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DROUGHT STRESS

Effect of Drought Stress on Yield and Quality of Maize/Sunflower and Maize/Sorghum Intercrops for Biogas Production

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Keywords
biogas; drought stress; energy crops; intercropping; nutrient composition; specific methane yield

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Abstract

Intercropping represents an alternative to maize (*Zea mays* L.) monoculture to provide substrate for agricultural biogas production. Maize was intercropped with either sunflower (*Helianthus annuus* L.) or forage sorghum [*Sorghum bicolor* (L.) Moench] to determine the effect of seasonal water supply on yield and quality of the above-ground biomass as a fermentation substrate. The two intercrop partners were grown in alternating double rows at plant available soil water levels of 60–80 %, 40–50 % and 15–30 % under a foil tunnel during the years 2006 and 2007 at Braunschweig, Germany. Although the intercrop dry matter yields in each year increased with increasing soil moisture, the partner crops responded quite differently. While maize produced significantly greater biomass under high rather than low water supply in each year, forage sorghum exhibited a significant yield response only in 2006, and sunflower in none of the 2 years. Despite greatly different soil moisture contents, the contribution of sorghum to the intercrop dry matter yield was similar, averaging 43 % in 2006 and 40 % in 2007. Under conditions of moderate and no drought stress, sunflower had a dry matter yield proportion of roughly one-third in both years. In the severe drought treatment, however, sunflower contributed 37 % in 2006 and 54 % in 2007 to the total intercrop dry matter yield. The comparatively good performance of sunflower under conditions of low water supply is attributable to a fast early growth, which allows this crop to exploit the residual winter soil moisture. While the calculated methane-producing potential of the maize/sorghum intercrop was not affected by the level of water supply, the maize/sunflower intercrop in 2006 had a higher theoretically attainable specific methane yield under low and medium than under high water supply. Nevertheless, the effect of water regime on substrate composition within the intercrops was small in comparison with the large differences between the intercrops.

Introduction

Whole-crop maize silage is the key substrate for agricultural biogas plants in Germany (Weiland, 2006, Schittenhelm, 2008). In the catchment area of biogas plants, the monoculture cropping of maize is a common practice. In order to avoid problems arising from maize monoculture such as decreasing crop species diversity, increasing pest pressure, and enhanced nutrient losses, agronomists are searching for alternative crops and cropping systems. A biomass double-cropping system comprising of a cool-season C3 first crop and warm-season C4 second crop has been proposed for agricultural biogas production (Karpenstein-Machan, 2001, Kauter and Claupein, 2004). Such double-crop sequences provide soil cover for most of the year and thus reduce soil and nutrient losses as compared with full-season monoculture crops. Schittenhelm et al. (2007) reported that forage sorghum as an alternative biomass crop produced the same dry matter yields as silage maize in a double-cropping system at a typical dry site in East Germany. Intercropping, the growing of two or more crops simultaneously on the same field, represents another option of diversifying agroecosystems. While intercropping is frequently practiced in low-input farming to stabilize and improve yield, this cropping system is so far of little interest to farmers in countries with temperate climates and highly mechanised agriculture (Zegada-Lizarazu et al., 2006). Anil et al. (1998) recognized that intercropping is gaining increased attention along with the growing interest in sustainable agriculture. They attributed this renewed interest inter alia to criticism of monocultural cropping systems and the advent of technology enabling more efficient sowing and harvesting of intercrops.

Yield advantages of intercropping compared with monoculture can result from complementary use of environmental growth resources over space and time (Midmore, 1993). The intercropped plants, for example, may extract water from different soil horizons and therefore more completely capture this growth resource (Zegada-Lizarazu et al., 2006). Contrary to this expectation, Ozier-Lafontaine et al. (1998) observed separate root systems of maize and sorghum grown in alternating rows. The potential agronomic and ecological effects are greatest when the component crops are completely mixed in the field but reduce to border-row effects in the case of strip intercropping.

