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

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.

Ayub et al. (2002) did not show statistically significant effect of sowing rates on sorghum biomass production. Conversely Scott et al. (1999) ascribed high yields of biomass in crop stand with narrow rows to better catching of light and more effective water use. Orak and Kavdr (1994) obtained the highest yield in case of the small inter-row distance and highest sowing rate. Higher row distance decreases biomass yield (Gonzales and Graterol 2000, Mokadem et al. 2002). Malik et al. (2007) confirmed a positive effect of increasing sowing

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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 m^2) in completely randomized blocks of 12.5 m^2 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 m^2). 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

Table 1. Agrometeorological data 2010–2012 in Červený Újezd

	2009/2010[1)]				2010/2011[1)]				2011/2012[1)]			
	Δt	temperature	%	precipitation	Δt	temperature	%	precipitation	Δt	temperature	%	precipitation
October	–0.9	normal	100	normal	–1.7	cold	20	dry	0.2	normal	66	normal
November	3.3	extraordinary warm	101	normal	1.9	very warm	188	very wet	0.2	normal	9	extraordinary dry
December	–0.5	normal	186	very wet	–4.9	very cold	179	wet	3.5	very warm	113	normal
January	–3.5	cold	168	very wet	1.3	normal	116	normal	2.9	warm	157	wet
February	–0.6	normal	55	dry	–0.4	normal	19	very dry	–3.0	cold	57	dry
March	1.0	normal	62	normal	2.0	normal	89	normal	4.1	extraordinary warm	34	dry
Cold half of the year	–0.2	normal	112	wet	–0.3	normal	102	normal	1.3	warm	70	normal
April	1.2	normal	87	normal	3.9	extraordinary warm	42	dry	1.2	normal	101	normal
May	–0.4	normal	140	wet	1.3	normal	69	normal	2.4	warm	55	dry
June	0.5	normal	88	normal	1.9	very warm	126	wet	1.5	warm	82	normal
July	2.8	extraordinary warm	191	very wet	–0.7	cold	208	very wet	1.7	very warm	179	very wet
August	0.9	normal	214	very wet	2.1	very warm	113	normal	2.6	extraordinary warm	94	normal
October	–1.9	cold	182	wet	1.9	warm	70	normal	0.3	normal	127	normal
Warm half of the year	0.5	normal	154	very wet	1.7	extraordinary warm	114	normal	1.6	extraordinary warm	108	normal
Agrometeorological year	0.2	normal	140	very wet	0.7	warm	110	normal	1.4	very warm	95	normal

[1)]Evaluation by Kožnárová and Klabzuba (2002) 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 m^3/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 m^3/ha in average of 3 years and

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)

