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FOLLOW-UP EFFECT OF HILLING ON GROWTH AND YIELDING OF MISCANTHUS (*Miscanthus x giganteus* Greef et Deu.)

NASTĘPCZY WPŁYW OBREDLANIA NA ROZWÓJ I PLONOWANIE MISKANTA OLBRZYMIEGO (*Miscanthus x giganteus* Greef et Deu.)

Abstract: In 2005–2007 in Pawlowice near Wroclaw, Poland, field experiments were conducted on the follow-up effect of hilling of Miscanthus in autumn after seeding. The split-plot experiment was set for the following three variable factors: I. Harvest date: a – autumn harvest after the vegetation period ends (11.07.2005, 14.12.2006; b – winter harvest before the vegetation starts (10.03.2006, 09.03.2007); II. Autumn treatment of rhizomes after seeding: a – with hilling; b – without hilling; III. N fertilization: 100, 150 and 200 kg N $\cdot$ ha^{-1}.

In the first years after the experiment had been set up, the morphological features, dry matter yield, water and ash contents were related to the age of the plantation.

Among the investigated factors, harvest dates had the most significant influence on yielding. Winter harvest resulted in a lower by 18.4 % dry matter yield and a decrease in water content in green matter by 23.8 % and in ash content by 43 %. However, it increased energy value in green matter by 52 %. In the second and the third year of the cultivation, out of 1 ha field of Miscanthus, it is possible to obtain biomass yield with a mean energy value of 294 GJ, which corresponds to 7.03 toe.

It is possible to obtain high dry matter yields of Miscanthus with autumn hilling and applying 150 kg N $\cdot$ ha^{-1}.

Keywords: Miscanthus, harvest date, hilling, N fertilization

Introduction

Energy development strategies of the developed countries focus more and more on obtaining renewable energy sources. In Poland, according to “The strategy for development of renewable energy” passed by the Polish Parliament, the renewable energy

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sources should make for 7.5 % of all the energy in 2010 and reach 14 % in 2020. In order to achieve these levels, it will be necessary to produce biomass on energy plantations located on arable lands additionally to firewood and agricultural by-products.

Potentially useful species for energy production in Polish environment include willow (*Salix* sp.), Miscanthus (*Miscanthus x giganteus* Greef et Deu), Virginia mallow (*Sida hermaphrodita* Rusby) and Jerusalem artichoke (*Helianthus tuberosus* L.).

Miscanthus x giganteus is a hybrid of a tetraploid *M. sinenss* and a diploid *M. sacchariflorus*. It was imported from Japan to Denmark in 1930 by Aksel Olsen and it gave start to cultivars grown at present in Europe. Since 1983 field experiments have been conducted with this species in the Northern Europe. The plant has been proved to be an effective energy crop and produce over 20 Mg d.m. per $ha^{-1} \cdot year^{-1}$ [1]. Miscanthus can be harvested twice: in autumn from October to November (and with favourable conditions in the first decade of December) when the vegetation period ends or in winter from February to March before the vegetation starts. Harvest dates affect the yield and the quality of the combusted biomass [1, 2].

Dry matter content in the harvested biomass in autumn is between 35–45 %, and in the winter harvest it is from 60 to 70 % [3]. The lower dry matter yield in winter is caused by some leaves falling down. The reduced yield is compensated by the increase in cellulose content which is low in leaves. The other reason for a lower yield of the aerial parts of the plants is the fact that in autumn the plants transport nutrients to the rhizomes which increase in mass and change in their chemical content. Since these are the rhizomes that determine winter survival, the plants gather in them osmotic active compounds which reduce the plants' susceptibility to low temperatures [4].

The yield of biomass in the autumn harvest is higher than in the spring harvest, the differences can be from 14 to 30 % [5]. The disadvantage of the autumn harvest is not only high moisture of the obtained biomass but also higher removal (accumulation and extraction) of the nutrients from the fields [6].

During the winter period the plants shed leaves, which makes potassium drain to soil [7]. As a consequence, sodium and potassium contents are reduced in Miscanthus straw and later in ashes [5]. Biomass of the highest quality for energy can be obtained in a winter–spring harvest. A later harvest results in biomass that is on average 30 % drier than in autumn. Winter harvest reduces also biomass chlorine content. The presence of chlorine in the biomass can cause emission of hydrogen chloride and dioxins in combustion [5, 8].

A drawback in growing Miscanthus is its little tolerance of low temperature in the first year after seeding. During the first winter after starting the plantation, rhizomes which are planted too shallow and those which are not fully formed are destroyed by frost and high moisture. Literature does not provide information on similar problems with winter survival of Miscanthus in the second and the following years of the cultivation [1]. After the second year of growth, Miscanthus survives well temperature drops below – 20 ^{o}C, even without a snow cover [4].