Although numerous studies deal with intercrops for forage production, only few data are published with respect to the use of intercrops as fermentation substrates for biogas production. Schmaler et al. (2007) showed that successfully established alfalfa-grass mixture, which in principle could be used as a biogas substrate, produced the same or even higher dry matter yields than silage maize. Arable forage cropping for biogas production has the advantage that it conserves organic soil substance and therefore contributes towards soil fertility in biogas crop rotations. Unfortunately, alfalfa-grass mixture has a lower methane-producing potential than silage maize and the demand for multiple cuttings causes additional production costs. Maize is the most common cereal component in forage that includes cereals (Anil et al. 1998), and is often combined with legumes to produce protein-rich forage silage (Pinter et al. 1993, Alford et al. 2003, Armstrong et al. 2008). Maize has also been studied in intercrops with sorghum (Pinter et al. 1992) and sunflower (Robinson 1984, Pinter et al. 1993). Maize/sunflower forage intercrops aim at complementing the superior characteristics of the two crops with respect to fibre, fat and protein content. Depending on the stage of maturity at harvest, sunflower has a higher fat and protein fraction than maize. Gross (2006) therefore proposed maize/sunflower strip intercropping to produce fermentation substrate with a higher biogas production potential.

Water is frequently the most limiting factor for crop production. Varying availability of soil water among years and sites may affect the biomass quality of intercrops for biogas production. A better knowledge of such effects is essential because of the importance of high and constant substrate quality for stable operation of biogas plants. The objectives of this study were to elucidate whether drought during the growing season affects the fermentation substrate quality of maize/sunflower and maize/sorghum intercrops and, if so, whether these changes in substrate quality are due to alterations in nutrient concentration of the intercrop partners, changes in intercrop competition, or both.

Materials and Methods

Study site and testing facility

The experiments were conducted during 2006 and 2007 under 50-m long and 9.2-m wide polythene tunnels (CASADO S.A.R.L., Douville, France) on the institute's experimental field (52°17′48″ N, 10°26′27″ E, altitude 76 m) at Braunschweig, Germany. The tunnels' passageway height of 3 m (roof height 4 m) allows the application of standard agricultural equipment for tilling, sowing and fertilizing. To exclude natural precipitation, the tunnel was covered with 200-μm polythene foil. A completely open front and back, together with 2-m sidewall clearance assured adequate ventilation of the tunnels. Twenty centimetre diameter tubes carried the runoff to an infiltration area. A windbreak installed in the predominant wind direction protected the testing facility. The loamy sand soil (Haplic Luvisol; FAO, 1997) at the site has a water-holding capacity of 120 mm of which 96 mm is plant-available soil water (PASW). The water table is 10 m below ground level. The average air temperature between crop emergence and harvest amounted to 17.6 °C in 2006 and 16.9 °C in 2007.

Experimental treatments and field management

The experiment was planted as a randomized complete block design with split-plot arrangement and two replications. The main plots carried the water treatments of 60–80 %, 40–50 % and 15–30 % PASW. The two types of intercrops comprising of 'ES Ultra Star' silage maize with either 'Alisson' sunflower or 'Rona 1' forage sorghum were the subplots. The crops were sown in 6-m long rows with 62.5-cm row spacing at densities of 10 plants m^{-2} for sunflower and maize and 20 plants m^{-2} for sorghum. The sowing time was 3 May each year.

