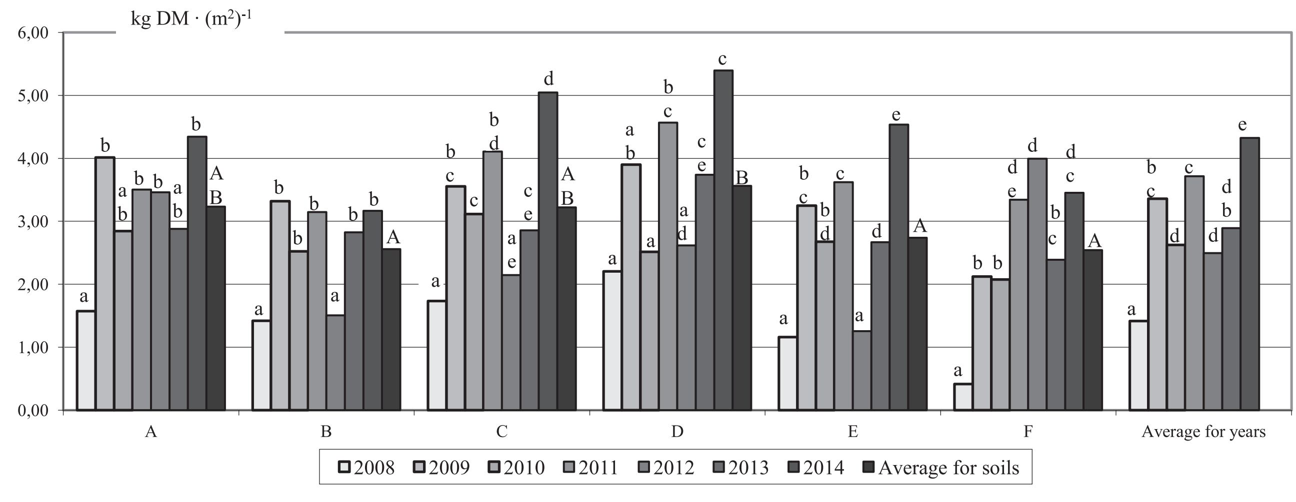

Fig. 2. Variation of dry matter yield (kg DM $(m^2)^{-1}$) of Miscanthus x giganteus depending on soil and year.
* Explanations: data marked with the same letters do not differ significantly at α = 0.05; the significance of differences was calculated separately for each soil and for the mean values (for soil and year).

Table 2. Yield and biometric features of *Miscanthus x giganteus* in different soils (average for the years 2008-14).

Types of soil	Yield (kg DM · $(m^2)^{-1}$)	Number of shoots for plant	Plant height (m)	Shoot diameter (mm)	The share of leaves in d.m. yield (%)
A	3.2 ab*	44 bc	2.3 abc	8.0 ac	33 ab
B	2.6 a	38 ab	2.2 abc	8.7 b	34 ab
C	3.2 ab	35 a	2.4 bc	8.7 b	35 ab
D	3.6 b	48 c	2.5 c	8.3 ab	31 a
E	2.7 a	38 ab	2.2 ab	8.1 a	35 b
F	2.5 b	33 a	2.0 a	7.5 c	39 c
Average	3.0	39	2.3	8.2	35

*Explanations: data marked with the same letters do not differ significantly at α = 0,05

Table 3. Yield and biometric features of *Miskanthus x giganteus* in different years (average for soils).

Year	Yield (kg DM · $(m^2)^{-1}$)	Number of shoots for plant	Plant height (m)	Shoot diameter (mm)	The share of leaves in d.m. yield (%)
2008	1.4 a*	29 a	2.1 a	7.0 a	37 a
2009	3.4 bc	44 b	2.3 b	8.0 b	29 b
2010	2.6 d	46 b	2.1 ab	8.4 bc	33 ab
2011	3.7 ce	45 b	2.7 c	8.5 c	33 ab
2012	2.6 d	26 a	1.5 d	8.1 bc	49 c
2013	2.9 bd	40 b	2.7 c	9.2 d	30 b
2014	4.4 e	45 b	2.6 c	8.4 bc	32 b
Average	3.0	39	2.3	8.2	35

