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Dry Matter Yield and Chemical Composition of Sorghum Cultivars with Varying Planting Density and Sowing Date

(Hasil Jirim Kering dan Komposisi Kimia Kultivar Sorgum dengan Perubahan Kepadatan Penanaman dan Tarikh Menyemai)

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ABSTRACT

*This two-year research was carried out to clarify the effect of varying sowing time, planting density and cultivar on the biomass yield and chemical composition of sorghum. The leaf area index of the sorghum plant stand reached a maximal value of 5.0–5.7 at 97 days after sowing (DAS). Cultivar 'Bovital' was more productive with respect to the number of tillers per plant as well as per m². Cultivars had clear impact on most of the quality parameters. Cultivar 'Goliath' (*Sorghum bicolor × S. bicolor *hybrid) had a higher biomass yield than Bovital (*S. bicolor × S. sudanense *hybrid). Dry matter yield was largely unaffected by the plant density at all sowing times. It was observed that Goliath exhibited higher sugar and neutral detergent fibre, while a greater content of protein was found in Bovital. Plant density had no clear influence on most of the quality parameters.*

Keywords: Biomass yield; neutral detergent fibre; sowing times; sugar content

ABSTRAK

*Penyelidikan dua tahun ini telah dijalankan untuk menerangkan kesan mengubah masa menyemai, kepadatan menanam dan kultivar ke atas biojisim dan komposisi kimia sorgum. Indeks kawasan daun dirian pokok sorgum mencapai nilai maksimum 5.0–5.7 pada 97 hari selepas penyemaian (DAS). Kultivar 'Bovital' adalah yang paling produktif daripada segi bilangan anak pokok per pokok dan juga per m². Kultivar menunjukkan kesan yang jelas kepada kebanyakan mutu parameter. Kultivar 'Goliath' (hibrid *Sorghum bicolor × S. bicolor*) mempunyai hasil biojisim yang lebih tinggi daripada Bovital (hibrid *S. bicolor × S. Sudanense*). Hasil jirim kering adalah tidak berkesan oleh kepadatan pokok pada semua masa menyemai. Adalah diperhatikan bahawa Goliath menunjukkan kandungan gula lebih tinggi dan serabut detergen netral, manakala kandungan protein adalah lebih tinggi telah ditemui dalam Bovital. Kepadatan pokok tidak mempunyai pengaruh ke atas kebanyakan mutu parameter.*

Kata kunci: Hasil biojisim; kandungan gula; masa menyemai; serabut detergen neutral

INTRODUCTION

Methane and biogas production from energy crops and animal manures mainly depends on biodegradability and composition. Chemical composition including crude protein, starch sugar, crude fat, crude fibre, cellulose and hemi-cellulose, significantly influence methane formation (Oslaj et al. 2010). Maize silage is considered as a key substrate for agricultural biogas production in Weiland (2006) and Schittenhelm (2008). Since last decades, mono-cropping of maize for biogas production causing different type of problems like decreasing the crop species diversity, enhancing pest, disease intensity as well as nutrient losses (Schittenhelm 2010). To tackle these problems sorghum is introduced as an alternative energy crop for biogas production. Sorghum (*Sorghum bicolor*) is a warm-season annual grass with great ability to produce high forage biomass yields (Fribourg 1995; Rooney et al. 2007). It can be used for the production of energy, fibre or paper, as well as for syrup and animal feed (Steduto et al. 1997).

Sorghum is a new crop in Germany and still not well adapted to the local climate. Agronomic measures like sowing and harvest dates have not been tested under climatic conditions of Germany, yet. These factors can affect biomass as well as chemical composition of sorghum which can ultimately influence the biogas and methane yield of sorghum. Therefore it is dire need to optimize various husbandry practices such as sowing date and plant density. The optimum seedlings per hill ensure the plants to grow in their both aerial and underground parts through efficient utilization of solar radiation, water and nutrients (Ahmad & Hasanuzzaman 2012; Ahmad et al. 2012a, 2012b; Hasanuzzaman & Karim 2007; Hasanuzzaman et al. 2008, 2009a, 2009b). When the planting densities exceed the optimum level, competition among plants becomes severe and consequently the plant growth slows down and the grain yield decreases. The objectives of this research were to study the effect of different planting density and cultivars on biomass production and chemical composition of sorghum grown for biogas production.

