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Athar Mahmood[2], **Bernd Honermeier**[1]

Effect of row spacing and cultivar on biomass yield and quality of *Sorghum bicolor* L. Moench

Effekt von Reihenabstand und Sorte auf den Biomasse-Ertrag
und die Qualität von *Sorghum bicolor* L. Moench

Abstract

Two years research was conducted to study comprehensively the effect of different row spacing on biomass yield and chemical composition of different sorghum cultivars under field conditions in Germany. Three row spacing (75 cm, 37.5 cm, double rows 75 cm apart with strip rows of 10–15 cm) and two cultivars (Goliath (*S. bicolor* × *S. bicolor*), Bovital (*S. bicolor* × *S. sudanense*)) were included in 2008, while the same row spacings and five cultivars (Goliath, Bovital, Aron (*S. bicolor*), Rona 1 (*S. bicolor*), Akklimat (*S. sudanense*)) were tested in 2009. In 2008 the leaf area index (LAI) difference between the tested cultivars was significant only after 90 days following germination when Bovital reached higher LAI than Goliath. Among all five tested cultivars in 2009 the lowest LAI was observed for Akklimat at all three measuring dates. The narrow row space of 37.5 cm led to increased LAI while the wider row spacing caused a significant decrease of the number of tillers/m² in both years. Dry matter yield of sorghum ranged in both experimental years from min. 10.10 t DM/ha (cv. Akklimat 2009) to max. 19.72 t DM/ha (cv. Goliath 2008). Row spacing had no clear effect on the dry matter yield in 2008 whereas in 2009 double rows of 75 cm and narrow row spacing (37.5 cm) led to significantly higher biomass yield than wide row spacing of 75 cm. Effects of row spacing were inverse between years regarding crude protein concentration. Cv. Rona 1 accumulated highest values of sugar concentration (18.7%) and together with cv. Aron lowest values for neutral detergent fiber (NDF), acid detergent fiber (ADF) and acid detergent lignin (ADL) concentration compared with other cultivars.

Key words: Sorghum, row spacing, number of tillers, leaf area index, dry matter yield, chemical composition

Zusammenfassung

Ein zweijähriges Forschungsprojekt wurde durchgeführt, um den Effekt verschiedener Reihenabstände auf den Biomasseertrag und die chemische Zusammensetzung verschiedener Sorghum-Sorten unter Feldbedingungen in Deutschland zu untersuchen. Es wurden drei Reihenweiten berücksichtigt (75 cm, 37,5 cm, Doppelreihen mit 75 cm zwischen und 10–15 cm innerhalb der Doppelreihe). Diese Reihenweiten wurden im Jahr 2008 in Kombination mit zwei Sorten (Goliath (*S. bicolor* × *S. bicolor*), Bovital (*S. bicolor* × *S. sudanense*)) und im Jahr 2009 mit fünf Sorten (Goliath, Bovital, Aron (*S. bicolor*), Rona 1 (*S. bicolor*) und Akklimat (*S. sudanense*)) untersucht. Im Jahr 2008 wurden signifikante LAI-Unterschiede 90 Tage nach Feldaufgang zwischen den getesteten Sorten beobachtet, wobei Bovital höhere LAI-Werte erreichte als Goliath. Von allen getesteten Sorten wurde der niedrigste LAI bei der Sorte Akklimat zu allen drei Terminen gemessen. Der niedrige Reihenabstand von 37,5 cm führte zu einer Erhöhung des LAI im Vergleich zu den anderen Reihenweiten. Darüber hinaus wurde beobachtet, dass ein weiterer Reihenabstand in beiden Jahren eine signifikante Verringerung der Anzahl an Trieben/m² verursachte. Der Biomasseertrag von Sorghum schwankte in beiden Experimenten von minimal 10,10 t TM/ha (cv. Akklimat 2009) bis maximal 19.72 t TM/ha (cv. Goliath 2008). Der Reihenabstand hatte im Jahr 2008 keinen Einfluss auf den Trockenmasseertrag, während im Jahr 2009 die Doppel-

Institute
Justus Liebig University, Institute of Agronomy and Plant Breeding, Giessen, Germany[1]
University College of Agriculture, University of Sargodha, Sargodha, Pakistan[2]

Correspondence
Athar Mahmood, Prof. Dr. Bernd Honermeier, Justus Liebig University, Institute of Agronomy and Plant Breeding, Ludwigstr. 23, 35390 Giessen, Germany, E-Mail: athar_1012@yahoo.com