*Explanations: data marked with the same letters do not differ significantly at α = 0.05

Statistical analysis of the significance of differences also indicates that the obtained yields differ significantly depending on the soil (Table 2). The observed trends for the average of the seven years (2008-14) were also reflected in the observations for each year (Fig. 2). In addition, they conclude that *Miscathus x giganteus* yields differ between years, which is largely conditioned by weather conditions (Table 1). The lowest yields of *Miscanthus x giganteus* were obtained in 2008, which was the second year of the experiment and which may need to fail in order to achieve the full potential of yielding plants, despite good weather conditions. The highest yields were obtained in 2014, when the course of the weather was favorable. The number and distribution of rainfall and temperature conditions in the following months have allowed the disclosure of yielding potential, which has *Miscantus x giganteus* as a crop of C_4 photosynthesis type.

Reducing crop yields in 2012 and 2013 can be explained by a significantly more frosty February 2012, when the average monthly temperature was almost three times lower than the average for 1871-2008. This is probably what caused the damage to root stocks, which resulted in the reduction of yields in those years.

In experiments conducted in Eastern Europe dry matter (DM) yield of *Miscanthus x giganteus* ranged from about 10 to 14 t DM ha^{-1} [20]. On the other hand, experiment yields in sandy soil were 23.4-29.9 t DM ha^{-1} [21]. According to the simulations for Eastern Europe, dry matter yield of *Miscanthus* on very good soils can fluctuate from 17.7 to 21.8 t DM ha^{-1} [22], while on good soils yields of dry matter could range from 12.9 to 17.1 t DM ha^{-1}. Diverse production potential of *Miscanthus x giganteus* is also confirmed by the results of experiments conducted in Denmark 5-15 t DM ha^{-1}, Germany 4.0-33.5 t DM ha^{-1}, Great Britain 10-15 t DM ha^{-1}, Switzerland 13-19 t DM ha^{-1}, Austria 22 t DM ha^{-1}, and Spain 14-34 t DM ha^{-1}. The highest yields of *Miscanthus x giganteus* were achieved on irrigated plantations, which were 30-32 t DM ha^{-1} in Italy, 44 t DM ha^{-1} in Greece, 28 t DM ha^{-1} in Turkey, and 49 t DM ha^{-1} in France [13, 14, 23]. In the United States the yield fluctuated between one 9.3-16.0 t DM ha^{-1} [24]. Research carried out in Germany showed lower yields on heavy soils [13]. In our experiment the yield ranged from about 10 to 14 t DM ha^{-1}, depending on the soil, and 14 to 44 t DM ha^{-1} depending on the year. Average yield was 30 t DM ha^{-1}. Nevertheless, it should

Table 4. The correlation coefficient |r| between the yield of *Miscanthus x giganteus* (kg DM $(m^2)^{-1}$) and selected biometric features in different soils (average of the years 2008-14).

Types of soil	The share of dry mass (%)	Number of shoots for plant	Plant height (m)	Shoot diameter (mm)	The share of leaves in d.m. yield (%)
A	0.68*	0.51*	0.33	0.48*	-0.45*
B	0.44	0.52*	0.68*	0.54*	-0.31
C	0.48*	0.69*	0.60*	0.33	-0.43
D	0.64*	0.62*	0.15	0.41	0.01
E	0.66*	0.62*	0.81*	0.39	-0.44*
F	0.63*	0.59*	0.47*	0.59*	-0.37
For all soils	0.55*	0.61*	0.51*	0.41*	-0.39*

* correlations significant for α <0.05

be noted that results of the microplots experiment should not be directly transferred to production conditions.

Biometric Features

Substantial degree of variability depending on soil and year also characterized the biometric features of *Miscanthus x giganteus* (Tables 2, 3). The most preferred values of biometric features were characterized plants growing on brown soil building forms a light sandy loam on heavy loam (D) and brown fen soil (A). They had the largest number of shoots from plants and were one of the highest, but their diameter was lower than the average (Table 2). Furthermore, in the statistical analysis these soils were placed in the same cluster. Extremely adverse biometric parameters were characterized by crops growing on black soil (F) that had the lowest number of shoots from plant, with low height and diameter. In addition, crops growing in this soil were characterized by the highest share of leaves in dry mass yield, whose condition the low yields obtained.