MATERIALS AND METHODS

Field experiments were carried out during the 2008 and 2009 growing seasons at the experimental station Giessen (50° N, 8° E) which is characterized by a long-term annual mean temperature of 8.5°C and long-term precipitation sum of 660 mm per year. The soil is characterized by the following parameters: clay content 30% (0 – 30 cm), humus content 2% (0 – 30 cm), available field capacity 202 mm (0 – 100 cm) and pH6.0 (0 – 30 cm). The soil analyses showed values of P: 5.0, 9.0 mg/100 g, K: 10.6, 8.7 mg/100 g and Mg: 12.0, 15.7 mg/100 g of soil in 2008 and 2009, respectively. The weather conditions during the sorghum growing period received precipitation of 315 and 300 mm and mean air temperature of 15.1 and 15.8°C in 2008 and 2009 respectively. In 2008, higher amounts of rainfall were measured in the phase May to July whereas relatively homogenous distribution was observed in 2009 (Figure 1). The air temperatures over the course of time were similar in both years.

Treatments consisted of different sowing dates, three plant densities (16, 24 and 32 plants m^{-2}) and two cultivars: Goliath (late maturing, *S. bicolor x S. bicolor,* source: Agroczemek KFT., Hungary) and Bovital (early maturing, *S. bicolor x S. sudanense,* source; Agroczemek KFT., Hungary). Three different sowing dates were used each year: May 16th, May 29th, June 7th in 2008 and May 14th, June 10th, June 8th in 2009. The experiment was designed using randomized complete block design (RCBD) with a factorial arrangement in four replications. Each plot area was 10 m^2. Nitrogen fertilizer, ammonium nitrate, was applied directly after sowing with 120 kg N ha^{-1}. Weeds were controlled both by the application of the herbicide Gardo Gold (chloroacetinelide) at a rate of 3.5 L ha^{-1} and manually.

LAI was determined at three times during the plant development (30, 60 and 90 days after germination) using a pre-calibrated Sun Scan canopy analysis system from Delta T Company, which measures the incident and transmitted photosynthetic active radiations (PAR) in crop canopies. Two meter area was marked from middle rows. Number of tillers were counted from marked area and then calculated on m^{-2} basis. At harvesting, plant samples were taken from 1 m^2 in each plot and separated into leaves, stems and panicles. The dry weight of each part (leaves, stems and panicles) was determined from 1 m^2. DM contents of whole sorghum plant samples were determined at a constant air temperature of 105°C. Immediately after harvest, the whole plant dry matter and moisture content of all samples were determined by keeping 100 g of each sample in a laboratory drying oven set at a constant temperature of 105°C for 48 h. Samples intended for NIRS analysis of the chemical composition of sorghum were dried, finely ground and stored.

The contents of protein, sugar, ash, neutral detergent fibre (NDF) and acid detergent lignin (ADL) of sorghum were determined using near infrared reflectance spectroscopy (NIRS). The NIRS technology exploits the fact that different chemical components of biomass absorb and reflect specific wavelengths within the infrared range (750 to 2500 nm). The prediction equations were used for analyzing the sorghum samples from the conducted research were based on calibration samples collected at the time of harvest from different experimental stations of the institute in 2008. The results from the calibrated sample were used to develop the prediction equation by modified partial least squares regression (Shenk & Westerhaus 1991). An analysis of variance (ANOVA) of the data was conducted using the PIAF software (planning information analysis program for field trials). General Linear Model (GLM) and multiple comparisons were performed using a t test. The means of the results in executed experiments were compared by using LSD at $p<0.05$.

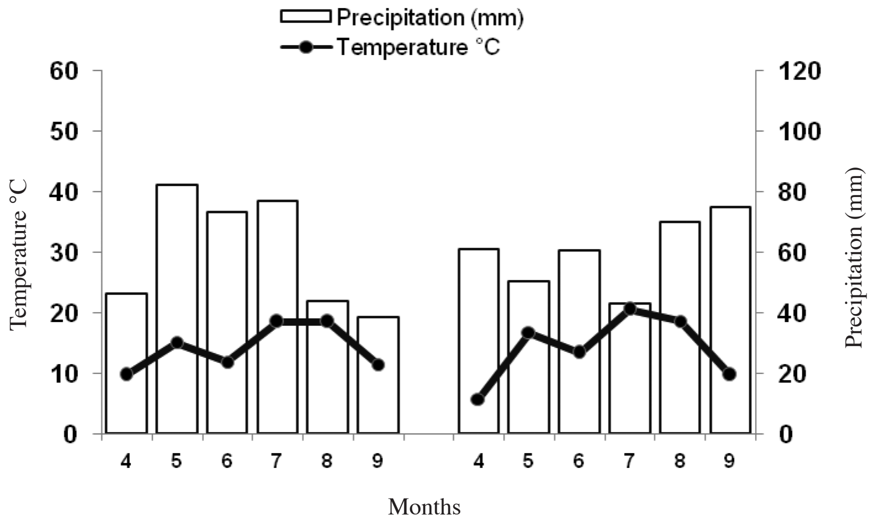

FIGURE 1. Monthly average air temperature (°C) and sum of precipitation (mm) for the growing season 2008 and 2009 at experimental station Giessen