In the Danish and Irish experiments the majority of Miscanthus plants grown through micropropagation (*in vitro*) did not survive the first winter after seeding, while the plants obtained from rhizomes managed well through the winter period. Numerous experiments indicate that the method of breeding of Miscanthus can affect its ability to survive in winter conditions [9].

Miscanthus needs relatively little fertilisation thanks to use and transport of nutrients in the plants from rhizomes and accumulation of large amounts of nutrients in rhizomes by the end of the vegetation period. It has been determined that a dose of 60 kg N · ha^{-1} is sufficient for an appropriate development of rhizomes. The leaves usually fall down and stay on the fields so nutrients absorption is relevant only for rhizomes. Miscanthus is capable to make a good use of nitrogen because it translocates it from rhizomes to shoots in spring and is again able to cumulate it in them at the end of the vegetation period [1, 10].

By the end of the vegetation period, 21–46 % of N, 36–50 % of P, 14–30 % of K and 27 % Mg accumulated in the aerial parts of the plants is translocated into the rhizomes [11].

The aim of the study was to determine the effect of hilling in *Miscanthus giganteus* in autumn after its seeding on growth, yielding and chemical content of the yield as well as on the energy value of this crop.

Materials and methods

In 2005–2007 in Pawlowice near Wroclaw, Poland, field experiments were conducted on the follow-up effect of autumn hilling of Miscanthus after seeding. The split-plot experiment was set for three following variable factors: I. Harvest dates: a – autumn harvest after the vegetation period ended – 11.07.2005 and 14.12.2006; II. Autumn treatment of rhizomes after seeding: a – with hilling, b – without hilling; III. N Fertilization: 100, 150 and 200 kg per ha^{-1}.

The experiments were set on a very light river alluvial soil with loose sand and sandy gravel. In 2004–2006 soil pH was acid to very acid with the following concentrations of microelements: P – very high, K – medium to high, Mg – very low.

Important features of Miscanthus growing in the year of seeding:

– harvest date: 07.05.2004,

– depth of rhizome seeding: 5–10 cm,

– row density: 70 cm,

– plant density in a row: 45 cm,

– number of rhizomes planted in a plot: 16 pieces,

– fertilization [kg · ha^{-1}]: N – 60,

– fertilization in all the years of the experiment [kg · ha^{-1}]: P_2O_5 – 60 (26 – P); K_2O – 100 (83 – K),

– size of a plot: 5.04 m^2,

– harvest date: 03.12.2004.

In 2004–2006 weed control was carried out – Roundup 360 SL at the dose of 4 dm^3 · ha^{-1} was applied focally. The plots were sporadically infested with White goosefoot (*Chenopodium album* L., Shepherd's purse (*Capsella bursa-pastoris* L.) and Common barnyard grass (*Echinochloa crus-galli* L.).

From the vegetation start in 2005 and 2006 observations and measurements were conducted on the growth and height of plants as well as diseases and insect infestations were monitored. After the vegetation period had ended, the shoots were numbered on every plot, the results were calculated per 1 m^2. From 10 shoots from every plot the following features were measures: plants' height, flag-leaf length, and stem diameter (on the height of 10 cm above the soil surface).

Autumn and winter harvests were done manually with use of a chainsaw for hedges and a circular saw. After harvest, Miscanthus green matter yield was measured from every plot.

Chemical analyses were conducted in the laboratory of the Department of Crop Production at the Wroclaw University of Environmental and Life Sciences. The following parameters were determined:

– dry matter – through drying of minced plant material for 4 hours at 105 ^oC,
– crude ash – by combusting plant material in 600 ^oC in an electric oven,
– total nitrogen content with Kjeldahl's method,
– mineral compounds contents: K, Ca (flame photometry), P, Mg (coulometry).

Based on the results obtained from the chemical analyses, water percentage content in the plant material and dry matter yield were calculated. Additionally, the contents of crude ash and of the investigated macronutrients were determined. Energy value of biomass was measured in the Institute of Agricultural Engineering, Wroclaw University of Environmental and Life Sciences. The analysis was conducted with use of a semi-automatic calorimeter Precyzja-BIT KL-10 which is designed to measure heat in solid fuels combustion such as turf, lignite, coal, coal and lignite pellets, coke and non-explosive, combustive organic substances. The method of measure is compatible with the requirements of the official Polish Standard for measuring heat of combustion and calculating of calorific value of solid fuels from 1981 [12]. On the basis of the research the relationship between biomass energy value and moisture was determined (Figs. 1 and 2).