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reihe und 37,5 cm Reihenweite zu signifikant höheren Biomasse-Erträgen führten. Die Proteinkonzentration war im Jahr 2008 bei geringen Reihenabständen gleich, während deutlich niedrigere Werte für 75 cm Reihenabstand festgestellt wurden. Im Jahr 2009 wurden dagegen bei der Reihenweite von 75 cm und bei der Doppelreihe signifikant höhere Proteinkonzentrationen beobachtet als bei einem Reihenabstand von 37,5 cm. Rona 1 erreichte mit 18,7% TM die höchsten Zucker-Konzentrationen aller getesteten Sorten. Unter den fünf getesteten Sorten zeigten Rona 1 und Aron niedrigere Konzentrationen an Neutral-Detergenzien-Faser (NDF), Säure-Detergenzien-Faser (ADF) und Säure-Detergenzien-Lignin (ADL).

Stichwörter: Sorghum, Reihenabstand, Triebzahl, Blattflächenindex, Trockenmasseertrag, chemische Zusammensetzung

Introduction

Sorghum (*Sorghum bicolor* L. Moench) is an annual or perennial grass which belongs to the family of *Poaceae* with high biomass yield potential (Fribourg, 1995; Rooney et al., 2007). Sorghum is used as grain crop as well as forage and energy crop. The most important producers of grain sorghum are USA, India, Nigeria and China (FAO, 2009). Within the species *Sorghum bicolor*, which is characterized by a diploid set of chromosomes (2n = 20), are several subspecies or races with different morphological and physiological characteristics (Zeller, 2000). Since plant breeders found first lines with cytoplasmatic male sterility in the 1950 s, hybrid breeding technology is established in *Sorghum bicolor* too. Presently several cultivars, most of them are hybrids, are available which have been selected specifically for high forage biomass (Roth and Harper, 1995; Redfearn et al., 2000; Blumenthal et al., 2007). Cultivars of sorghum differ in their chemical composition, including content of water-soluble carbohydrates (WSC) and crude protein (CP), as well as in their structural fibrous ingredients, including neutral detergent fiber (NDF), acid detergent fiber (ADF) and acid detergent lignin (ADL). Consequently, clear differences between varieties with respect to dry matter and NDF digestibility of silage have been found (Hanna et al., 1981; Pedersen et al., 1982; Ashbell et al., 1999).

Studies with sorghum indicated higher biomass yields from narrow rows than from wide rows under favorable conditions (Steiner, 1986; Staggenborg et al., 1999). Blum and Naveh (1976), who carried out experiments with grain sorghum, reported that at the same plant density, double-row planting resulted in reduced dry matter, tillering and LAI during early plant growth compared to single-row planting due to increased intra-specific plant competition.

Presently sorghum is introduced as a new crop used for biogas production in Germany. Agronomic measures like row spacing, sowing and harvest dates have not been tested under climatic conditions of Germany, yet. The objectives of this research were to study the effect of different row spacing and cultivars on biomass production and chemical composition of *Sorghum bicolor* under field conditions in Germany.

Materials and Methods

Field experiments were conducted in 2008 and 2009 at the experimental station Giessen (50°35'N, 8°40'E) characterized by long term annual mean temperature of 8.5°C and long term precipitation sum of 660 mm per year. The station is located in the valley of the Lahn river about 1°12' northward displacement. The soil is a fluvisol, characterized by the following parameters: 30% clay (0–30 cm), 2% humus (0–30 cm), 202 mm available field capacity (0–100 cm) and pH 6.0 (0–30 cm). The soil analyses showed values of 5.0 or 9.0 mg P/100 g, 10.6 or 8.7 mg K/100 g and 12.0 or 15.7 mg Mg/100 g of soil in 2008 or 2009, respectively. The weather conditions during the growing period of sorghum were characterized by precipitation of 315 or 300 mm and mean air temperature of 15.1 or 15.8°C in 2008 or 2009, respectively. In 2008 higher amounts of rainfall were measured in May to July whereas relatively homogenous distribution was observed in 2009 (Fig. 1). The development of air temperature was similar in both years. Three row spacing (75 cm, 37.5 cm, double rows 75 cm apart with strip rows of 10–15 cm) and two cultivars (biomass sorghum cv. Goliath (*S. bicolor* × *S. bicolor*) and forage sorghum cv. Bovital (*S. bicolor* × *S. sudanense*)) were included in 2008, while same row spacing and five cultivars (Goliath, Bovital, biomass sorghum cv. Aron (*S. bicolor*), cv. Rona 1 (*S. bicolor*) and forage sorghum cv. Akklimat (*S. sudanense*)) were tested in 2009. The experimental design was randomised complete block design under split-plot arrangement with row spacing as main plots and cultivars as subplots in four replications. Each subplot area was 10 m^2. The sowing time of sorghum was 8 May 2008 and 20 May 2009. Plant density of 20 plants m^{-2} was maintained by thinning. Fertilizers were applied with 120, 80 and 80 kg/ha nitrogen, phosphorous and potassium directly after sowing. Weeds were controlled by the application of herbicide Gardo Gold at 3.5 l/ha and additionally by manual practices. Crops were harvested on 9 September 2008 and 6 October 2009 when they reached approximately soft dough stage.

