Sorghum bicolor (L.) Moench is used as feed for animals worldwide, especially in irrigated areas, although it is typically crop of dry regions (Bolsen et al. 2003). Sorghum grains are important as staple food, too (Taylor et al. 2014). The biomass production for silage (as a raw material for biogas stations) is verified in the Czech Republic (Kára et al. 2007). Thanks to high biomass yields (app. 50 t/ha, but sometimes more than 100 t/ha) with dry matter (DM) up to 35%, the sorghum can be counted as a very good raw material for biological fermentation, i.e. biogas production (Sanderson et al. 1992). Main competitors in the European conditions are the maize and the sugar beet (Smutka et al. 2013).

The sorghum needs average daily soil temperature of 7–10°C for germination; on the other hand young plants are able to survive ground morning frosts. The late sowing is preferred in the Czech Republic conditions. Its xerophytic characteristics allow sorghum to tolerate, escape and renew from short-term drought (Hermuth et al. 2012).

The stem contains about 15% of fibre, the rest are sugar juice, organic and mineral salts, proteins and starch. Sweet sorghum juice usually contains 16–18% of fermentable sugar (Ratnavathi et al. 2011). These characteristics predestine sorghum as good biomass crop for industrial purposes and even as tasty feed for animals, too.


**The influence of sweet sorghum crop stand arrangement on biomass and biogas production**

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**ABSTRACT**

The possibility of sweet sorghum cultivation with different inter-row distances (20, 50, 75 cm) was verified in small scale plots with 3 cultivars (Bovital, Goliath, Sucrosorgho). The maize cv. Atletico (rows 75 cm) was used as a control. The influence of row width and cultivar on fresh and dry biomass, methane and biogas production per area was statistically significant. The methane and biogas production was evaluated in laboratory, via fermentation in Oxi Top Control Merck bottles. Generally, sorghum was more productive than maize. The highest biogas production per hectare was found in case of 25 cm row spacing. Goliath was the most yielding cultivar (in all parameters). The experiment proved possibility to produce biomass from sorghum in narrow rows for biogas stations in the Czech Republic.

**Keywords:** Sorghum bicolor; row width; methane yield; corn

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rate and Bishnoi and Mays (2002) reported a positive influence of narrow rows on biomass yield. Many of these results were obtained in irrigated areas; for that reason the aim of this experiment was to verify yield potential of sorghum without irrigation for silage production for feeding animal or energy purposes.

MATERIAL AND METHODS

The evaluation of production traits is based on the results from field trials in the years 2010–2012 at Červený Újezd (Research Experimental Station of the Faculty of Agrobiology, Food and Natural Resources). Sorghum cvs. Bovital, Sucrosorgho and Goliath were sown in 25, 50 and 75 cm wide rows with the same seed rate (22 seeds per 1 m²) in completely randomized blocks of 12.5 m² in the second half of May (soil temperature 10°C). Control maize cv. Atletico was grown in traditional 75 cm rows (10 seeds per 1 m²). All treatments were harvested in the half of October. Weather conditions in experimental years are shown in Table 1. The fresh and dry biomass production and methane and biogas production were determined after harvest. The biogas and methane production was evaluated from 0.5 g of homogenized dry biomass with 10 mL of inoculum (active sediment from biogas station) in Oxi Top Control Merck apparatus (WTW, Weilheim, Germany), 28 days at temperature 39°C. Results were recalculated per ton and per hectare.

The obtained results were statistically evaluated by the General Linear Model (GLM ANOVA) method in the SAS system (version 9.3, Carry, USA) at a significance level of $P \leq 0.05$. Differences between means were evaluated by the Tukey’s HSD (honestly significant difference) test.

RESULTS AND DISCUSSION

The results show differences in plant height with inter-row distances. The maximum plant height of
sorghum (in average of all cultivars) was 341 cm (rows 75 cm), about 127 cm higher (significantly) than control. Totally, Goliath had the highest plants (369–377 cm), the shortest plants were recorded in case of Bovital (294–301 cm) (Table 2).

Treatments (in cultivars average) with row distance 25 cm and 50 cm had the highest fresh biomass yields (66.23 and 63.51 t/ha, respectively), significantly different from maize yield. With regard to relatively small differences in DM content both treatments had the highest yields of dry biomass in comparison with maize (about 4.44 and 4.18 t/ha, respectively). Goliath in 50 cm rows had the highest dry biomass yield in 3 year average (22.87 t/ha). Figures 1–3 show differences in DM yield between treatments in each year.

Obtained results confirm high auto regulation ability of sorghum plants in relation to inter row distance. We agree with conclusions of Scott et al. (1999) that the main advantage of narrow rows (at the same plant numbers per area) is better crop stand organization. The results correspond with findings of Orak and Kavdr (1994), too.

The highest biogas production per ton of dry biomass was 410.76 m³/t in treatment with 75 cm rows (with the lowest DM content, in cultivar average), on the other hand the lowest biogas production was detected in case of 50 cm row width (the highest DM content). As for the cultivars, Goliath and Sucrosorgo biogas production were relatively stable.