Cultivar	Row spaces (cm)	Biomass yield (t/ha)	DM content (%)	DM yield (t/ha)	Plant height	Methane production (m^3/t)	Methane yield (m^3/ha)	Biogas production (m^3/t)	Biogas yield (m^3/ha)
Bovital	25	44.30^{ab}	26.26^{a}	11.59^{a}	294^{a}	220.22^{a}	2552.48^{a}	332.55^{b}	3853.82^{b}
	50	45.11^{a}	26.67^{a}	12.02^{a}	286^{a}	205.67^{b}	2475.97^{a}	343.41^{b}	4126.98^{ab}
	75	41.73^{b}	26.52^{a}	11.12^{a}	301^{a}	196.44^{c}	2198.60^{b}	414.06^{a}	4662.88^{a}
HSD		3.3	0.7	1.00	24.6	6.2	237.7	26.9	581.3
Sucrosorgo	25	77.54^{a}	23.39^{a}	18.16^{a}	317^{b}	261.56^{a}	4737.55^{a}	395.64^{b}	7196.94^{a}
	50	65.01^{b}	24.37^{a}	15.82^{b}	335^{a}	238.00^{b}	3764.81^{b}	388.74^{b}	6127.65^{c}
	75	68.11^{c}	24.03^{a}	16.42^{b}	344^{a}	231.89^{c}	3793.20^{b}	413.28^{a}	6777.15^{b}
HSD		2.1	1.1	0.80	14.9	5.0	232.7	13.7	387.6
Goliath	25	76.84^{b}	28.20^{a}	21.73^{b}	369^{a}	266.78^{a}	5774.21^{a}	399.51^{a}	8646.51^{a}
	50	80.42^{a}	28.58^{a}	22.87^{a}	374^{a}	239.33^{b}	5461.89^{b}	378.55^{b}	8624.97^{a}
	75	58.91^{c}	26.93^{b}	15.76^{c}	377^{a}	233.11^{c}	3666.27^{c}	402.68^{a}	6322.88^{b}
HSD		2.1	0.9	0.73	20.3	3.7	185.6	13.4	372.2
Average rows	25	66.23^{a}	25.95^{b}	17.16^{a}	327^{b}	249.52^{a}	4354.31^{a}	376.31^{a}	6566.00^{a}
	50	63.51^{a}	26.54^{b}	16.90^{a}	332^{ab}	227.70^{b}	3901.02^{b}	369.46^{b}	6293.20^{ab}
	75	56.25^{c}	25.82^{b}	14.44^{b}	341^{a}	220.44^{c}	3219.30^{c}	410.76^{b}	5922.70^{b}
Atletico 75 cm (maize)		50.05^{c}	31.34^{a}	12.72^{c}	214^{c}	193.50^{d}	2486.43^{d}	337.40^{c}	4307.50^{c}
HSD		3.5	1.3	0.75	11.2	3.5	172.2	13.5	371.3
Average Bovital		43.71^{c}	26.48^{c}	11.58^{d}	294^{c}	207.44^{b}	2409.02^{c}	358.58^{b}	4214.56^{c}
Average Sucrosorgo		70.22^{a}	23.93^{d}	16.80^{b}	332^{b}	243.82^{a}	4098.52^{b}	398.73^{a}	6700.58^{b}
Average Goliath		72.06^{a}	27.90^{b}	20.12^{a}	373^{a}	246.41^{a}	4967.46^{a}	393.43^{a}	7864.78^{a}
Atletico 75 cm (maize)		50.05^{b}	31.34^{a}	12.72^{c}	214^{d}	193.50^{c}	2486.43^{c}	337.40^{c}	4307.50^{c}
HSD		3.5	1.3	0.75	11.2	3.5	172.2	13.5	371.3

Values with the same letters are not significantly different (P = 0.05). Honestly significant difference (*HSD*) corresponds with values in each block

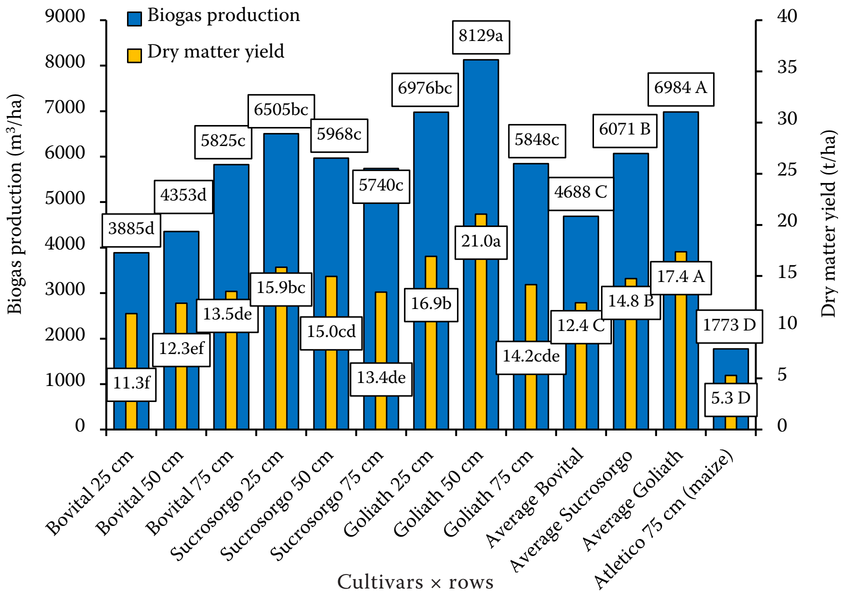

Figure 1. Influence of row spacing and cultivar of *Sorghum bicolor* (L.) on production of biogas per hectare and dry matter (DM) yield in the year 2010. Significance between cultivars × rows are labelled with small letters (*HSD* = 583.5 for biogas production, *HSD* = 1.9 for DM yield); significance between cultivars (average) and maize are labelled with capital letters (*HSD* = 455.1 for biogas production, *HSD* = 1.0 for DM yield)

