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# Evaluation of *Miscanthus* grown for energy use

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**Abstract**

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In the years 2003–2012 the effects of nitrogen fertilization and term of harvest on the dry matter yield and biomass quality of *Miscanthus* × *giganteus* were examined. The harvest was carried out each year in the autumn and in the spring following year. No significant differences in yields between the sites were observed but the effect of weather conditions in individual years dominated. The nitrogen fertilization increased average biomass yields at the site Prague-Ruzyně by about 14% at the dose of 100 kg/ha and at the site Lukavec by about 11% at the dose of 150 kg/ha in comparison without N fertilization. Average yields of dry matter at Prague-Ruzyně 19.60 t/ha and at Lukavec 18.24 t/ha were achieved at the autumn term of harvest. The loss of biomass over the winter period was 24.3% at Prague-Ruzyně and 24.0% at Lukavec. In the spring term of harvest lower contents of all monitored elements were detected in the biomass of *Miscanthus* compared to the autumn term of harvest.

**Keywords**: *Miscanthus* × *giganteus*, yields; N-fertilization; term of harvest; biomass quality

The consensus is that the use of renewable energy does not have so serious negative impact on the environment as fossil fuels. This is often explained by a reduced consumption of finite primary energy and reduced emissions of greenhouse gases. Among today's renewable energy carriers, solid biofuels seem to be favourable. Energy crops suitable for the production of solid biofuels are characterized by high lignin and cellulose contents. In such ligno-cellulose crops the whole aboveground biomass is harvested and energetically used. Among potential plants *Miscanthus*, a genus with $C_4$ photosynthesis and native of Asia, is known to have the most promising biomass for the production of solid biofuels in temperate regions of Europe and can be used as a biomass energy crop (Jones, Walsh 2001). Over the past 20 years *Miscanthus* grass has been widely studied as a perennial energy crop for Europe. Most of the research has been conducted on *Miscanthus* × *giganteus* Hodk. et Renvoize a natural hybrid between *M. sacchariflorus* (Maxim.) Hack. and *M. sinensis* (Andersson) (Christian et al. 2005). Field trials in Europe with *Miscanthus* × *giganteus* have shown that this genotype can, from its second to third year following establishment after planting, produce annual yields ranging from 10 to 40 t/ha of dry matter (Lewandowski, Clifton-Brown 2000). The objectives of the present study were to investigate the effects of site, nitrogen fertilization and terms of harvest on dry matter yields and other important characters in *Miscanthus* × *giganteus.*

## MATERIAL AND METHODS

In the period 2003–2012 the field experiments with *Miscanthus* × *giganteus* were performed at two different sites (Prague-Ruzyně and Lukavec) with four levels of nitrogen fertilization. Site conditions are shown

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Table 1. Experimental site conditions

| Experimental site | Prague-Ruzyně | Lukavec |
|---|---|---|
| Latitude | 50°04' | 49°37' |
| Longitude | 14°26' | 15°03' |
| Height above sea level (m) | 350 | 620 |
| Soil texture | clay-loam | sandy-loam |
| Great soil group | Orthic Luvisol | Vertic Cambisol |
| Average annual air temperature (°C) | 8.2 | 6.8 |
| Average annual precipitation sum (mm) | 477 | 686 |
| Agrochemical properties of topsoil | | |
| Humus content (%) | 3.00 | 2.32 |
| pH (KCl) | 6.57 | 6.11 |
| P content (Mehlich III, mg/kg soil) | 220.5 | 128.4 |
| K content (Mehlich III, mg/kg soil) | 425.0 | 377.0 |

in Table 1. *Miscanthus* stands were established at both sites using rhizomes. The planting density was 1 plant per 1 m$^2$. The plot size was 3 × 5 meters. Nitrogen fertilization was as follows. In the year of planting nitrogen fertilization was not applied. From the second year the following N doses were used: N0 – without N fertilization, N1 – 50 kg/ha (one dose in ammonia sulphate after harvest in spring), N2 – 100 kg/ha (fertilization in two doses – 50 kg N in ammonia sulphate after harvest in spring – in March and 50 kg/ha N in ammonia nitrate with limestone at the stand height of approx. 50 cm – at the end of May), N3 – 150 kg/ha (fertilization in two doses – 75 kg N in ammonia sulphate in spring – in March and 75 kg N/ha in ammonia nitrate with limestone at the stand height of approx. 50 cm – at the end of May). The harvest was carried out each year in two terms: (1) in the autumn (at the end of November) and (2) in the following year in spring (at the end of March) before emergence of plants. Subsequently, the plot yields of dry matter were determined.