TABLE 1. Effect of different cultivars and planting densities on leaf area index (LAI) of sorghum at different sowing time in Giessen 2008 and 2009

Treatment	1st sowing time						2nd sowing time						3rd sowing time					
	LAI (37 DAS)		LAI (67 DAS)		LAI (97 DAS)		LAI (37 DAS)		LAI (67 DAS)		LAI (97 DAS)		LAI (37 DAS)		LAI (67 DAS)		LAI (97 DAS)	
	2008	2009	2008	2009	2008	2009	2008	2009	2008	2009	2008	2009	2008	2009	2008	2009	2008	2009
Cultivar																		
Goliath	2.3a	–	3.4a	4.6a	5.1a	4.4b	1.8a	2.4a	3.4a	3.6a	5.4a	4.1a	2.0a	2.0a	4.2a	3.5a	5.2a	4.1a
Bovital	2.4a	–	3.4a	4.8a	4.8a	4.9a	1.4b	2.2a	3.3a	3.8a	5.0a	4.0a	1.9a	1.7a	3.7b	3.7a	4.8a	3.9a
$LSD_{0.05}$	ns	–	ns	ns	ns	0.4	0.3	ns	ns	ns	ns	ns	ns	ns	0.3	ns	ns	ns
Plant density (m^{-2})																		
16	2.2a	–	3.3a	4.4a	4.9ab	4.5a	1.4a	2.1b	3.2b	3.4a	4.6b	3.6a	1.7a	1.4a	3.6b	3.2a	4.9a	3.6a
24	2.4a	–	3.5a	4.7a	5.3a	4.5a	1.6a	2.2b	3.3ab	3.7a	5.3a	4.3a	2.0a	2.0a	4.1a	3.7a	5.0a	4.2a
32	2.3a	–	3.3a	5.1a	4.8b	5.0a	1.7a	2.6a	3.6a	4.0a	5.7a	4.3a	2.1a	2.1a	4.2a	3.8a	5.2a	4.1a
$LSD_{0.05}$	ns	–	ns	ns	0.4	ns	ns	0.3	0.3	ns	0.6	ns	ns	ns	0.3	ns	ns	ns

Sowing times are analyzed separately. Significant differences were measured by the least significant differences (LSD) at p <0.05 and indicated by different letters

TABLE 2. Effect of different cultivars and planting densities on number of tillers (m^{-2}), dry matter concentration (DMC) and dry matter yield (DMY) of sorghum at different sowing time in Giessen 2008 and 2009

Treatment	1st sowing time						2nd sowing time						3rd sowing time					
	Tillers(m^{-2})		DMC		DMY(t ha^{-1})		Tillers(m^{-2})		DMC		DMY(t ha^{-1})		Tillers(m^{-2})		DMC		DMY(t ha^{-1})	
	2008	2009	2008	2009	2008	2009	2008	2009	2008	2009	2008	2009	2008	2009	2008	2009	2008	2009
Cultivar																		
Goliath	26b	21b	24.3b	24.1a	11.2a	15.6a	34b	17b	24.2a	22.7b	11.3a	13.8a	13b	19b	16.5b	23.0b	6.2a	13.8a
Bovital	37a	26a	26.5a	24.0a	9.6b	9.7b	46a	27a	25.8a	23.4a	9.1b	9.6b	27a	30a	20.5a	24.7a	4.8b	11.3a
$LSD_{0.05}$	6	2	1.4	ns	1.3	1.7	7	2	ns	0.7	1.4	0.9	3	2	1.8	1.1	0.46	ns
Plant density (m^{-2})																		
16	30a	21b	24.8a	23.9a	9.6a	11.7a	38a	17c	24.3a	22.4b	9.8a	10.3b	16c	22c	18.7a	28.3a	5.5a	11.6a
24	33a	22b	25.5a	24.1a	10.7a	12.4a	40a	22b	25.4a	23.6a	10.4a	12.4a	19b	24b	18.6a	24.0a	5.6a	13.3a
32	31a	28a	25.9a	24.3a	10.9a	13.9a	43a	27a	25.3a	23.1ab	10.4a	12.4a	24a	28a	18.2a	24.7a	5.5a	12.8a
$LSD_{0.05}$	ns	3	ns	ns	ns	ns	ns	3	ns	0.8	ns	1.1	2	2	ns	ns	ns	ns