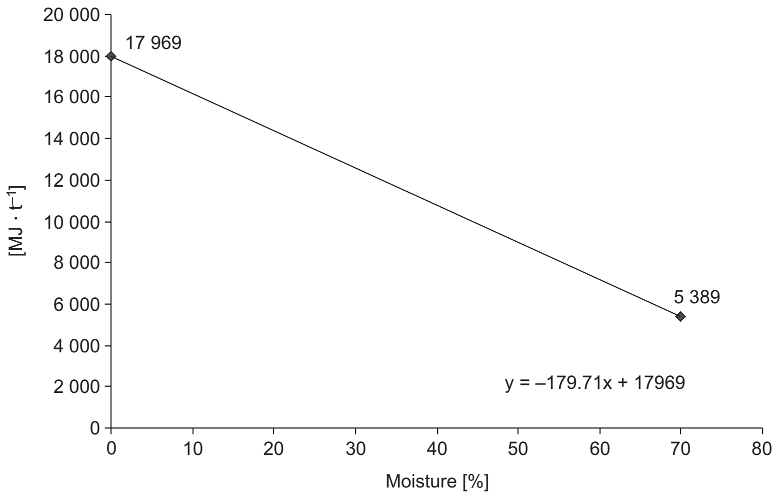

Fig. 1. The relationship between energy value and biomass moisture content (autumn harvest)

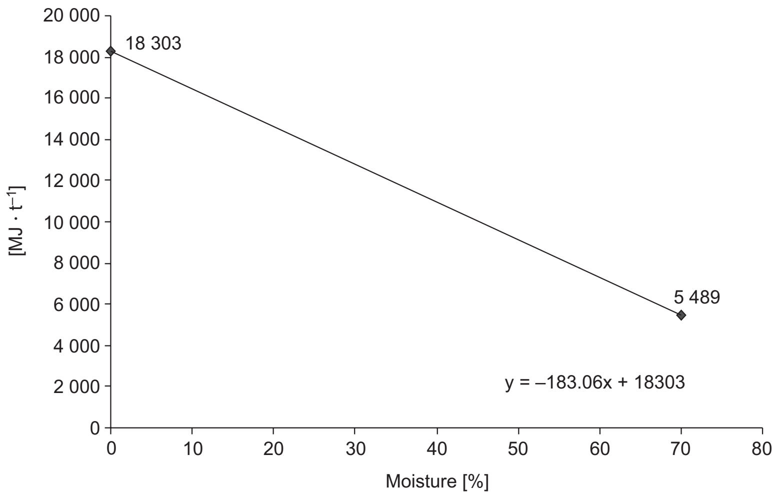

Fig. 2. The relationship between energy value and biomass moisture content (winter harvest)

In 2004–2006 the Department of Plant Protection, Wroclaw University of Environmental and Life Sciences, monitored diseases and insect infestation in Miscanthus. Low numbers of phytophagous organisms were observed in all the years of the experiment. A higher infestation was noted by aphids: the bird cherry-oat aphid *Rhopalosiphum padi* L. and rose-grain aphid *Metopolophium dirhodum* Walk, and thrips: *Frankliniella tenuicornis* Uzel., and *Haplothrips aculeatus* Fabricius.

In 2005–2006 on Miscanthus leaves was sparsely recorded one fungi species: *Alternaria alternata* (Fr.) Keissl.

Results and discussion

Before the autumn harvest 03.12.2004 it was calculated that for 1 m^2, Miscanthus produced 14 shoots with a mean length of 112 cm and the stem diameter of 6.7 mm, and a 66 cm long flag-leaf. Green matter yield was 3.8 $t \cdot ha^{-1}$ with 64 % water content, and dry matter yield was 1.37 $t \cdot ha^{-1}$.

In 2005 and 2006 the vegetation started on April 20, and ended on November 10, 20, respectively. In these two years of the experiment, the mean monthly temperatures from April to October, except for August, were higher than multiyear means. The sum of precipitations was similar to the mean values of a multiyear. It needs to be underlined that the pattern of precipitation was unfavourable (Table 1).

So far the research has indicated that Miscanthus starts growing in spring when the soil temperature reaches 10–12 ^{o}C. Air temperature of 5–10 ^{o}C is a threshold from which leaves start growing [1, 13].

Despite a low transpiration ration of 300 dm^3 of water per kg d.m., Miscanthus has high water requirements because of a high production of biomass [2]. According to Beale et al [14] Miscanthus plants use from 80 to 330 g of water per 1 g of dry matter.