Different features were characterized by the crops growing on brown soil building from light sandy loam on poorly sandy loam (B), brown soil generated from loess (C), and brown soil building forms a light loam on heavy loam (E) (Table 2). They had an average of 35 to 37 shoots from the plant, and height and diameter were similar to the average for all observations. It is important that in the case of these plants the share of leaves in the dry mass yield was equal to or lower than the average.

The lowest values for biometric features of *Miscanthus x giganteus* were obtained in 2008, which was the second year of the experiment. This confirms the conclusion made in the analysis of obtained DM yields, that crops in the second year of vegetation do not reach their full yield potential, and their stumps are not sufficiently developed. This process can be considered as completed in the third year of vegetation, which is confirmed by research results obtained between 2009 and 2010.

Obtained results concerning the diversification of biometric features are also confirmed by other authors [25].

Relations between Yield and Biometric Features

Correlation analysis shows that the DM yield of *Miscanthus x giganteus* is dependent on other biometric features in different soils (Table 4). But in the vast majority have the strongest relationship between DM yield and the share of dry mass, number of shoots from the plant, and their height.

This is confirmed also by being generated on the basis of these results in a mathematical model of *Miscanthus x giganteus* yield, which is based on the multiple regression equation. In addition to the above-mentioned features, this model also takes into account the height of plant shoots:

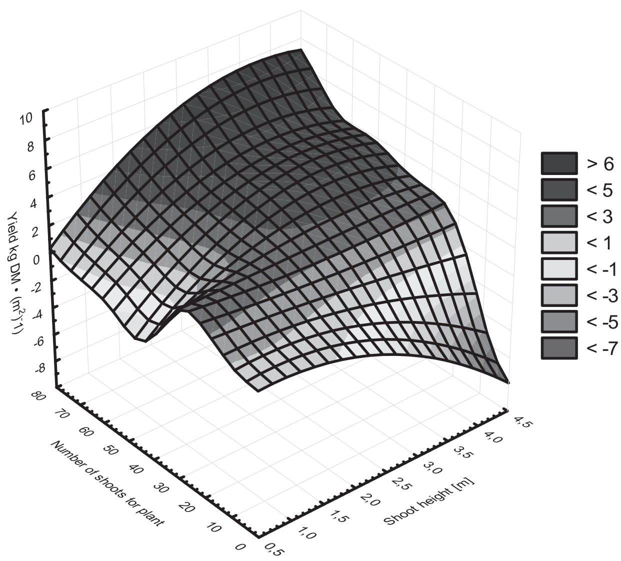

Fig. 3. The yielding model for *Miscanthus x giganteus* determined by number of shoots and their height.

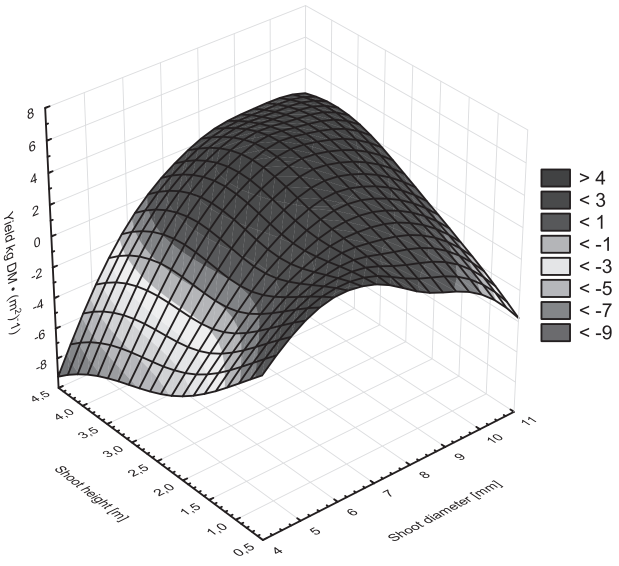

Fig. 4. The yielding model for *Miscanthus x giganteus* determined by shoot diameter and height.