Sowing times are analyzed separately. Significant differences were measured by the least significant differences (LSD) at p <0.05 and indicated by different letters

RESULTS

In all the sowing times, leaf area index (LAI) of the sorghum plant ranged from 1.4 to 2.6 at 37 days after sowing (DAS), 3.2 to 5.1 at 67 DAS and 3.6 to 5.7 at 97 DAS in both cultivars and planting densities during both years (Table 1). In the 1st sowing time, LAI was unaffected by cultivars at 37 and 67 DAS stages of measurement. Goliath showed a significantly higher LAI than Bovital at 37 in the 2nd sowing and 67 DAS in the 3rd sowing during 2008. An increasing trend in LAI was observed in most cases with higher plant density (PD) except in 1st sowing measured at 97 DAS; in that case the medium level of PD (24 plants m^{-2}) exhibited a significantly higher LAI value, followed by 16 plants m^{-2}, while the lowest value was determined for higher plant density (32 plant m^{-2}).

Cultivars affected the numbers of tillers m^{-2}, with Bovital producing significantly more tillers than Goliath. During 2009, in the 1st and 2nd sowing, plots where 32 plants of sorghum was maintained recorded higher number of tillers (m^{-2}) than 16 or 24 plants m^{-2}. Similar trend was found in 2008, when PD of 32 plants m^{-2} produced markedly higher numbers of tillers m^{-2} in the 3rd sowing time (Table 2).

Planting densities did not influence the dry matter (DM) content except in 2nd sowing time during 2009 where medium plant density showed the highest DM content (Table 2). Mostly, the DM content was significantly affected by cultivar. Early maturing cv. Bovital exhibited a considerably higher DM content than late maturing cv. Goliath. The DM yield increased from 4.80 to 15.6 t ha^{-1}. Comparable average DM yields were determined for all PDs except in 3rd sowing time (2009) where the minimum DM yield was produced with lowest PD. Cultivars had a marked effect on DM yield, with Goliath producing significantly higher DM yields than Bovital. A significant interaction between cultivar and plant density was noticed in the 3rd sowing during 2008. Goliath produced the maximum DM yield with a higher PD than other treatments (Figure 2).

The biomass distribution of sorghum organs was highly significant between cultivars in all sowing times. Late maturing cv. Goliath has a greater proportion of both leaves and stems compared with early maturing cv. Bovital. Bovital produced a greater proportion of panicles than did cv. Goliath (Figure 3). Planting densities did not affect days to flowering initiation, however cultivars were differ for days to flowering initiation. Early maturing cv. Bovital initiated flowering 25 days earlier than that of Goliath (data not shown).

Cultivar differed for protein concentration with Bovital producing significantly higher protein concentration compared with Goliath. In 2008, PD had a clear effect on protein concentration in the 2nd and 3rd sowing time (Table 3). Significant interaction of PD and CV was observed for protein concentration in the 1st and 2nd sowing times (Figures 4(a) and 5(a)). In the 1st sowing time, Bovital produced higher protein content with 32 plants m^{-2} in comparison with other treatments (Figure 4(a)). In the 2nd sowing time, comparable protein content was obtained with Bovital (16, 24 and 32 plants m^{-2}) and Goliath (32 plants m^{-2}) but clearly lower protein content was found in Goliath at 16 and 24 plants m^{-2} (Figure 5(a)). During 2009, protein content was not affected by PD in the 1st and 3rd sowing times. In contrast, in the 2nd sowing time, PD had a marked effect on the protein concentration of sorghum. Higher PD induced a clear decline in protein content, while comparable content were obtained with lower and medium PD (Table 3). Bovital showed markedly higher protein content compared to Goliath.