Table 1

Mean monthly air temperature [°C] and precipitation sum [mm] in 2004–2007

Year \ Month	I	II	III	IV	V	VI	VII	VIII	IX	X	XI	XII
Temperature												
2004	–2.9	5.9	4.8	9.8	13.2	16.7	18.6	19.6	14.4	10.5	4.9	2.0
2005	2.1	–1.5	1.7	9.8	14.3	16.9	19.7	17.7	15.2	9.9	3.3	0.8
2006	–6.0	–1.9	0.6	9.9	14.3	18.5	23.4	17.3	16.1	11.0	6.7	4.3
2007	4.9	2.7	6.5	10.9	16.2	19.2	19.2	18.9	12.9	8.3	2.8	1.0
Multiyear means for 1970–2000	–1.0	0.1	3.7	8.1	13.9	16.7	18.5	17.7	13.3	8.8	3.6	0.5
Precipitation												
2004	36.6	32.8	54.9	21.5	39.1	43.9	66.1	33.0	25.8	51.4	77.7	15.8
2005	41.7	39.1	9.3	25.5	121.0	36.3	109.3	51.0	20.2	5.4	26.3	95.9
2006	23.5	39.3	22.1	51.1	15.9	56.6	12.0	166.7	17.6	57.9	68.3	35.2
2007	52.0	59.0	48.8	2.7	50.3	69.2	92.4	52.8	46.1	21.7	53.9	21.0
Multiyear sums for 1970–2000	30.5	24.8	33.2	31.9	49.9	64.9	75.4	63.5	44.7	35.5	33.9	36.3

There was no correlation noted between the investigated factors and the growth of Miscanthus during the vegetation period. Therefore, mean measures from the particular years of the experiment were used to describe the plant growth as a function of time. From the vegetation start to mid-June, Miscanthus reached 80 % of its full height (Figs. 3 and 4). In a two-year experiment conducted in Greece, where the plants were watered every 6–7 days, Miscanthus shoots were growing on average 3 cm per 24 hours from May to the end of June, reaching the height of 170 cm. In the next months the shoots

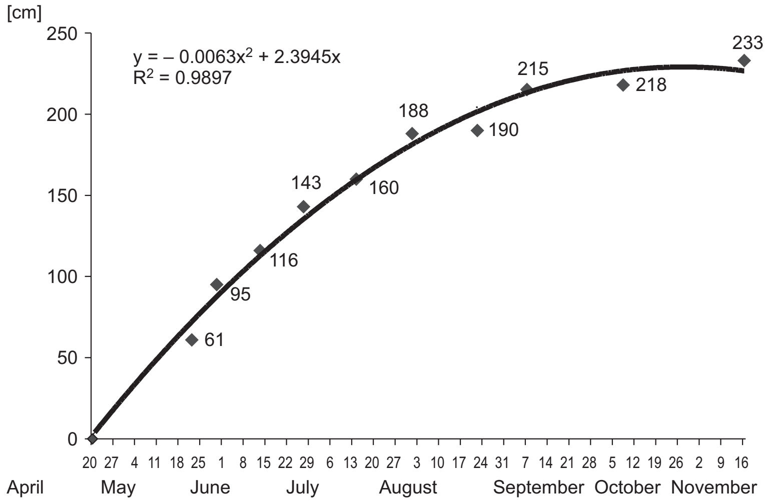

Fig. 3. Growth of Giant Miscanthus (*Miscanthus x giganteus* Greef et Deu.) in 2005

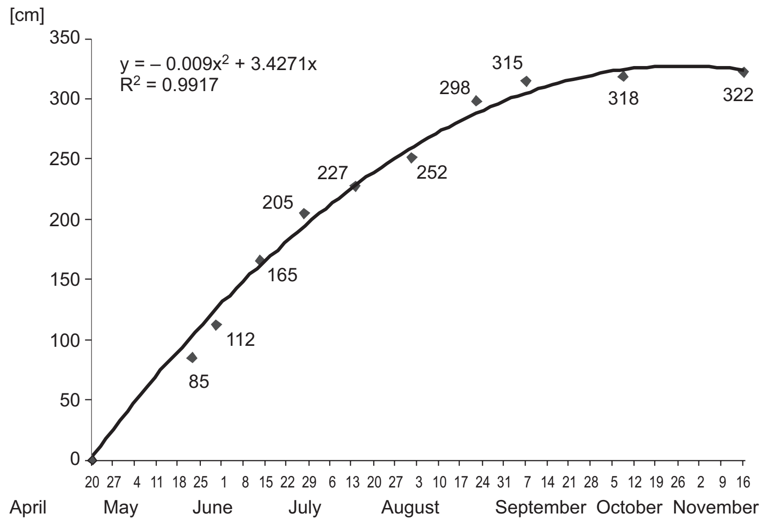

Fig. 4. Growth of Giant Miscanthus (*Miscanthus x giganteus* Greef et Deu.) in 2006

grew from 0.5 to 1 cm per 24 h until they reached their maximal height in August. The full length of shoots was 233 cm in the first year after seeding and 323 cm in the second year [15].