LAI were measured at three stages of plant development (30, 60 and 90 days after germination) by using a pre-calibrated Sun Scan canopy analysis system (Delta T Company) which measures and analyses incident and transmitted photosynthetic active radiations (PAR) in crop canopies. Before harvest, plant samples of 1 m^2 from each plot were taken and separated into leaves, stems and panicles. The dry weight of each fraction (leaves, stems and panicles) was detected for the whole plant samples from 1 m^2. Plant height at the time of harvest was measured by using bricklayer ruler. Immediately after harvest dry matter content of all samples was determined

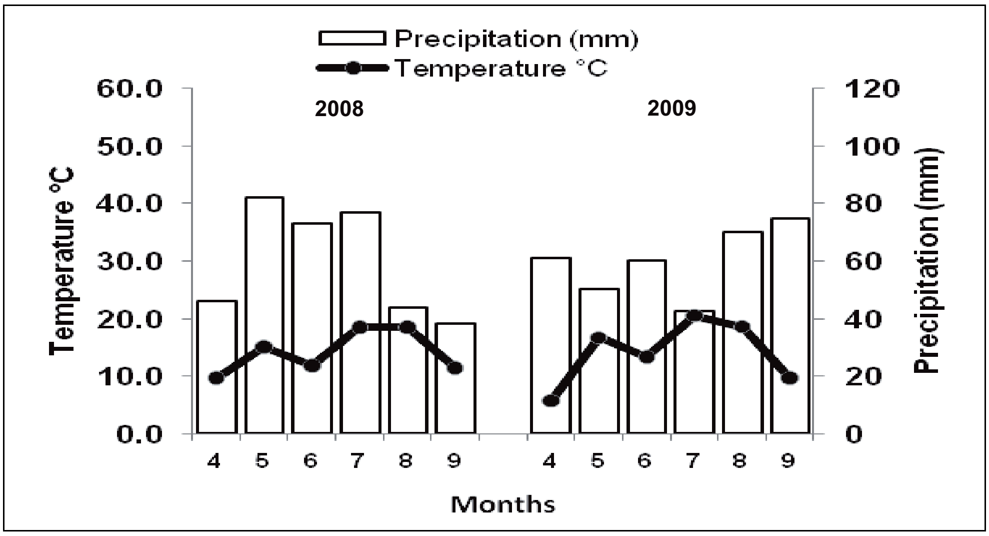

Fig. 1. Monthly average air temperature [°C] and sum of precipitation [mm] for the growing seasons 2008 and 2009 at experimental station Giessen.
Monatliche Durchschnittstemperatur [°C] und Niederschlagssumme [mm] der Vegetationsperioden 2008 und 2009 an der Versuchsstation Gießen.

by drying at 105°C for 48 hours. Plant samples intended for NIRS analysis were dried, finely grounded, packaged into dry paper sachets and stored.

NIRS (Near-Infrared Reflectance Spectroscopy) was used to determine ash, lipids (XL), crude protein (XP), sugar (XZ), neutral detergent fibre (NDF), acid detergent fibre (ADF) and acid detergent lignin (ADL) concentrations. Scanning of the samples was done with a Foss NIR-system scanning monochromator (Model 6500, Silver, Spring, MD) at the range of 780 to 2500 nm. The prediction equation based on a calibration established in our lab with sorghum in 2008. Results from the calibrated samples were used to develop a prediction equation by modified partial least squares regression (Shenk and Westerhaus, 1991). The volatile solids (VS) content was calibrated as weight loss during incineration at 550°C by muffle furnace for the estimation of organic matter in the samples. The ash content was measured as the incineration residues.

An analysis of variance (ANOVA) of the data was conducted by using the PIAF software (planning information analysis program for field trials) and a General Linear Model (GLM) (Tab. 4; 5). Means were compared based on t-tests by LSD at $p < 0.05$. Correlation analysis was performed using PASW version 18 software (SPSS INC., Chicago, IL) to determine the relationship among the studied parameters according to Spearman's rho methods (Tab. 6).