Moisture content was determined by drying samples in a dryer at 90°C to a constant weight. The 90°C temperature was chosen so that the volatile substances did not vaporize from the dried sample.

The content of individual elements in plants was determined in compliance with the Czech National Standard ISO 11 885:2009 – Determination of 33 Elements by ICP-AES. Plants were decomposed in an MLS-1200 Mega microwave decomposing device from MILESTONE s.r.l. (Sorisole, Italy). The 10-position rotor (low-pressure decomposition) was used for plants. Measurements were performed using Thermo Jarrell Ash inductively coupled plasma – optical emission spectrometer from Trace Scan (Franklin, USA).

UNISTAT 5.0 package was used for statistical analyses of the experimental data. Data fulfil the requirements for normality of distribution, which was evaluated by Kolmogorov-Smirnov test. Two-tail probability value 0.3716 was lower than K-S test statistic 0.9156.

## RESULTS AND DISCUSSION

Average biomass dry matter yields of *Miscanthus* obtained after autumn harvest at the sites Prague-Ruzyně and Lukavec are presented in Table 2.

The biomass yields of *Miscanthus* have increased since establishment until the third or fourth year. *Miscanthus* stands were able to give desirable high yields since the 3$^{rd}$ year at Prague-Ruzyně and 4$^{th}$ year at Lukavec. We can expect similar yields in these soil-climatic conditions in the following years (Strašil 2009; Strašil, Vach 2014).

The average yields for the whole period of 10 years were similar when we compare both sites. However, variability of yield data have been highly significant over the years (Table 3) due to the effect of weather conditions in individual years, particularly due to differences in distribution of rainfall and also in temperatures during vegetation period in individual years and sites.

It is evident from our results that the highest average dry matter yield was reached at the site Prague-Ruzyně at N2 dose (23.69 t/ha) and doses of nitrogen exceeding 100 kg/ha did not result in the yield

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Table 2. Yields of dry matter of *Miscanthus* (t/ha) harvested in late autumn according to year and N fertilization effects at Praha-Ruzyně site

| Year | N-fertilization | | | | |
|---|---|---|---|---|---|
| | N0 | N1 | N2 | N3 | Average |
| **Prague-Ruzyně site** | | | | | |
| 1. | 1.319 | – | – | – | 1.319 |
| 2. | 7.165 | 5.554 | 8.867 | 4.094 | 6.420 |
| 3. | 17.793 | 15.512 | 20.547 | 19.966 | 18.454 |
| 4. | 21.997 | 23.117 | 25.333 | 21.617 | 23.016 |
| 5. | 18.044 | 19.769 | 22.045 | 18.176 | 19.508 |
| 6. | 30.069 | 30.462 | 30.879 | 32.625 | 31.009 |
| 7. | 23.575 | 24.327 | 31.060 | 24.309 | 25.818 |
| 8. | 20.467 | 25.398 | 26.593 | 27.275 | 24.933 |
| 9. | 29.729 | 29.027 | 29.306 | 26.594 | 28.664 |
| 10. | 14.703 | 14.959 | 18.536 | 19.248 | 16.862 |
| Average 2–10 | 20.394 | 20.903 | 23.685 | 21.545 | 21.632 |
| Average 4–10 | 22.655 | 23.866 | 26.250 | 24.463 | 24.259 |
| **Lukavec site** | | | | | |
| 1. | 1.256 | – | – | – | 1.256 |
| 2. | 4.538 | 4.042 | 4.440 | 5.132 | 4.538 |
| 3. | 6.044 | 4.831 | 6.417 | 6.885 | 6.044 |
| 4. | 18.680 | 21.935 | 21.935 | 18.342 | 20.223 |
| 5. | 12.264 | 17.301 | 18.323 | 19.199 | 16.772 |
| 6. | 15.928 | 24.174 | 27.342 | 29.165 | 24.152 |
| 7. | 28.460 | 30.570 | 29.840 | 35.915 | 31.196 |
| 8. | 23.800 | 18.270 | 20.400 | 22.180 | 21.163 |
| 9. | 31.568 | 27.367 | 27.117 | 24.466 | 27.629 |
| 10. | 30.358 | 26.072 | 29.730 | 31.641 | 29.450 |
| Average 2–10 | 19.071 | 19.396 | 20.616 | 21.436 | 20.130 |
| Average 4–10 | 23.008 | 23.670 | 24.955 | 25.844 | 24.369 |