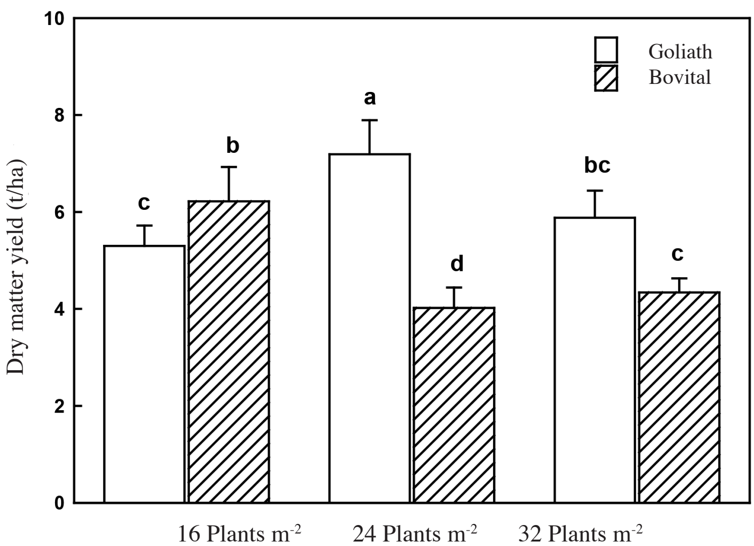

FIGURE 2. Interaction between planting density and cultivars regarding dry matter (DM) yield of sorghum during the growing season 2008. Values represent means ± S.D. significant differences were measured by the least significant differences (LSD) at $p<0.05$ and indicated by different letters

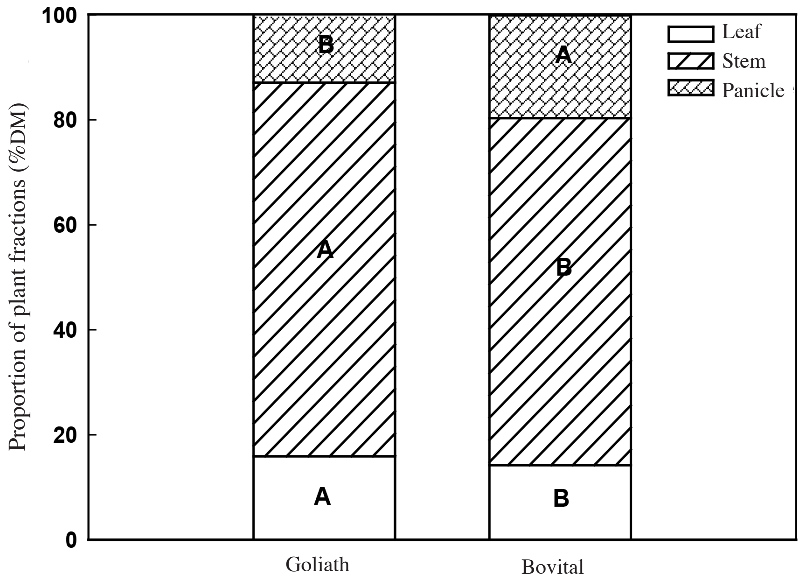

FIGURE 3. Impact of cultivars on biomas distribution sorghum during the growing season 2009. Values represent means ± S.D. significant differences were measured by the least significant differences (LSD) at $p<0.05$ and indicated by different letters

NDF content ranged from 51 (3rd sowing) to 60% (1st sowing). Goliath reached significantly higher NDF than that of Bovital (Table 3). An interaction between cultivar and PD regarding NDF content was observed in the 1st and 2nd sowing time in 2008. During 1st sowing time, Bovital with 32 plant m^{-2} showed the lowest NDF content among the treatments (Figure 4(c)). In the 2nd sowing time comparable NDF content were observed in both cultivars at all levels of PD except Bovital at 16 plants m^{-2} (Figure 5(c)).

In most of cases, both cultivars produced similar lignin content (Table 3). Lignin content was not affected by different PD except in the 2nd sowing time where plant density of 32 plant m^{-2} reached significantly higher content compared with other PDs. There was a significant interaction (CV by PD) regarding the ADL content in the 1st and 2nd sowing times during 2008. A similar ADL content was determined for Goliath at all levels of PD in 1st sowing time. Bovital also showed comparable averages of ADL content at all three levels of PD; these averages were significantly lower than other treatments (Figure 4(b)). Almost the same trend was noticed in the 2nd sowing time except in the case of Bovital with higher PD (Figure 5(b)).

Cultivars had significant impact on sugar content with Goliath producing higher sugar content compared with Bovital. Sugar content was not clearly influenced by different PD (Table 4).

During 2008, ash content was not affected by cultivar in the 1st and 2nd sowing times but Bovital reached higher ash content than Goliath in the 3rd sowing time. Goliath exhibited significantly lower ash content compared to Bovital in 2009 (Table 4). Plant density had no clear effect on ash content of sorghum.