Results

In both experimental years sorghum cultivars considerably differed for plant heights determined at harvest. In 2008 cv. Goliath reached a plant height of 364 cm, while significantly lower value was observed with cv. Bovital (284 cm). In 2009 maximal plant heights were observed with Goliath (262 cm), followed by cv. Bovital (248 cm) and the other three cultivars Aron, Rona 1 and Akklimat (225, 235 and 231 cm, respectively; Tab. 1). Row spacing had also a significant effect on the plant height of sorghum in 2008, while no influence was observed for plant height in 2009. Double row spacing (DR) and 37.5 cm led to similar plant heights of 324 and 321 cm whereas significantly lower plant height of 311 cm was determined for 75 cm. Regarding plant height no interaction between cultivars and row spacing was observed in both experimental years.

Leaf area index (LAI) of sorghum canopies ranged from 2.1 to 4.1 (30 days after germination) up to 3.9 to 5.5 (60 days after germination) and 4.3 to 5.4 (90 days after germination) (Tab. 1). In 2008 the LAI differed between cultivars only at 90 days after germination when Bovital reached higher LAI (5.0) than Goliath (4.7). In 2009 the LAI difference between cv. Goliath and Bovital was not significant. Among cultivars in 2009 the lowest LAI was observed for cv. Akklimat at all three measuring dates. Row spacing of 37.5 cm increased LAI in comparison to the other treatments inconsistently as this effect was observed at two measuring dates in 2008 (30 and 60 days after germination) and at one measuring date (90 days after germination) in 2009. Cultivars and row spacing clearly influenced the numbers of tillers/m^2 in both years. Cv. Bovital and Akklimat produced higher number of tillers/m^2 compared with other cultivars in 2008 and 2009 respectively. Wider row spacing caused a significant decrease of the number of tillers/m^2 in both years (Tab. 2). The DM yield of sorghum ranged from 10.10 t DM/ha (cv. Akklimat 2009) up to 19.72 t DM/ha (cv. Goliath 2008). In both experiments cv. Goliath produced significantly higher DM yields (Tab. 2). Row spacing had no clear effect on the DM yield in 2008 whereas in 2009 significant effects caused by row spacing were observed. Narrow row spacing of 75 cm (DR) and 37.5 cm exhibited significantly higher DM yield than wider row spacing of 75 cm (Tab. 2). However regarding DM yield no significant interaction was present between cultivars and row spacing. In 2008 the DM concentration of the harvested biomass was about 25 to 26% which was not influenced either by cultivar or by the row spacing. In 2009 cv. Goliath,

Tab. 1. Effect of cultivars and row spacing on leaf area index (LAI) and plant height (Ph) of *Sorghum bicolor* (Giessen 2008, 2009)
Effekt von Sorte und Reihenabstand auf Blattflächenindex (LAI) und Pflanzenhöhe (Ph) von Sorghum bicolor *(Gießen 2008, 2009)*

	Ph 1 (cm)	Ph 2 (cm)	Ph 3 (cm)	LAI 1 (m^2/m^2)	LAI 2 (m^2/m^2)	LAI 3 (m^2/m^2)
2008						
Goliath	143 a	247 a	363 a	3.5 a	4.3 a	4.7 b
Bovital	141 a	210 b	274 b	3.0 a	4.9 a	5.0 a
75 cm	126 b	214 b	311 b	3.0 b	4.4 b	4.9 a
37.5 cm	147 a	239 a	322 ab	4.1 a	5.5 a	5.4 a
75 cm (DR)	152 a	234 a	324 a	2.8 b	4.0 b	4.4 b
2009						
Goliath	135 a	228 a	262 a	3.2 a	4.6 a	4.7 ab
Bovital	120 b	193 b	248 b	3.2 a	4.7 a	4.9 a
Aron	113 bc	189 b	225 c	2.9 a	4.7 a	4.9 a
Rona 1	122 b	188 b	235 c	3.2 a	4.7 a	4.8 a
Akklimat	105 c	181 b	232 c	2.1 b	3.9 b	4.3 b
75 cm	129 a	204 a	238 a	2.9 a	4.4 a	4.3 b
37.5 cm	110 b	193 b	243 a	2.8 a	4.7 a	5.1 a
75 cm (DR)	118 b	191 b	241 a	3.0 a	4.5 a	4.8 a

Years are separately analyzed; different letters (a, b, c, d) differ significantly at $p < 0.05$. LAI 1, Ph 1 = 30 days after germination, LAI 2, Ph 2 = 60 days after germination, LAI 3, Ph 3 = 90 days after germination.
Jahre separat analysiert; verschiedene Buchstaben (a, b, c, d) unterscheiden sich signifikant ($p < 0.05$); LAI 1, Ph 1 = 30 Tage nach der Keimung, LAI 2, Ph 2 = 60 Tage nach der Keimung, LAI 3, Ph 3 = 90 Tage nach der Keimung.