The number of shoots before harvest and the morphological features of the plants were affected mostly by N fertilization, and later to a lesser and lesser degree by hilling and harvest dates (Table 2). Autumn hilling, compared to the control, considerably increased the height of plants, the length of the flag with leaf and the stem diameter. Because of dynamic growth of Miscanthus in the second and the third year after seeding, significant differences were recorded in the number of shoots per 1 m^2, the height of plants and the length of the flag-leaf between the years of the experiment.

Table 2

Number of shoots before harvest and morphological features of Miscanthus plants (*Miscanthus x giganteus* Greef et Deu.) in 2005–2006 (means for factors 2005–2006)

Harvest date	Type of growing	N rate [kg · ha^{-1}]	Number of shoots per 1 m^2	Plant height [cm]	Flag-leaf length [cm]	Stem diameter [mm]
Autumn			39	280	46.0	9.4
Winter			40	276	46.1	9.2
LSD (α = 0.05)			NSD	NSD	NSD	0.15
	with hilling		39	288	48.2	9.5
	without hilling		40	268	43.8	9.2
LSD (α = 0.05)			NSD	6	1.0	0.25
		100	37	266	44.5	9.1
		150	41	278	46.3	9.2
		200	41	290	47.3	9.6
LSD (α = 0.05)			2	6	1.6	0.19
Years		2005	25	233	55.1	9.3
		2006	54	322	37.0	9.3
LSD (α = 0.05)			4	4	1.3	NSD

NSD – no significant difference.

In the environment of Greece, the number of shoots per 1 m^2 from May to June was: 80–85 in the first year and 90–100 in the second year. Later it gradually decreased down to 75 shoots [15]. Jezowski et al [16] stated that Miscanthus yielding depends mostly on the growth stage of the plants, their branching and the diameter of the clump.

Miscanthus green and dry matter yields as well as energy yield and water content depend mostly on the harvest date. In the autumn harvest, the dry matter yield was higher by 23 % than in the winter harvest, but it also contained 23.8 % more water and its energy value per 1 kg of green matter was 34 % lower (Table 3). Hilling increased, among other things, dry matter yield by 75 %. The highest dry matter yields were obtained with 150 kg N · ha^{-1} fertilization.

Table 3

Green and dry matter yields, water content in green matter and energy value in Miscanthus (*Miscanthus x giganteus* Greef et Deu.) in 2005–2006 (means for factors in 2005–2006)

Harvest date	Type of growing	N rate [kg · ha^{-1}]	Green matter				Dry matter		
			yield [t · ha^{-1}]	water content [%]	energy value		yield [t · ha^{-1}]	energy value	
					[GJ · t^{-1}]	[GJ · ha^{-1}]		[GJ · ha^{-1}]	[toe · ha^{-1}]
Autumn			36.9	52.3	8.58	322	17.9	322	7.68
Winter			20.6	28.5	13.09	267	14.6	267	6.38
LSD (α = 0.05)			1.4	3.1	0.57	12	0.6	12	0.27
	with hilling		29.6	40.3	10.85	305	16.8	305	7.28
	without hilling		27.8	40.4	10.82	284	15.7	284	6.78
LSD (α = 0.05)			1.2	NSD	NSD	6	0.3	6	0.15
		100	27.2	40.7	10.77	279	15.4	279	6.66
		150	29.8	41.0	10.72	305	16.8	305	7.28
		200	29.2	39.4	11.02	300	16.5	300	7.16
LSD (α = 0.05)			1.3	NSD	NSD	14	0.8	14	0.33
Years		2005	20.7	42.6	10.43	199	11.0	199	4.75
		2006	36.8	38.1	11.24	390	21.5	390	9.31
LSD (α = 0.05)			1.4	3.1	0.57	12	0.6	12	0.27

NSD – no significant difference; dry matter calorie content in 1 t of Miscanthus: autumn harvest: 17.97 GJ; winter harvest: 18.30 GJ.

Many researchers [1, 2] claim that the quality of Miscanthus biomass for combustion and the yield are determined by the harvest date. The autumn harvest yield is higher than from the spring harvest, and the losses can range from 14 to 30 % [5]. The disadvantage of the autumn harvest is not only high moisture of the obtained biomass but also higher removal (accumulation) of the nutrients from the fields [6].