Sowing was performed in such a way that double rows of sunflower and sorghum were bordered by maize double rows on either side. The outer maize rows functioned as border rows. The experimental units consisted of the two inner maize rows and the enclosed two rows of sunflower or sorghum. In each subplot, a 5-m^2 area of each intercrop partner was hand-harvested on 7 September 2006 and 13 September 2007. Spring barley (*Hordeum vulgare* L.) was the previous crop in 2006 and phacelia (*Phacelia tanacetifolia* Benth.) followed by white mustard (*Sinapis alba* L.) as winter cover crop was the previous crop in 2007. The field received a base fertilization of 133, 14 and 16 kg ha^{-1} of K, Mg and S on 19 August 2005. A preliminary soil analysis indicated that no base fertilization was necessary for the 2007 experiment. Nitrogen fertiliser was broadcast in two splits of granular calcium ammonium nitrate to total rates of 80 kg N ha^{-1} for sunflower, 130 kg N ha^{-1} for sorghum and 160 kg N ha^{-1} for maize using a reconstructed Nodet drill as plot fertilizer distributor. To ensure that the plots received sufficient rainfall for good germination and early plant growth as well as to incorporate the surface supplied nitrogen, the roof foil of the tunnel was mounted 41 days after sowing (DAS) in 2006 and 28 DAS in 2007. The weeds were controlled by regular hand hoeing. Gauze bags covered sunflower heads to prevent damage by birds.

Crop measurements

The whole-crop fresh weights of the 5-m^2 harvest areas were determined separately for each intercrop partner. Samples comprising of 20 plants of maize and 30 plants of sunflower or sorghum from each plot were mashed in a cutter. Duplicate subsamples were taken from the mash and dried at 105 °C for 48 h to determine dry matter concentration, which was used to convert fresh harvest weights to dry matter yield. A further subsample of the mash was stored at −20 °C for later chemical analyses. The intercrop dry matter and methane hectare yields were calculated by combining the respective yields of the intercrop components. The nutrient analyses were determined according to standard protocols (VDLUFA, 1976) as briefly outlined below. The volatile solids (VS) concentration was measured as the weight lost during incineration at 550 °C in a muffle furnace and is thus an estimation of organic matter in the sample. The crude ash concentration was determined as the residue after incineration. Crude fat was extracted with petroleum ether in a Soxhlet apparatus after prior HCl hydrolysis. The crude protein concentration (N × 6.25) was determined with an automated FP-2000 LECO analyser (LECO Corporation, St. Joseph, MI, USA). The crude fibre is the residue remaining after sequential digestion with sulphuric acid and potassium hydroxide solutions, followed by oven-drying and incineration. The nitrogen-free extract (NFE), largely representing non-structural carbohydrates, was determined by subtracting crude ash, crude fat, crude protein and crude fibre from 100. Based on the concentration of nutrients and their digestibility, the theoretically attainable specific methane yields in a biogas fermenter were estimated for each crop according to the formula given in Schattauer and Weiland (2004). The digestibility coefficients were taken from feed nutrient value tables for ruminants (DLG, 1997). Weighted means were calculated for the intercrop nutrient concentration with weightings being based on the proportion of each partner crop in the intercrop.

Soil measurements

Irrigation was practised by means of pressure-compensating drip lines (Netafim Ltd., Tel Aviv, Israel) placed between all plant rows. The soil water level was monitored using ML2x probes (Delta-T Services, Cambridge, UK) installed in the inter-row space between the two intercrop components at 15- and 45-cm soil depth in all plots of one replication of the experiment. To maintain the target soil moistures, the plots with high, moderate and low water supply received 24, 19 and 14 irrigations with a total of 332, 242 and 138 mm in 2006 and 15, 14 and 5 irrigations with a total of 300, 185 and 40 mm in 2007. The greater amount of irrigation applied in 2006 than in 2007 is attributable to the higher evapotranspiration caused by the higher air temperature in that year. The PASW at the time of crop emergence amounted to 75 mm in 2006 and 86 mm in 2007. The water content in the upper 60 cm of the soil was determined gravimetrically after crop emergence and after crop harvest. For that purpose, soil samples were taken in the rows of adjacent intercrops at three positions in each subplot using a soil core sampler. The water use efficiency (WUE) was calculated as the ratio of biomass dry matter yield divided by total crop water use or evapotranspiration (ET). Evapotranspiration from emergence to harvest was estimated for each subplot using the soil-water-balance equation (Ehlers and Goss, 2003):

$$\mathrm{ET} = \mathrm{P} + \mathrm{I} - \mathrm{D} - \mathrm{R} + \Delta S\,(\mathrm{mm}),$$

where ET equals the amount of water lost from soil surface and plants to the atmosphere, P the precipitation which occurred before mounting the roofing foil, I the amount of irrigation thereafter and until harvest, D the subsoil drainage, R the surface runoff, and ΔS the change in soil water storage. The amount of water lost by deep drainage before fixing the polythene foil was estimated at