N fertilization in mineral fertilizers (kg/ha): N0 – 0, N1 – 50, N2 – 100, N3 – 150

increase (Table 2). However, in the colder site Lukavec with not so rich soils, lower soil productivity biomass yields increased from 19.07 t/ha (N0) to 21.44 t/ha (N3 – 150 kg/ha N) (Table 2). These results show that due to adequate N fertilization dry matter yield can be increased on average by 11–14%.

The highest dry matter yield of *Miscanthus* biomass during experimental period was achieved at the site Prague-Ruzyně in the 6$^{th}$ year of cultivation (31.01 t/ha), at the site Lukavec in the 7$^{th}$ year of cultivation (31.20 t/ha). Variation ranges similar at both sites (Table 2). The similar results were presented by Strašil and Vach (2014). These findings imply a good adaptability of examined *Miscanthus* clone to different soil-climatic conditions. Lower temperature sums may be also compensated by higher precipitation in the site Lukavec in comparison with Prague-Ruzyně.

Table 3. ANOVA of autumn biomass yields and factors of the field experiment with *Miscanthus*

| Source of variability | df | Mean square | Significance |
|---|---|---|---|
| Site | 1 | 0.172 | 0.8770 |
| Year | 6 | 121.684 | 0.0000** |
| N fertilization | 3 | 21.953 | 0.0506 |
| Site × Year | 6 | 88.303 | 0.0000** |
| Site × N fertilization | 3 | 5.004 | 0.5546 |
| Year × N fertilization | 18 | 7.766 | 0.4116 |
| Error | 18 | 6.979 | |

** statistically significant effect ($P \leq 0.01$)

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Table 4. Yields of dry matter of *Miscanthus* (t/ha) according to harvest term at Prague-Ruzyně and Lukavec sites

| Year and term of harvest | Prague-Ruzyně | | | Lukavec | | |
|---|---|---|---|---|---|---|
| | autumn | spring | difference (%) | autumn | spring | difference (%) |
| 1. | 1.319 | 1.112 | 15.7 | 1.256 | 1.024 | 18.5 |
| 2. | 6.420 | 4.958 | 22.8 | 4.538 | 3.600 | 20.7 |
| 3. | 18.454 | 13.701 | 25.8 | 6.044 | 4.437 | 26.6 |
| 4. | 23.016 | 16.571 | 28.0 | 20.223 | 14.414 | 28.7 |
| 5. | 19.508 | 14.964 | 23.3 | 16.772 | 12.650 | 24.6 |
| 6. | 31.009 | 23.404 | 24.5 | 24.152 | 17.930 | 25.8 |
| 7. | 25.818 | 17.878 | 30.8 | 31.196 | 24.719 | 20.8 |
| 8. | 24.933 | 18.192 | 27.0 | 21.163 | 16.198 | 23.5 |
| 9. | 28.664 | 22.330 | 22.1 | 27.629 | 23.500 | 25.0 |
| 10. | 16.862 | 12.913 | 23.4 | 29.450 | 21.925 | 25.6 |
| Average | 19.600 | 14.602 | 24.3 | 18.242 | 14.040 | 24.0 |

In field trials performed in Austria (Schwarz et al. 1994) dry biomass yield of 8 t/ha was achieved in the second year after planting and 22 t/ha in the third year. The highest yields were obtained after harvest in November and then continuously decreased until February as a result of litter.

According to Clifton-Brown at al. (2001) yields of *Miscanthus* × *giganteus* harvested after winter fluctuated in different places of Europe (depending on irrigation) between 7 and 26 t/ha of dry matter in the third year after planting. The highest yields of non-irrigated plants ranged between 15 and 19 t/ha of dry matter.