Cv. Goliath had the highest biogas production per hectare, 7865 m³/ha in average of 3 years and

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Table 2. The influence of inter-row distance and cultivar on fresh and dry biomass (DM) yield, DM content and production of biogas and methane per DM ton and hectare (average 2010–2012)

<table>
<thead>
<tr>
<th>Cultivar</th>
<th>Row spaces (cm)</th>
<th>Biomass yield (t/ha)</th>
<th>DM content (%)</th>
<th>DM yield (t/ha)</th>
<th>Plant height</th>
<th>Methane production (m³/t)</th>
<th>Methane production (m³/ha)</th>
<th>Biogas production (m³/ha)</th>
<th>Biogas yield (m³/ha)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bovital</td>
<td>25</td>
<td>44.30</td>
<td>26.26</td>
<td>11.59</td>
<td>294</td>
<td>220.22</td>
<td>2552.48</td>
<td>332.55</td>
<td>3853.82</td>
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<tr>
<td></td>
<td>50</td>
<td>45.11</td>
<td>26.67</td>
<td>12.02</td>
<td>286</td>
<td>205.67</td>
<td>2475.97</td>
<td>343.41</td>
<td>4126.98</td>
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<tr>
<td></td>
<td>75</td>
<td>41.73</td>
<td>26.52</td>
<td>11.12</td>
<td>301</td>
<td>196.44</td>
<td>2198.60</td>
<td>414.06</td>
<td>4662.88</td>
</tr>
<tr>
<td></td>
<td><strong>HSD</strong></td>
<td>3.3</td>
<td>0.7</td>
<td>1.00</td>
<td>24.6</td>
<td>6.2</td>
<td>237.7</td>
<td>26.9</td>
<td>581.3</td>
</tr>
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<td>Sucrosorgo</td>
<td>25</td>
<td>77.54</td>
<td>23.39</td>
<td>18.16</td>
<td>317</td>
<td>261.56</td>
<td>4737.55</td>
<td>395.64</td>
<td>7196.94</td>
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<tr>
<td></td>
<td>50</td>
<td>65.01</td>
<td>24.37</td>
<td>15.82</td>
<td>335</td>
<td>238.00</td>
<td>3764.81</td>
<td>388.74</td>
<td>6127.65</td>
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<tr>
<td></td>
<td>75</td>
<td>68.11</td>
<td>24.03</td>
<td>16.42</td>
<td>344</td>
<td>231.89</td>
<td>3793.20</td>
<td>413.28</td>
<td>6777.15</td>
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<tr>
<td></td>
<td><strong>HSD</strong></td>
<td>2.1</td>
<td>1.1</td>
<td>0.80</td>
<td>14.9</td>
<td>5.0</td>
<td>232.7</td>
<td>13.7</td>
<td>387.6</td>
</tr>
<tr>
<td>Goliath</td>
<td>25</td>
<td>76.84</td>
<td>28.20</td>
<td>21.73</td>
<td>369</td>
<td>266.78</td>
<td>5774.21</td>
<td>399.51</td>
<td>8646.51</td>
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<td></td>
<td>50</td>
<td>80.42</td>
<td>28.58</td>
<td>22.87</td>
<td>374</td>
<td>239.33</td>
<td>5461.89</td>
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<td>15.76</td>
<td>377</td>
<td>233.11</td>
<td>3666.27</td>
<td>402.68</td>
<td>6322.88</td>
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<tr>
<td></td>
<td><strong>HSD</strong></td>
<td>2.1</td>
<td>0.9</td>
<td>0.73</td>
<td>20.3</td>
<td>3.7</td>
<td>185.6</td>
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<td>372.2</td>
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<tr>
<td>Average rows</td>
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<td>25.95</td>
<td>17.16</td>
<td>327</td>
<td>249.52</td>
<td>4354.31</td>
<td>376.31</td>
<td>6566.00</td>
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<td></td>
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<td>63.51</td>
<td>26.54</td>
<td>16.90</td>
<td>332</td>
<td>227.70</td>
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<td>369.46</td>
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<tr>
<td></td>
<td>75</td>
<td>56.25</td>
<td>25.82</td>
<td>14.44</td>
<td>341</td>
<td>220.44</td>
<td>3219.30</td>
<td>410.76</td>
<td>5922.70</td>
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<td>Atletico 75 cm (maize)</td>
<td>50.05</td>
<td>31.34</td>
<td>12.72</td>
<td>214</td>
<td>193.50</td>
<td>2486.43</td>
<td>337.40</td>
<td>4307.50</td>
<td></td>
</tr>
<tr>
<td></td>
<td><strong>HSD</strong></td>
<td>3.5</td>
<td>1.3</td>
<td>0.75</td>
<td>11.2</td>
<td>3.5</td>
<td>172.2</td>
<td>13.5</td>
<td>371.3</td>
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<tr>
<td>Average Bovital</td>
<td>43.71</td>
<td>26.48</td>
<td>11.58</td>
<td>294</td>
<td>207.44</td>
<td>2409.02</td>
<td>358.58</td>
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<tr>
<td>Average Sucrosorgo</td>
<td>70.22</td>
<td>23.93</td>
<td>16.80</td>
<td>332</td>
<td>243.82</td>
<td>4098.52</td>
<td>398.73</td>
<td>6700.58</td>
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<tr>
<td>Average Goliath</td>
<td>72.06</td>
<td>27.90</td>
<td>20.12</td>
<td>373</td>
<td>246.41</td>
<td>4967.46</td>
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<td>7864.78</td>
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<tr>
<td>Atletico 75 cm (maize)</td>
<td>50.05</td>
<td>31.34</td>
<td>12.72</td>
<td>214</td>
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<td>3.5</td>
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<td>3.5</td>
<td>172.2</td>
<td>13.5</td>
<td>371.3</td>
</tr>
</tbody>
</table>