Tab. 2. Effect of cultivars and row spacing on DM yield, DM %, tillers/m^2, leaf, stem and panicle proportion of *Sorghum bicolor* (Giessen 2008, 2009)
Effekt von Sorte und Reihenabstand auf Trockenmasse-Ertrag (DM), Trockenmasse [%], Bestockungstriebe/m^2, Blatt-, Stängel- und Rispenanteil von Sorghum bicolor *(Gießen 2008, 2009)*

	DM (t/ha)	DM (%)	Tillers/m^2	Organ partitioning (% of total DM)		
				Leaf	Stem	Panicle
2008						
Goliath	19.72 a	26.4 a	31.3 b	–	–	–
Bovital	12.64 b	25.4 a	45.4 a	–	–	–
75 cm	15.04 a	25.9 a	28.5 b	–	–	–
37.5 cm	16.50 a	25.9 a	45.7 a	–	–	–
75 cm (D.R)	17.00 a	26.0 a	40.7 ab	–	–	–
2009						
Goliath	15.81 a	26.3 a	30.6 c	21.3 a	66.0 a	12.7 d
Bovital	12.26 b	26.9 a	42.8 b	16.5 cd	54.1 c	29.4 a
Aron	10.19 c	22.0 b	34.2 bc	18.6 b	61.3 b	20.1 c
Rona 1	12.36 b	23.8 b	35.7 bc	16.0 d	60.7 b	23.3 bc
Akklimat	10.10 c	25.7 a	110.7 a	17.4 bc	58.5 b	24.1 b
75 cm	12.72 a	24.3 a	43.0 b	17.6 b	58.9 a	23.5 a
37.5 cm	10.24 b	24.9 a	54.6 a	18.8 a	60.3 a	20.9 a
75 cm (D.R)	13.47 a	25.6 a	54.8 a	17.4 b	61.2 a	21.4 a

Years are separately analyzed; different letters (a, b, c, d) differ significantly at $p < 0.05$, DM = dry matter yield.
Jahre separate analysiert; verschiedene Buchstaben (a, b, c, d) unterscheiden sich signifikant ($p < 0.05$); DM = Trockenmasse-Ertrag.

Bovital and Akklimat had nearly the same DM percentage but significantly lower value was observed with cv. Aron and Rona 1. Row spacing did not affect the DM content of sorghum biomass and no interaction of cultivar × row spacing was observed in either year. The relative proportion of stems in terms of dry matter which ranged from 54 to 66% had the highest proportion within the whole biomass followed by the proportion of panicles (13–29%) and leaves (16–21%) (Tab. 2). The biomass of cv. Goliath had the highest proportion of stems (66%) while lowest was observed with cv. Bovital (54%). Row spacing had no significant impact on relative proportion of stem and panicle. However it could be observed that cultivars had clear effect on the relative proportion of the panicles. Early maturing cv. Bovital had significantly higher proportion of panicle whereas late maturing cv. Goliath had lowest among the cultivars. There were main effects of different row spacing and cultivars on the relative proportion of leaves. Cv. Goliath produced considerably higher relative proportion of leaves whereas cv. Rona 1 exhibited the minimum value among cultivars. Row spacing of 37.5 cm led to increase the leaves relative proportion in comparison with 75 cm and double row (DR) 75 cm apart.