Analysis of variance (Table 3) showed highly significant year and site by year interaction effects, but site effect was not significant. The effect of N fertilization was low ($P$ = 0.05) and interactions of N fertilization with both site and year were not significant. Schwarz et al. (1994) also did not find highly significant effects of different N doses (0, 60, 90, 120 and 180 kg/ha) applied at the beginning of April on yield of *Miscanthus*.

Influence of autumn and spring term of harvest on dry matter yields of *Miscanthus* during monitored period at Prague-Ruzyně and Lukavec sites is given in Table 4. Loss of biomass over the winter period was on average of the monitored period 24.3% at the site Prague-Ruzyně and 24.0% at Lukavec. These losses of biomass over the winter period (24.2% on average) are not high in comparison with some other energy crops. For example, loss of biomass over the winter period was reported to be 35.1% in knotweed and 37.5% in sorghum. Biomass losses of 20–25% in *Miscanthus* are significant during winter period and they are similar as in other grass species, e.g. 27.3% in *Phalaris arundinacea* or 28.9% in *Festuca arundinacea* (Kára et al. 2004).

Table 5. *Miscanthus* dry matter content of biomass (%) obtained at two sites in various terms of harvest (average 2003–2012)

| Site | Autumn harvest | Spring harvest |
|---|---|---|
| Prague-Ruzyně | 48.9 | 79.4 |
| Lukavec | 52.7 | 81.2 |
| Average | 50.8 | 80.3 |

The loss is compensated by the moisture reduction, as one would need to dry the harvested biomass in autumn. A stand of *Miscanthus* × *giganteus* usually does not lodge over winter, which reduces losses of biomass during winter and spring harvest.

Lewandowski and Heinz (2003) observed the yield loss of *Miscanthus* biomass in field experiments at three locations in the south of Germany at various terms of the harvest. At the February term of harvest the losses of biomass were 14–15% and at the March term of harvest 13% in comparison with the December term of harvest. 30% loss of *Miscanthus* biomass over the winter period was also shown by Himken et al. (1997). Similarly Bischoff and Emmerling (1995) found the loss over winter period to be 33%.

It is obvious that the spring dry matter yields are reduced particularly mainly due to the loss of part of leaf and branches biomass, in relation to particular weather conditions during winter period.

Differences in moisture content (in dry matter) for *Miscanthus* at different harvest terms are shown

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Table 6. Elements content in plants of *Miscanthus* in various terms of harvest (average 2006–2009)

| Term of harvest | Elements content (g/kg in dry matter) | | | | | |
|---|---|---|---|---|---|---|
| | N | P | K | Ca | Mg | S |
| 1st term* | 0.966 | 0.139 | 0.555 | 0.444 | 0.139 | 0.122 |
| 2nd term** | 0.777 | 0.112 | 0.230 | 0.302 | 0.113 | 0.043 |
| Average | 0.921 | 0.105 | 0.643 | 0.429 | 0.113 | 0.083 |

*harvest in autumn (end of November); **early spring harvest (half of March next year)

in Table 5. At the autumn term of harvest we found the average moisture content to be around 51%. Without drying this biomass of *Miscanthus* is not suitable for immediate burning even at the end of November. There are two possibilities to get rid of the excessive water by winter: either to desiccate the stand in autumn or harvest and dry it artificially. If soil, climate and snow conditions permit, the stand may also be harvested over the winter season, or not until spring before it starts to grow again. First frosts will dry the stand so that it can be harvested and directly combusted. Moisture below 20% at the spring harvest time is suitable for direct pressing into briquettes or pellets, storage, or immediate burning.

Spring harvest is recommended also because at this harvest term the content of potassium, chlorine, nitrogen and sulphur in the biomass of *Miscanthus* and other crops decreases compared to early harvest term (in the autumn). A reason for this is the translocation of nutrients to the root part and its leaching during winter (Katterer, Andren 1999). A comparison of the elements content in *Miscanthus* at different harvest times per 1 kg of air-dried material according to our observations is given in Table 6.