Values with the same letters are not significantly different (P = 0.05). Honestly significant difference (HSD) corresponds with values in each block
Figure 1. Influence of row spacing and cultivar of *Sorghum bicolor* (L.) on production of biogas per hectare and dry matter (DM) yield in the year 2010. Significance between cultivars × rows are labelled with small letters (*HSD* = 583.5 for biogas production, *HSD* = 1.9 for DM yield); significance between cultivars (average) and maize are labelled with capital letters (*HSD* = 455.1 for biogas production, *HSD* = 1.0 for DM yield).

Figure 2. Influence of row spacing and cultivar of *Sorghum bicolor* (L.) on dry matter (DM) yield and production of biogas per hectare in the year 2011. Significance between cultivars × rows are labelled with small letters (*HSD* = 1290.4 for biogas production, *HSD* = 2.3 for DM yield); significance between cultivars (average) and maize are labelled with capital letters (*HSD* = 721.2 for biogas production, *HSD* = 1.3 for DM yield).

Figure 3. Influence of row spacing and cultivar of *Sorghum bicolor* (L.) on dry matter (DM) yield and production of biogas per hectare in the year 2012. Significance between cultivars × rows are labelled with small letters (*HSD* = 1518.4 for biogas production, *HSD* = 3.2 for DM yield); significance between cultivars (average) and maize are labelled with capital letters (*HSD* = 848.6 for biogas production, *HSD* = 1.8 for DM yield).
all row distances. Treatments with smaller row spacing were more productive. Similar reaction was recorded in case of Sucrosorgo. Early cv. Bovital had the highest biogas production from 75 cm treatment. As the best cultivar, Goliath touched record level of biogas production per hectare 9676 m³ in case of 25 cm row distance in 2012 (Figure 3).

Kára et al. (2007) presented that a determinant factor for biogas production and quality (methane yield) is fiber content in stalk, leaves and partially in panicle. With continuous ripening the content of hardly fermented lignin increases and fiber degradability decreases. Higher share of worse degradable cellulose extends hydrolytic and acidogenic phase of degradation, equally in case of sorghum and maize. For this reason necessary DM content is to be preferably to 30–33%. DM of sorghum in the experiment varied between 23.39% and 28.58% depending on row width and cultivar.

The methane content in biogas varies between 50–75% according to fermented material and its physical and chemical characteristics (Straka and Ciahotný 2010). The methane content in biogas of evaluated sorghum cultivars varied from 47% to 68%. Determined percentage of methane was influenced significantly by inter-row distance, cultivar and year (data is not shown).

Hermuth et al. (2012) reported the yield of methane from maize between 1700–7000 m³/ha, about 6–16% higher than in case of sorghum. Klimíuk et al. (2010) even found biogas yield higher about 20%. In this experiment 3-year yield of methane per hectare was 5774.21 m³/ha (cv. Goliath, rows 25 cm). In case of maize, Kára et al. (2007) determined average methane yield per ton of DM as 306 m³/t, higher about 14.7% in comparison with our experimental data (266.78 m³/t, the best methane yield).

Thanks to higher production of fresh and dry biomass per area (in average of all cultivars and row width) biogas production from sorghum exceeded production from maize (about 45%). Obtained data confirm the possibility to grow sorghum in narrow rows; such arrangement resulted in potentially lower negative effects to water erosion in comparison with maize. However, this fact has not been researched enough, from view of the area when we use sweet sorghum for biomass production instead of maize.

The area of sorghum is small in the Czech Republic at the present time, because its production of methane per ton of silage is lower than in case of maize and whole technology of silage production is optimized for the maize, too. Nevertheless sorghum production potential per area promises interesting future. Petříková et al. (2006) mention other benefits, as higher drought tolerance and better water use efficiency (WUE). Similarly Varga et al. (2013) point out importance of cereals with higher WUE for current climatic conditions. Sorghum can find use for light soils and in dry areas (Bolsen et al. 2003).

On the basis of the obtained results it is possible to pronounce that sweet sorghum can be cultivated successfully in narrow spacing in comparison with maize. Sorghum exceeds maize mainly in production of fresh and dry biomass and biogas production per area. Goliath was the most yielding (in fresh and dry biomass, methane and biogas) cultivar from all tested genotypes. Even the least productive cv. Bovital was comparable with maize in biogas production per area.

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