Chemical Composition

Cultivars significantly differed in the concentration of protein, sugar, NDF, ADF, ADL, XL and XA during the testing period (Tab. 3). Sugar concentration was not influenced by row spacing during 2008. In 2009, an average sugar concentration of 12.8, 10.7 and 12.3 g/100 g of DM were determined for 75 cm, 37.5 cm and 75 (DR), respectively. During 2008 Bovital was characterized by lower sugar concentration compared with cv. Goliath. Among cultivars, Rona 1 accumulated the highest sugar concentration (18.7%), similar to cv. Aron. Row spacing of 37.5 cm and 75 cm (DR) exhibited similar level of protein concentration while a clearly lower value was determined for 75 cm in 2008. In 2009 a significantly higher concentration was observed at 37.5 cm spacing compared to other row spacing. Cultivars markedly differed for protein concentration in their biomass. In 2008, cv. Bovital produced significantly higher protein concentration compared with Goliath (Tab. 3). In 2009, cv. Akklimat showed the highest protein concentration among cultivars. During 2008, ADF concentration was similar in all three row spacing. In 2009, same level of ADF concentration was observed at row spacing of 75 cm and 37.5, while significantly lower concentration was exhibited by 75 cm (DR). In either year, the highest ADF concentration was determined for cv. Goliath among cultivars. During 2009, cv. Akklimat exhibited an ADF concentration similar to Goliath, whereas significantly lower ADF concentrations were observed in cv. Rona 1 and Aron (Tab. 3). In 2008, row spacing had no significant effect on NDF concentration but clear impact was observed in 2009. Row spacings of

Tab. 3. Effect of cultivars and row spacing on protein (XP), sugar (XZ), acid detergent fiber (ADF), neutral detergent fiber (NDF), lignin (ADL), lipids (XL) and ash (XA) concentration of *Sorghum bicolor* (Giessen 2008, 2009)
Effekt von Sorte und Reihenabstand auf den Gehalt von Protein (XP), Zucker (XZ), Säure-Detergenzien-Faser (ADF), Neutral-Detergenzien-Faser (NDF), Lignin (ADL), Lipide (XL) und Asche (XA) von Sorghum bicolor *(Gießen 2008, 2009)*

	XP (%)	XZ (%)	ADF (%)	NDF (%)	ADL (%)	XL (%)	XA (%)
2008							
Goliath	6.9 b	7.4 a	42.5 a	63.6 a	6.3 a	1.2 b	7.9 b
Bovital	9.0 a	4.6 b	35.8 b	58.9 b	5.0 b	1.6 a	8.3 a
75 cm	7.5 b	5.9 a	39.0 a	61.8 a	5.6 a	1.3 a	8.1 a
37.5 cm	8.1 a	6.3 a	39.7 a	61.3 a	5.8 a	1.4 a	8.1 a
75 cm (DR)	8.3 a	5.9 a	38.7 a	60.7 a	5.6 a	1.4 a	8.0 a
2009							
Goliath	8.9 c	10.9 b	37.8 a	58.4 ab	5.6 b	1.5 d	8.8 c
Bovital	10.0 b	6.4 c	34.9 b	56.7 b	5.3 c	1.8 b	9.3 b
Aron	10.0 b	17.9 a	28.3 c	51.5 c	4.9 d	1.9 a	8.3 d
Rona 1	9.5 b	18.7 a	27.6 c	50.8 c	4.3 e	1.8 b	7.8 e
Akklimat	10.6 a	5.8 c	36.8 a	59.9 a	6.2 a	1.7 c	10.6 a
75 cm	9.6 b	12.8 a	33.3 a	53.2 b	5.0 b	1.6 c	8.8 a
37.5 cm	10.2 a	10.7 b	33.5 a	56.4 a	5.4 a	1.8 a	9.0 a
75 cm (DR)	9.6 b	12.3 a	32.4 b	56.7 a	5.3 ab	1.7 b	9.0 a

Years are separately analyzed; different letters (a, b, c, d) differ significantly at $p < 0.05$, XP = protein, XZ, sugar, ADF = acid detergent fiber, NDF = neutral detergent fiber, ADL = lignin, XL = lipids, XA = ash
Jahre separate analysiert; verschiedene Buchstaben (a, b, c, d) unterscheiden sich signifikant ($p < 0.05$); XP = Protein, XZ = Zucker, ADF = Säure-Detergenzien-Faser, NDF = Neutral-Detergenzien-Faser, ADL = Lignin, XL = Lipide, XA = Asche

Tab. 4. ANOVA p values for main effects and interaction between row spacing (RW) and cultivars (CV) on NIRS parameters (Giessen 2008, 2009)
p-Werte der ANOVA für Haupt- und Wechselwirkung von Reihenabstand (RW) und Sorte (CV) auf NIRS-Parameter (Gießen 2008, 2009)

	2008			2009		
Parameter	CV	RW	CV X RW	CV	RW	CV X RW
XP %	0.000	0.013	0.389	0.000	0.000	0.718
XZ %	0.000	0.779	0.229	0.000	0.006	0.851
ADF %	0.000	0.335	0.061	0.000	0.040	0.922
NDF %	0.000	0.284	0.226	0.000	0.000	0.714
ADL %	0.000	0.213	0.429	0.000	0.001	0.118
XL %	0.000	0.168	0.595	0.000	0.000	0.196
XA %	0.023	0.930	0.423	0.000	0.399	0.717