Determination of elements in plants is important for determining not only nutrient uptake by crops, but also for combustion of biomass. The smallest N content in biomass (generating less $N_{ox}$), small content of S and Cl (reduces the possibility of corrosion of boiler), low content of K, Mg, etc. (increases the melting point of ash) is advantageous for combustion (Strašil 2009).

## CONCLUSION

Yields of *Miscanthus* biomass during the monitored period were significantly affected by weather conditions in the individual year.

At the site Prague-Ruzyně the doses of nitrogen exceeding 100 kg/ha did not already lead to increase of biomass yields in *Miscanthus*. At colder site Lukavec with lower soil fertility the highest average yield was obtained at a dose of 150 kg/ha of nitrogen.

Average dry matter yields of biomass in the case of harvest once a year in autumn were 19.60 t/ha at Prague-Ruzyně and 18.24 t/ha at Lukavec.

Yield results for the experimental sites suggest a good adaptability of examined *Miscanthus* × *giganteus* clone to different soil-climatic conditions.

Loss of biomass over the winter period was on average 24.3% of the monitored period at the site Prague-Ruzyně and 24.0% at Lukavec.

In the spring term of harvest lower contents of all monitored elements were detected in the biomass of *Miscanthus* compared to the autumn term of harvest.

### References

Bischoff R., Emmerling R. (1995): Demands and performance of *Miscanthus sinensis* – five-year results at a dry site. Kongressband 1995 Garmisch-Partenkirchen. Vortrage zum Generalthema des 107. VDLUFA-Kongresses vom September 18–23, 1994, Garmisch-Partenkirchen: Grunland als Produktionsstandort und Landschaftselement: 241–244.

Clifton-Brown J.C., Lewandowski I., Andersson B., Basch G., Christian D.G., Kjeldsen J.B., Jørgensen U., Mortensen J.V., Riche A.B., Schwarz K.U., Tayebi K., Teixeira F. (2001): Performance of 15 Miscanthus genotypes at five sites in Europe. Agronomy Journal, 93: 1013–1019.

Christian D.G., Yates N.E., Riche A.B. (2005): Establishing *Miscanthus sinensis* from seed using conventional sowing methods. Industrial Crops and Products, 21: 109–111.

Jones M.B. Walsh M. (2001): Miscanthus – for Energy and Fibre. London, James and James (Science Publishers).

Himken M., Lammel J., Neukirchen D., Czypionka-Krause U., Olfs H.W. (1997): Cultivation of *Miscanthus* under West European conditions: seasonal changes in dry matter

doi: 10.17221/31/2014-RAE

production, nutrient uptake and remobilization. Plant and Soil, 189: 117–126.

Kára J., Strašil Z., Hutla P., Andert D., Jevič P., Šedivá Z., Adamovský R., Polák M. (2004): Technologické systémy pro využití biopaliv z energetických plodin. Final Report RIAE, p.r.i., Prague-Ruzyně, project QD 1209: 121.

Katterer, R., Andren, O. (1999): Growth dynamics of reed canarygrass (*Phalaris arundinacea* L.) and its allocation of biomass and nitrogen below ground in a field receiving daily irrigation and fertilization. Nutrient Cycling in Agroecosystems, 54: 21–29.

Lewandowski I., Clifton-Brown J.C. (2000): European *Miscanthus* Improvement Project (EMI), FAIR3 CT-96-1392. Final Report: 260.

Lewandowski I., Heinz A. (2003): Delayed harvest of *Miscanthus*-influences on biomass quantity and quality and environmental impacts of energy production. European Journal of Agronomy, 19: 45–63.

Schwarz H., Liebhard P., Ehrendorfer K., Ruckenbauer P. (1994): The effect of fertilization on yield and quality of *Miscanthus sinensis* 'Giganteus'. Industrial Crops and Products, 2: 153–159.

Strašil Z. (2009): Základy pěstování a možnosti využití ozdobnice (*Miscanthus*). Applied methodics for agricultural practice. Prague, Crop Research Institute: 48.

Strašil Z., Vach M. (2014): Effect of nitrogen fertilization on the phytomass yield of *Miscanthu*s × *giganteus* intended for energy utilization. Proceedings of the 13$^{th}$ Alps-Adria Scientifec Workshop, Villach, Ossiacher See, Austria April 28–May 3, 2014. Növénytermelés, 63, Suppl.: 91–94.

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