DISCUSSION

Leaf area index (LAI) is an important structural property of crop canopy that predicts photosynthesis and can be characterized as a reference tool for crop growth measurements (Lan et al. 2009). In recent experiments, it was observed that LAI values of tested sorghum cultivars were higher than those of grain sorghum (Wiedenfeld & Matocha 2010). The higher PD (24 and 32 plant m^{-2}) resulted in an increase in the LAI value of sorghum during the testing period. The increase in LAI with higher plant densities may be due to an increase in light interception as a result of more leaf cover than with lower plant density. These findings conform to previous work that showed a clear increase in LAI of grain sorghum as plant density increased from 5 to 26 plants m^{-2} (Rosenthal et al. 1993). Under current environmental conditions, the highest LAI achieved was 97 DAS with different sowing times. The continuous increase in leaf area index of sorghum from 37 to 97 DAS might be due to increase in plant height, number of leaves and single leaf area of sorghum plants under the specific environmental conditions of the current study.

The methane yield ha^{-1} is the product of biomass yield and specific methane yield per $(kg\ VS)^{-1}$. The present study showed that Goliath produced a consistently higher DM yield compared with Bovital. It can be supposed that greater genetic potential and a longer growth cycle (late maturing characteristics) enable Goliath to yield more biomass ha^{-1} than Bovital. Therefore it can be suggested that Goliath may produce higher biogas as well as methane yield ha^{-1} compared to Bovital due to its higher biomass yield. PD has no clear impact on the DM yield of sorghum in the present study. The lower PDs caused a slight decline in the DM yield of sorghum. This similarity in DM yields might be due to the

TABLE 3. Effect of different cultivars (CV) and planting densities (PD) on number of protein (XP), neutral detergent fiber (NDF) and acid detergent lignin (ADL) content of sorghum at different sowing time (ST) in Giessen 2008 and 2009

Treatment	1st sowing time						2nd sowing time						3rd sowing time					
	Protein (%)		NDF (%)		ADL (%)		Protein (%)		NDF (%)		ADL (%)		Protein (%)		NDF (%)		ADL (%)	
	2008	2009	2008	2009	2008	2009	2008	2009	2008	2009	2008	2009	2008	2009	2008	2009	2008	2009
Cultivar																		
Goliath	7.5b	8.3b	61.4a	53.8a	5.4a	5.0a	8.1b	9.2b	57.9a	53.8a	5.3a	4.9a	10.4a	8.9b	53.1a	53.1a	4.1a	4.9a
Bovital	8.0a	10.3a	59.5b	51.6b	5.2b	4.6a	9.1a	11.1a	58.7a	51.5b	5.0a	4.6b	10.4a	10.1a	54.3a	51.1b	4.4a	4.8a
$LSD_{0.05}$	0.4	0.4	1.1	0.6	0.2	ns	0.5	0.3	ns	0.6	ns	0.2	ns	0.4	ns	1.4	ns	ns
Plant density (m^{-2})																		
16	7.8a	9.4a	60.9a	52.5a	5.3a	4.7a	8.6b	10.4a	57.8a	52.5a	5.1a	4.6b	10.9a	9.5a	53.5a	51.9a	4.1a	4.9a
24	7.5a	9.5a	60.3a	52.6a	5.3a	4.7a	9.3a	10.2a	57.2a	52.6a	5.0a	4.6b	10.0b	9.6a	54.5a	52.4a	4.4a	4.8a
32	7.9a	9.1a	60.2a	52.9a	5.3a	4.9a	8.0b	9.8b	60.0a	52.9a	5.3a	4.9a	10.4ab	9.3a	53.1a	52.0a	4.4a	4.8a
$LSD_{0.05}$	ns	ns	ns	ns	ns	ns	0.6	0.4	ns	ns	ns	0.2	0.5	ns	ns	ns	ns	ns

Sowing times are analyzed separately. Significant differences were measured by the least significant differences (LSD) at $p < 0.05$ and indicated by different letters