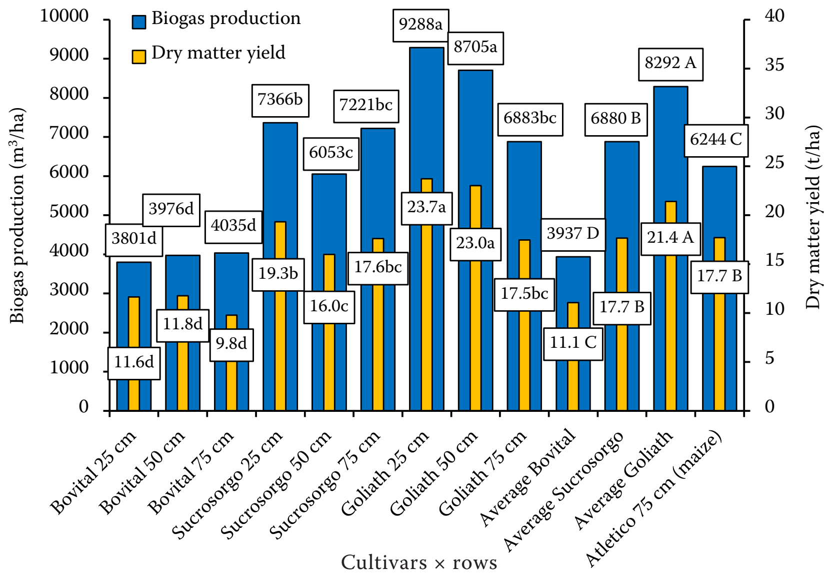

Figure 2. Influence of row spacing and cultivar of *Sorghum bicolor* (L.) on dry matter (DM) yield and production of biogas per hectare in the year 2011. Significance between cultivars × rows are labelled with small letters (*HSD* = 1290.4 for biogas production, *HSD* = 2.3 for DM yield); significance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

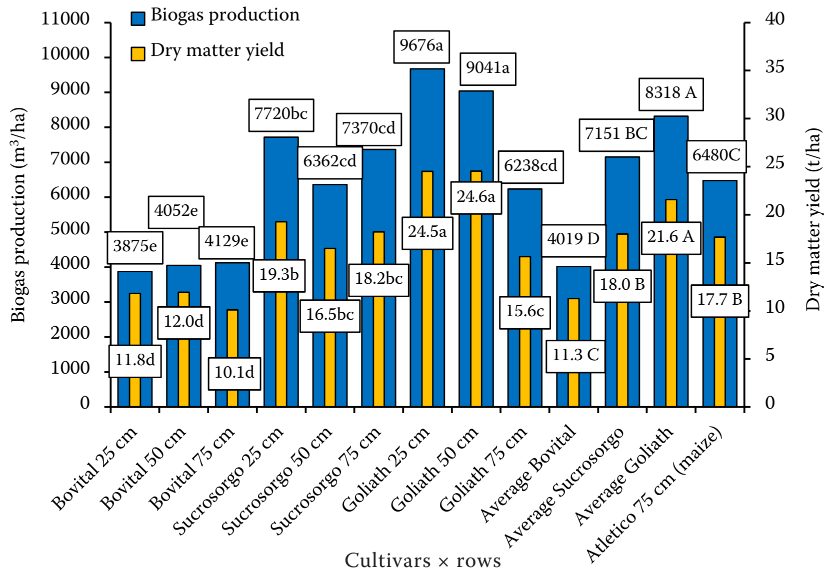

Figure 3. Influence of row spacing and cultivar of *Sorghum bicolor* (L.) on dry matter (DM) yield and production of biogas per hectare in the year 2012. Significance between cultivars × rows are labelled with small letters (*HSD* = 1518.4 for biogas production, *HSD* = 3.2 for DM yield); significance 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 m^3 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 neccessary 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 m^3/ha, about 6–16% higher than in case of sorghum. Klimiuk et al. (2010) even found biogas yield higher about 20%. In this experiment 3-year yield of methane per hectare was 5774.21 m^3/ha (cv. Goliath, rows 25 cm). In case of maize, Kára et al. (2007) determined average methane yield per ton of DM as 306 m^3/t, higher about 14.7% in comparison with our experimental data (266.78 m^3/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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