XP = protein, XZ = sugar, ADF = acid detergent fiber, NDF = neutral detergent fiber, ADL = lignin, XL = lipids, XA = ash
XP = Protein, XZ = Zucker, ADF = Säure-Detergenzien-Faser, NDF = Neutral-Detergenzien-Faser, ADL = Lignin, XL = Lipide, XA = Asche

Tab. 5. ANOVA p values for main effects and interaction between row spacing (RW) and cultivars (CV) on morphological parameters (Giessen 2008, 2009)
p-Werte der ANOVA für Haupt- und Wechselwirkung von Reihenabstand (RW) und Sorte (CV) auf morphologische Parameter (Gießen 2008, 2009)

	2008			2009		
Parameter	CV	RW	CV X RW	CV	RW	CV X RW
Ph 1 (cm)	0.000	0.650	0.905	0.000	0.000	0.920
Ph 2 (cm)	0.000	0.006	0.882	0.000	0.039	0.526
Ph 3 (cm)	0.000	0.035	0.138	0.000	0.560	0.514
LAI 1 (m^2/m^2)	0.093	0.004	0.768	0.000	0.693	0.760
LAI 2 (m^2/m^2)	0.112	0.008	0.358	0.027	0.324	0.499
LAI 3 (m^2/m^2)	0.041	0.002	0.070	0.018	0.000	0.590
DM (t/ha)	0.000	0.841	0.403	0.000	0.000	0.123
DM (%)	0.083	0.987	0.020	0.000	0.179	0.942
Tillers/m^2	0.006	0.017	0.447	0.000	0.009	0.143

Ph = plant height, DM = dry matter yield, LAI = leaf area index
Ph = Pflanzenhöhe, DM = Trockenmasse-Ertrag, LAI = Blattflächenindex

75 cm (DR) and 37.5 cm showed similar averages of NDF concentration, while significantly lower concentration was attained at 75 cm in 2009. Cultivars significantly differed for NDF concentration. In 2008, cv. Bovital showed clearly lower concentration of NDF compared with Goliath. In 2009, cv. Rona 1 and Aron exhibited lower NDF concentration while markedly higher value was determined for cv. Akklimat and Goliath (Tab. 3). The lignin concentration was not affected by row spacing in 2008 but wider row spacing reduced lignin concentration in 2009 (Tab. 3). In either year, cultivars had clear impact on lignin concentration. During 2008, cv. Bovital was characterized by a lower lignin concentration than cv. Goliath. In 2009 cv. Akklimat produced the highest concentration of lignin among cultivars. The lipid concentration was very low (around 1–2%) with small but partially significantly differences between the cultivars (Tab. 3). The ash concentration of sorghum varied between around 8 and 11%. In both years there was an effect of the tested cultivars on ash concentration with maximal ash concentration in cv. Akklimat.

Discussion

Leaf area index (LAI) is an important structural property of crop canopy which predicts the photosynthesis and can be used as a reference tool for crop growth. We found

Tab. 6. Correlation coefficients between quality parameters
Korrelationskoeffizienten zwischen Qualitätsparametern

	XP	XZ	XL	XA	ADF	ADL
2008						
XZ	−0.719**					
XL	0.926**	−0.692**				
XA	0.541**	−0.333	0.435*			
ADF	−0.823**	0.677**	−0.912**	−0.320		
ADL	−0.868**	0.759**	−0.913**	−0.435*	0.970**	
NDF	−0.856**	0.511*	−0.914**	−0.381	0.954**	0.922**
2009						
XZ	−0.402**					
XL	0.576**	.099				
XA	0.540**	−0.838**	−0.027			
ADF	0.001	−0.826**	−0.540**	0.647**		
ADL	0.270*	−0.780**	−0.167	0.769**	0.765**	
NDF	0.116	−0.793**	−0.226	0.739**	0.774**	0.841**

** Correlation is significant at the 0.01 level; *. Correlation is significant at the 0.05 level
*** Korrelation signifikant auf Niveau von 0,01; *. Korrelation signifikant auf Niveau von 0,05*

that significantly higher LAI was reached with 37.5 cm row spacing in 2008 while similar values were recorded during 2009 suggesting that LAI can be expected to be different in different years. In the present study, cultivars had clear impact on the leaf area index of sorghum. Earlier plant development and specific leaf formation (leaf expansion, individual leaf area, position and angle of leaves) might be the reason of higher LAI with cv. Bovital, Aron, Rona 1 and Goliath compared with cv. Akklimat.