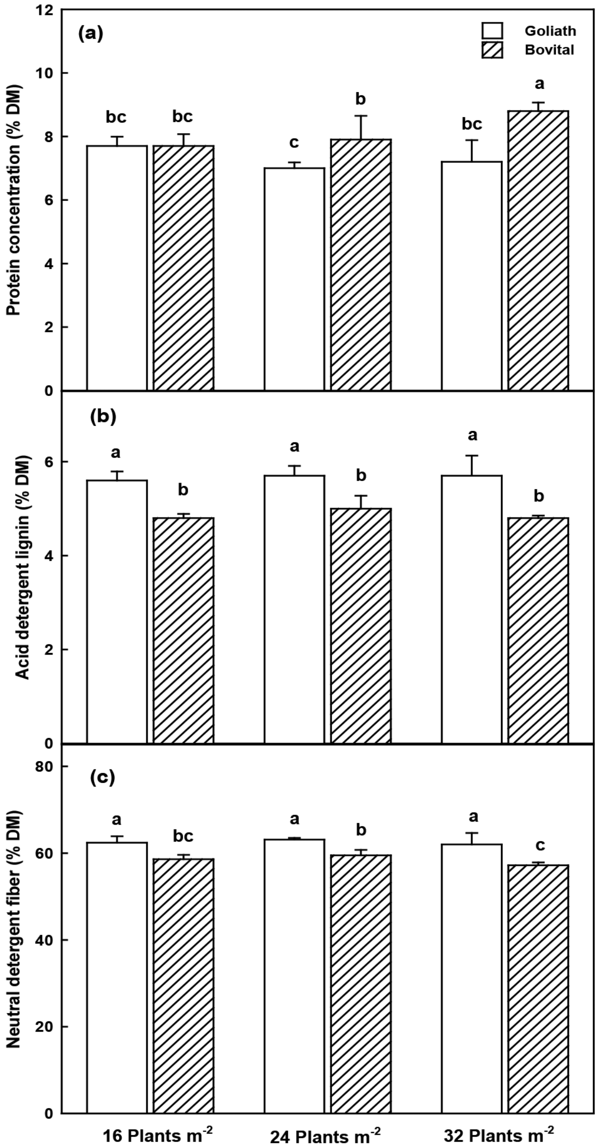

FIGURE 4. Interaction between planting density and cultivars for (a) protein concentration, (b) acid detergent lignin and (c) neutral detergent fiber of sorghum at 1st sowing time during the growing season 2008. Values represent means ± S.D. significant differences were measured by the least significant differences (LSD) at $p<0.05$ and indicated by different letters

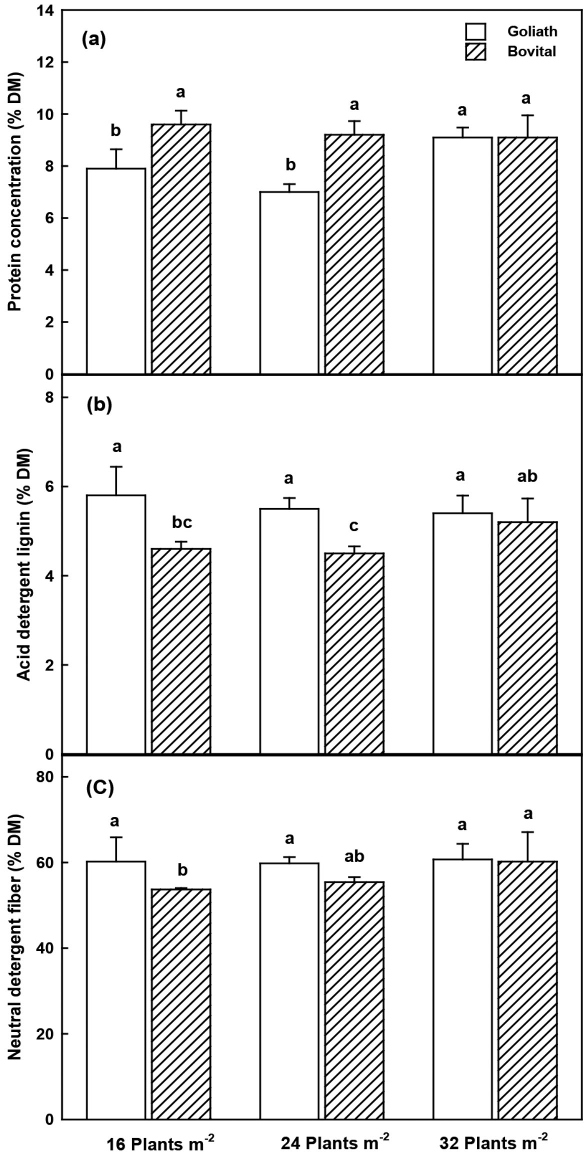

FIGURE 5. Interaction between planting density and cultivars for (a) protein concentration, (b) acid detergent lignin and (c) neutral detergent fiber of sorghum at 2nd sowing time during the growing season 2008. Values represent means ± S.D. significant differences were measured by the least significant differences (LSD) at $p<0.05$ and indicated by different letters

compensation of fewer plants m^{-2} by other yield parameters including a higher number of tillers per plant, thicker stems and taller plants. An extremely lower DM yield with the delayed sowing time (first week of June) was observed at Giessen (2008). In fact, the plants with a delayed sowing time (first week of June) at Giessen (2008) received a markedly lower precipitation of 150 mm during the whole period of their development. The lesser availability of water might be the reason for the clear decline in DM yield because of the reduced photosynthesis activity. The gross and net photosynthesis in sunflowers declined in linear proportion from low to moderate water stress (Krampitz et al. 1984). Other effects of water stress given in the literature are a reduction in intercellular CO^2 concentration with a consequent reduction in the net photosynthesis observed in sorghum (Kreig & Hutmacher 1986).