According to several researchers [1, 11] N fertilization at the rate of 50–70 $kg \cdot ha^{-1} \cdot year^{-1}$ is sufficient for Miscanthus's requirements when applied in spring at the beginning of shooting. Kaack and Schwarz [17] argue that high doses of N in growing *M. x giganteus* (over 75 kg of $N \cdot ha^{-1}$) can result in an increased lodging, on fields not sheltered from wind.

The harvest dates and the age of the plantation affected chemical content of Miscanthus biomass. Harvested in winter, Miscanthus contained 40 % less ash and 25–48 % less of all the investigated macronutrients than the crops harvested in autumn. This was due to a translocation of nutrients from shoots to rhizomes and their draining with rain during the winter period.

Table 4

Chemical composition of Miscanthus biomass [%] (*Miscanthus x giganteus* Greef et Deu.)
(means for factors in 2005–2006)

Harvest date	Type of treatment	N rate [$kg \cdot ha^{-1}$]	Crude ash	N	P	K	Ca	Mg
Autumn			3.16	0.31	0.06	0.43	0.23	0.08
Winter			1.79	0.23	0.04	0.22	0.12	0.06
LSD (α = 0.05)			0.14	0.02	0.01	0.02	0.03	0.01
	with hilling		2.49	0.27	0.05	0.32	0.18	0.07
	without hilling		2.46	0.27	0.05	0.33	0.17	0.07
LSD (α = 0.05)			NSD	NSD	NSD	NSD	NSD	NSD
		100	2.55	0.27	0.05	0.33	0.17	0.07
		150	2.41	0.27	0.05	0.32	0.18	0.07
		200	2.46	0.27	0.05	0.32	0.18	0.07
LSD (α = 0.05)			NSD	NSD	NSD	NSD	NSD	NSD
Years		2005	3.04	0.28	0.07	0.48	0.26	0.07
		2006	1.91	0.26	0.03	0.17	0.09	0.07
LSD (α = 0.05)			0.14	NSD	0.01	0.02	0.03	NSD

NSD – no significant difference.

According to the studies conducted by Lewandowski et al [18] a delayed harvest decreased on average ash content in Miscanthus by 28 % in Portugal and the Great Britain, by 42 % in Germany, and by 50 % in Sweden and 54 % in Denmark.

All the agrotechnical factors and the age of the stand affected the accumulation of crude ash and the investigated macronutrients in Miscanthus biomass (Table 5). The winter harvest lowered crude ash content by 50 % and nutrient content by 40–58 % compared with the autumn harvest.

Table 5

Accumulation of crude ash and macrocomponents in Miscanthus biomass [kg · ha^{-1}] (*Miscanthus x giganteus* Greef et Deu.)

Harvest date	Type of growing	N rate [kg · ha^{-1}]	Crude ash	N	P	K	Ca	Mg
Autumn	with hilling	100	513	53.1	7.87	57.3	29.8	14.2
		150	566	57.6	9.86	62.7	35.1	16.7
		200	541	59.9	9.07	65.9	38.6	13.9
	without hilling	100	496	50.5	7.92	60.6	29.9	13.1
		150	458	53.7	8.83	64.2	37.1	13.4
		200	538	54.0	8.89	67.1	34.5	13.4
Winter	with hilling	100	248	30.7	4.70	29.3	13.2	9.3
		150	264	35.2	4.22	29.6	16.0	7.5
		200	240	32.2	3.92	27.1	14.5	10.1
	without hilling	100	238	31.6	5.06	28.3	14.7	9.0
		150	239	33.9	4.80	27.9	13.7	8.3
		200	242	32.8	4.49	28.3	14.6	8.2
LSD (α = 0.05)			35	NSD	0.5	NSD	1.7	1.5

Table 5 contd.

Harvest date	Type of growing	N rate [kg · ha^{-1}]	Crude ash	N	P	K	Ca	Mg
Means for factors								
Autumn			519	54.8	8.74	63.0	34.2	14.1
Winter			245	32.7	4.53	28.4	14.5	8.7
LSD (α = 0.05)			12	1.6	0.17	1.1	0.6	0.6
	with hilling		395	44.8	6.60	45.3	24.6	11.9
	without hilling		369	42.8	6.66	46.1	24.1	10.9
LSD (α = 0.05)			6	0.8	NSD	0.7	0.4	NSD
		100	374	41.5	6.38	43.9	21.9	11.4
		150	382	45.1	6.93	46.1	25.5	11.5
		200	390	44.7	6.59	47.1	25.6	11.4
LSD (α = 0.05)			NSD	2.1	0.25	1.6	0.9	0.8
Years		2005	340	30.8	7.58	53.6	29.5	7.8
		2006	423	56.8	5.69	37.7	19.1	15.1
LSD (α = 0.05)			12	1.6	0.17	1.1	0.6	NSD

NSD – no significant difference.