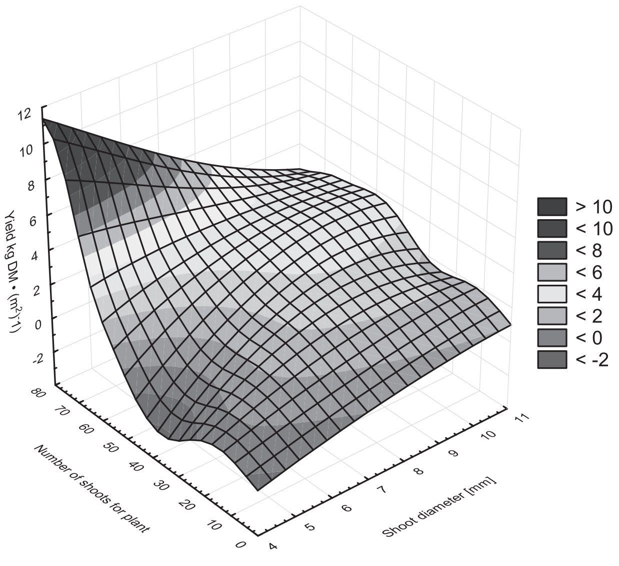

Fig. 5. The yielding model for *Miscanthus x giganteus* determined by number of stems and their diameter.

$$y = -4.19 + 6.92 \cdot X_1 + 0.03 \cdot X_2 + 0.64 \cdot X_3$$
$$R^2 = 0.62$$

…where:

y – yield kg DM $(m^2)^{-1}$,
X_1 – the share of dry mass [%],
X_2 – number of shoots for plant,
X_3 – plant height (m).

To further explain the relationship between the yield of *Miscanthus x giganteus* and its biometric features we used modeling with neural networks, which are part of the aforementioned data mining (Figs 3-5). Analysis of the results shows that the achievement of *Miscanthus x giganteus* yield in level 2-4 kg DM $(m^2)^{-1}$, regardless of the soil, is possible when plants have the following biometric features:

- Number of shoots per plant = <30-60<
- Shoot diameter (mm) = <7-9<
- Plant height (m) = >2.5

These results, in addition to the nature of cognition, may serve as a benchmark for further work on the selection and breeding of new genotypes of miscanthus.

Cluster analysis showed that the division into cluster by the criteria of yield, biometric features, and all the parameters together converge (Table 5). This allows for the conclusion that the level of obtained yield is largely determined by biometric features.

Table 5. The results of cluster analysis (k-means method) for the soils, taking into account different criteria for allocation.

Criteria for allocation	Data cluster I	Data cluster II
Yield and biometric features	A, D*	B, C, E, F
Yield	B, E, F	A, C, D
Biometric features	A, D	B, C, E, F

* type of soil

Jeżowski [26], in research on the various clones of *Miscanthus,* showed that the yield of dry matter was significantly positively correlated with the diameter of the rootstocks and indirectly with a number of shoots, a correlation coefficient that increased with plant age of about 0.8 to 0.9. Angelini et al. [27], in a more than 10-year study, also described a significant correlation between the dry matter yield of *Miscanthus x giganteus* and the number of shoots from the rootstocks, for which the value of the correlation coefficient was 0.75.

Conclusions

Following this study it was found that to obtain high yields *Miscanthus x giganteus* don't need cultivation on the best agricultural soils. This plant has best yields on soils of average quality, not too heavy. This is particularly important from the standpoint of competition for land resources between production for food and energy. The obtained results show that the introduction of this plant to cultivation should not restrict the area of land for food production to the best quality only.

Analysis of the obtained results can also conclude that *Miscanthus x giganteus* crops achieve full potential yield, regardless of the soil, from the third year of vegetation.

Achieving yield at 2-4 kg DM $(m^2)^{-1}$, it is possible in the case of plants that grow from 30 to 60 shoots for stump with a diameter of 7-9 mm and a height exceeding 2.5 m.

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