Tillering is an important agronomical trait as it has major impact on leaf area development of *Sorghum bicolor* (Hammer et al., 1987; Lafarge et al., 2002) and on crop water use pattern (van Oosterom et al., 2008). Our study demonstrated that 75 cm row spacing exhibited the lowest number of tillers/m^2 than narrow row spacing. This is likely the result of greater plant to plant competition in 75 cm row spacing for light. It might be possible that due to better distribution of plants more light was reached the base of plants which resulted in higher number of tillers per plant at narrow row spacing compared with wider row spacing. Among cultivars, cv. Akklimat showed maximum number of tillers per m^2. Being as hybrids *S. sudanense*, cv. Akklimat, possesses higher capability for tiller formation than that of *S. bicolor* hybrids like cv. Goliath, Aron and Rona 1.

We found a clear difference of DM yield among the tested cultivars of sorghum. Tall and late maturing cv. Goliath accumulated more DM in vegetative parts (stems and leaves). It can be suggested that cv. Goliath has higher potential for biomass production than the other tested cultivars. Remarkable changes in DM yield due to different cultivars of forage sorghum have been also reported by other researchers (Habyarimana et al., 2004; Amaducci et al., 2004; Zhao et al., 2009). According to Carmi et al. (2005) for appropriate silage production DM content should not be lower than 26% as it leads to decrease the quality of silage. Cv. Goliath and Bovital reached the optimum DM content for silage production. However, DM contents were below this level in cv. Aron and Rona 1.

Maximum protein concentration was recorded in the present study for cv. Bovital and cv. Akklimat in 2008 and 2009, respectively. We suppose that this effect could be due to their higher capability of tiller formation. Tillers are physiologically younger plant organs with higher activity of protein synthesis than physiologically older leaves and main stems. Additionally the accumulation of carbohydrates and the synthesis of fiber compounds like cellulose are increasing in main stems. These processes might explain the higher protein concentration in cv. Bovital and cv. Akklimat in the current study. Considerable differences within the cultivars of sorghum have been previously reported (Carmi et al., 2006; Miron et al., 2006; Beck et al., 2007).

The results which are observed under our conditions indicate that cultivars had a clear effect on sugar concentration. Cv. Aron and Rona 1 accumulated markedly higher concentration of sugar in comparison with other tested cultivars. Both cultivars belong to *S. bicolor* which has higher potential for sugar concentration than *S. sudanense* like cv. Akklimat and Bovital. Significant differences among the sorghum cultivars regarding sugar concentration have been previously documented (Dolciotti et al., 1998).

The NDF concentration in current trials varied from 50 to 56% which is similar with the previous findings in forage sorghum (Miron et al., 2005; Carmi et al., 2005) as well as in maize ranging from 50–52% (Marsalis et al., 2010). A clear difference among cultivars for NDF, ADF and ADL concentration in the present study confirms the findings of other researchers who carried out investigations with forage sorghum hybrids (Carmi et al., 2005; Miron et al., 2006; Beck et al., 2007). We suppose that lower ADF, NDF and ADL concentrations determined for cv. Rona 1 and Aron were caused by higher WSC concentration in stems which reduced the fiber concentration in both cultivars. The concentration of lignin in biomass of sorghum differed among the cultivars evaluated in our experiments. Higher content of lignin was found in cv. Goliath and Akklimat but lower in Bovital, Aron and Rona 1. These differences may explain partially the differences in NDF digestibility between the five cultivars.

Generally it can be supposed that some of the above mentioned differences in chemical composition among the sorghum cultivars can be explained by different capability for tillering and biomass distribution to plant organs (leaves, stems and panicles). Regarding phenotype and plant morphology there is a high diversity within the species of sorghum. For that reason more cultivars should be included in future experiments.

Narrow row spacing increased biomass of sorghum as it reduced the competition between the plants (intra row specific competition). Interactions between row spacing and cultivars were not observed either for biomass or for quality parameters of sorghum. In future investigation on this subject, plants should be separated into main stem and side stems (tillers) which may help to provide some more information about the chemical composition of sorghum. Maize silage is the most important source of biogas production, but further intensification of maize cropping may increase the risk of pest damage and nutrient losses. An attractive alternative to maize is sorghum, which can produce a biomass compositionally similar to that of maize and known to be highly productive with respect to biomass. Therefore it can be supposed that sorghum can be efficiently used for biogas production.

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