In the experiments carried out by Clifton-Brown et al [19] on a 16-year old Miscanthus stand, it was recorded that the contamination of nutrients in the autumn harvest was as follows: 145 ± 9.4 kg N · ha^{-1}, 23 ± 1.1 kg P · ha^{-1} and 111 ± 9.9 kg K · ha^{-1}. When the harvest date was moved to March, the concentration of nutrients was lowered: 51 ± 6.1 kg N · ha^{-1}, 8.3 ± 0,7 kg P · ha^{-1} and 42 ± 7.9 kg K · ha^{-1}. The mean yields for 15 years were as follows: 13.4 ± 1.1 kg d.m. · ha^{-1} $year^{-1}$ for autumn harvests and 9.0 ± 0.7 kg d.m. · ha^{-1} $year^{-1}$ in winter harvests.

Conclusions

1. In the first years of the experiment on Miscanthus, morphological features, d.m. yield, water and ash contents depended on the age of the stand.
2. Harvest dates proved to have the most significant effect on Miscanthus yielding among all the investigated factors. Compared with the autumn harvest, the winter harvest lowered d.m. yield by 18.4 % and water content by 23.4 % in green matter. With winter harvest crude ash content also decreased by 43 %, while green biomass energy value increased by 52 %.
3. It is possible to obtain a mean biomass energy yield of 294 GJ (which corresponds to 7.03 toe*) from 1 ha of Miscanthus field in the second and the third year of the cultivation.
4. It is possible to obtain high d.m. yields in Miscanthus with autumn hilling and by applying 150 kg N · ha^{-1}.
5. Although the winter harvest results in lower biomass yields, it is more favourable in terms of quality of the plant material for energy production than the autumn harvest.

References

[1] Lewandowski I., Clifton-Brown J.C., Scurlock J. M.O. and Huisman W.: *Miscanthus: European experience with a novel energy crop*. Biomass and Bioenergy 2000, **19**(4), 209–227. http://dx.doi.org/10.1016/S0961-9534(00)00032-5.

[2] Jeżowski S.: *Energia w trawie*. Czysta Energia 2004, **5**(33), 15–16.

[3] Kozak M.: *Możliwości uprawy i wykorzystania Miskanta olbrzymiego na cele energetyczne w Polsce.* Cz. II, Ekonatura, Wrocław 2006, **3**, 20–22.

[4] Roszewski R.: Miskant olbrzymi – *Miscanthus sinensis giganteus*, Nowe rośliny uprawne na cele spożywcze, przemysłowe i jako odnawialne źródła energii. SGGW, Warszawa 1996, 123–135.

[5] Clifton-Brown J.C. and Lewandowski I.: *Screening Miscanthus genotypes in field trials to optimize biomass yield and quality in Southern Germany*. Eur. J. Agron. 2002, **16**, 97–110. http://dx.doi.org/10.1016/S1161-0301(01)00120-4.

[6] Lewandowski I. and Heinz A.: *Delayed harvest of miscanthus – influences on biomass quantity and quality and environmental impacts of energy production*. Eur. J. Agron. 2003, **19**, 45–63. http://dx.doi.org/10.1016/S1161-0301(02)00018-7.

[7] Kahle P., Beuch S., Boelcke B., Leinweber P. and Schulten H.-R.: *Cropping of Miscanthus in Central Europe: biomass production and influence on nutrients and soil organic matter*. Eur. J. Agron. 2001, **15**, 171–184. http://dx.doi.org/10.1016/S1161-0301(01)00102-2.

* toe – ton of oil equivalent (fuel with caloric value of 41.87 GJ · t^{-1}).