Biogas and biomethane production mainly depends on the crude protein content of maize biomass (Oslaj et al. 2010). In the present study, protein concentrations of tested sorghum cultivars ranged from 6 to 9%, which is similar to those of hybrids of maize and forage sorghum as recorded by Iptas and Acar (2006; 6–8%), Marsalis et al. (2010; 6–7%) and Miron et al. (2006; 6–8%). The data demonstrated that sorghum cultivars exhibited differences in protein content. The higher protein content in the present trials for Bovital might be the higher number of tillers per

TABLE 4. Effect of different cultivars and planting densities on number of sugar and ash content of sorghum at different sowing time (ST) in Giessen 2008 and 2009

Treatment	1st sowing time				2nd sowing time				3rd sowing time			
	Sugar content		Ash content (XA)		Sugar content		Ash content (XA)		Sugar content		Ash content (XA)	
	2008	2009	2008	2009	2008	2009	2008	2009	2008	2009	2008	2009
Cutivar												
Goliath	6.9a	15.5a	8.4a	8.6b	9.5a	12.7a	8.8a	8.6b	13.1a	12.1a	9.4b	8.7b
Bovital	7.4a	9.4b	8.3a	9.2a	7.2b	10.1b	9.1a	9.4a	11.5b	11.0b	9.8a	9.2a
$LSD_{0.05}$	0.4	1.7	ns	0.2	2.0	0.8	ns	0.2	1.0	1.2	0.4	0.3
Plant density (m^{-2})												
16	6.9a	11.9a	8.5a	8.7a	7.6a	11.3a	9.0a	9.3a	11.7a	12.0a	9.8a	8.9a
24	7.4a	13.6a	8.1b	8.9a	8.0a	11.1a	8.9a	9.1a	12.0a	11.6a	9.6a	8.9a
32	7.1a	11.9a	8.5a	8.9a	9.3a	11.8a	9.0a	8.7b	13.3a	11.9a	9.6a	8.8a
	7.1	12.5	8.3	8.9	8.3	11.4	9.0	9.0	12.3	11.6	9.6	8.6
$LSD_{0.05}$	ns	ns	0.3	ns	ns	ns	ns	0.3	ns	ns	ns	ns

Sowing times are analyzed separately. Significant differences were measured by the least significant differences (LSD) at $p < 0.05$ and indicated by different letters plant. In comparison with main stems and older leaves, tillers are physiologically younger plant organs with higher protein synthesis activity. It can be supposed that increased protein content in Bovital may enhance the specific biogas and methane yield of this cultivar than that of Goliath. The higher NDF content in Goliath might be a result of greater fraction of leaves and stems in this variety which contain more NDF (Carmi et al. 2005). In the present study PD has no clear effect on the NDF content of sorghum. These findings are in accordance with Carmi et al. (2006) and Marsalis et al. (2010), who reported that an increase in PD did not affect the NDF contents of sorghum, but are in contrast with observations in corn (Widdicombe & Thelen 2002). Thus, it appears that the responses to PD of sorghum and corn are different concerning NDF concentration. The efficiency of the fiber content to biogas and methane conversion depends on the ratio of polysaccharide to lignin content in the plant biomass (Klimiuk et al. 2010).

Lignin is highly resistant to chemical cleavage and protects cellulose fibers from cellulose hydrolysis to glucose (Chang & Holtzapple 2000). The content of lignin in the biomass of sorghum was comparable for both cultivars evaluated in the present experiments. Therefore it can be assumed that rate of fiber content to biogas and methane conversion may be almost similar. Planting density has little impact on composition of sorghum. Significant interactions between cultivars and plant density for quality parameters suggest that the chemical composition of sorghum cultivars can be expected to be different with varying plant densities. A lower availability of water can significantly reduce the biomass yield of sorghum. Biomass yield is of prime importance because higher biomass yields per ha can significantly affect methane yields ha^{-1}. Although higher gain of specific methane yield is expected with Bovital due to higher protein contents but cultivars with higher biomass yields like Goliath can enhance methane production ha^{-1}. However, further experiment should be conducted including more cultivars on this aspect.

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