[8] Lewandowski I. and Kicherer A.: *Combustion quality of biomass: practical relevance and experiments to modify the biomass quality of Miscanthus x giganteus*. Eur. J. Agron. 1997, **6**, 163–177. http://dx.doi.org/10.1016/S1161-0301(96)02044-8.
[9] Lewandowski I.: *Propagation method as an important factor in the growth and development of Miscanthus x giganteus*. Ind. Crops and Prod. 1998, **8**, 229–245. http://dx.doi.org/10.1016/S0926-6690(98)00007-7.
[10] Beale C.V. and Long S.P.: *Seasonal dynamics of nutrient accumulation and partitioning in the perennial C4-grasses Miscanthus x giganteus and Spartina cynosuroides*. Biomass and Bioenergy 1997, **12**(6), 419–428. http://dx.doi.org/10.1016/S0961-9534(97)00016-0.
[11] Himken M., Lammel J., Neukirchen D., Czypionka-Krause U. and Olfs H.W.: *Cultivation of Miscanthus under West European conditions: Seasonal changes in dry matter production, nutrient uptake and remobilization*. Plant and Soil 1997, **189**, 117–126. http://dx.doi.org/10.1023/A:1004244614537.
[12] Polska Norma. PN-G-04513:1981 Paliwa stałe. Oznaczanie ciepła spalania i wartości opałowej. 1981.
[13] Clifton-Brown J.C. and Jones M.B.: *The thermal response of leaf extension rate in genotypes of the C4-grass Miscanthus: an important factor in determining the potential productivity of different genotypes*. J. Exp. Bot. 1997, **48** (313), 1573–1581. http://dx.doi.org/ 10.1093/jxb/48.8.1573.
[14] Beale C.V., Morison J.I.L. and Long S.P.: *Water use efficiency of C4 perennial grasses in a temperate climate*. Agricult. Forest Meteorol. 1999, **96**, 103–115. http://dx.doi.org/10.1016/S0168-1923(99)00042-8.
[15] Danalatos N.G., Archontoulis S.V. and Mitsios I.: *Potential growth and biomass productivity of Miscanthus x giganteus as affected by plant density and N-fertilization in central Greece*. Biomass and Bioenergy 2007, **31**(2–3), 145–152. http://dx.doi.org/10.1016/j.biombioe.2006.07.004.
[16] Jeżowski S., Głowacka K. and Bocianowski J.: *Zmienność wybranych klonów traw olbrzymich z rodzaju Miscanthus pod względem plonowania w pierwszych latach uprawy*. Zesz. Probl. Post. Nauk Roln. 2007, **517**, 339–348.
[17] Kaack K. and Schwarz K.U.: *Morphological and mechanical properties of Miscanthus in relation to harvesting, lodging, and growth conditions*. Ind. Crops and Prod. 2001, **14**, 145–154. http://dx.doi.org/10.1016/S0926-6690(01)00078-4.
[18] Lewandowski I., Clifton-Brown J.C., Andersson B., Basch G., Christian D.G., Jorgensen U., Jones M.B., Richie A.B., Schwarz K.U., Tayebi K. and Teixeira F.: *BIOFUELS, Environment and Harvest Time Affects the Combustion Qualities of Miscanthus Genotypes*. Agron. J. 2003, **95**, 1274–1280. http://dx.doi.org/10.2134/agronj2003.1274.
[19] Clifton-Brown J.C., Breuer J. and Jones M.B.: *Carbon mitigation by the energy crop Miscanthus*. Global Change Biol. 2007, **13**, 2296–2307. http://dx.doi.org/10.1111/j.1365-2486.2007.01438.x.

NASTĘPCZY WPŁYW OBREDLANIA NA ROZWÓJ I PLONOWANIE MISKANTA OLBRZYMIEGO (*Miscanthus x giganteus* Greef et Deu.)

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Abstrakt: W latach 2005–2007 w Pawłowicach koło Wrocławia prowadzono badania polowe nad następczym wpływem obredlania miskanta olbrzymiego jesienią, po posadzeniu. Doświadczenie założono w układzie „split–plot" na trzy czynniki zmienne, którymi w kolejności były: I. Terminy zbioru: a – jesienny po zahamowaniu wegetacji – 11.07.2005 r., 14.12.2006 r., b – zimowy przed ruszeniem wegetacji – 10.03.2006 r., 09.03.2007 r., II. Jesienna pielęgnacja kłączy po posadzeniu a – z obredlaniem, b – bez obredlania, III. Nawożenie w kg N · ha^{-1}: 100, 150 i 200.

W początkowych latach po założeniu doświadczenia z miskantem olbrzymim cechy morfologiczne, plon suchej masy, zawartość wody i popiołu zależały od wieku plantacji.

Spośród badanych czynników agrotechnicznych największy wpływ na poziom plonu i jego jakość miał termin zbioru. Zimowy zbiór, w porównaniu z jesiennym, spowodował zmniejszenie: plonu suchej masy o 18,4 %, zawartości wody w świeżej masie o 23,8 % i popiołu surowego 43 % oraz wzrost wartości energetycznej świeżej masy o 52 %. Z 1 ha uprawy miskanta olbrzymiego w drugim i trzecim roku uprawy można uzyskać plon biomasy o średniej wartości energetycznej 294 GJ, co odpowiada 7,03 toe.

Duże plony suchej masy miskanta olbrzymiego można uzyskać przy jesiennym obredlaniu plantacji i zastosowaniu 150 kg N · ha^{-1}.

Słowa kluczowe: miskant olbrzymi, terminy zbioru, obredlanie, nawożenie azotem