35 mm in 2006 and 30 mm in 2007 using the agrometeorological advisory system 'Agrowetter' of the German Weather Service (DWD, 2008) based on weather data of a DWD station located ca. 700 m from the experimental field. 'Agrowetter' assumes that excess water above 150 % PASW immediately drains away and for PASW between 100 % and 150 % half the excess water is lost each day. Surface runoff did not occur because of the flat experimental land and the controlled amounts of irrigation water applied. The target soil moisture of 15–30 % PASW in the most severe drought stress treatment was not reached before the end of June.

Statistical analyses

Analyses of variance were carried out for all measured and calculated data with the PLABSTAT computer program (Utz, 2005). In these ANOVA, years and replications were considered random effects and water regimes and crops or intercrops fixed effects. Because substantial variation was found to exist in year × treatment interactions, years were analyzed separately to better elaborate on differences between the two years. Conclusions will be limited to individual years. When F-ratios were significant ($P < 0.05$), LSD values at that level were used to compare treatment means.

Results

The plant height as well as the fresh and dry matter yield of both intercrops increased with increasing water supply (Table 1). For all water levels, the dry matter content of the maize/sunflower intercrop exceeded the critical level of 280 g (kg FM)$^{-1}$ necessary for the production of good quality silage. The maize/sorghum intercrop occasionally had dry matter contents slightly below this critical level. The lowest dry matter yield (9.8 t ha^{-1}) was attained by the maize/sunflower intercrop under sever drought stress in 2006 whereas in the absence of drought stress the maize/sorghum intercrop attained the highest dry matter

Table 1 Agronomic characteristics of maize/sunflower and maize/sorghum intercrops grown at different water supply under a foil tunnel

	2006		2007	
Water supply	Maize/Sunflower	Maize/Sorghum	Maize/Sunflower	Maize/Sorghum
Plant height[2] (cm)				
High	212 c[1]	239 c	273 b	280 b
Medium	177 b	206 b	254 b	270 b
Low	116 a	136 a	195 a	165 a
Dry matter content [g (kg FM)$^{-1}$]				
High	346 a	268 a	316 a	275 a
Medium	343 a	278 a	315 a	287 b
Low	339 a	283 a	354 a	309 c
Fresh matter yield (t ha^{-1})				
High	41.8 b	65.5 c	55.8 a	67.8 b
Medium	46.0 b	55.9 b	46.9 a	64.2 b
Low	29.0 a	40.6 a	33.5 a	38.2 a
Dry matter yield (t ha^{-1})				
High	14.5 b	17.5 c	17.7 a	18.6 b
Medium	12.3 ab	15.5 b	14.6 a	18.4 b
Low	9.8 a	11.5 a	11.9 a	11.8 a
Methane yield (m^3 VS ha^{-1})				
High	3.997 b	4.697 c	4.800 a	4.852 b
Medium	3.449 ab	4.139 b	3.941 a	4.755 b
Low	2.792 a	3.041 a	3.258 a	3.029 a
N uptake (kg ha^{-1})				
High	176 a	197 b	217 a	225 c
Medium	155 a	169 a	183 a	202 b
Low	146 a	147 a	172 a	140 a
WUE (kg DM ha^{-1} mm^{-1})				
High	37 a	45 a	47 a	49 a
Medium	40 a	51 ab	52 a	64 b
Low	45 a	55 b	75 a	76 c

[1] Mean values within a column for a given character followed by the same letter are not significantly ($P < 0.05$) different using Fisher's protected LSD.

[2] Average of the two crop partners.

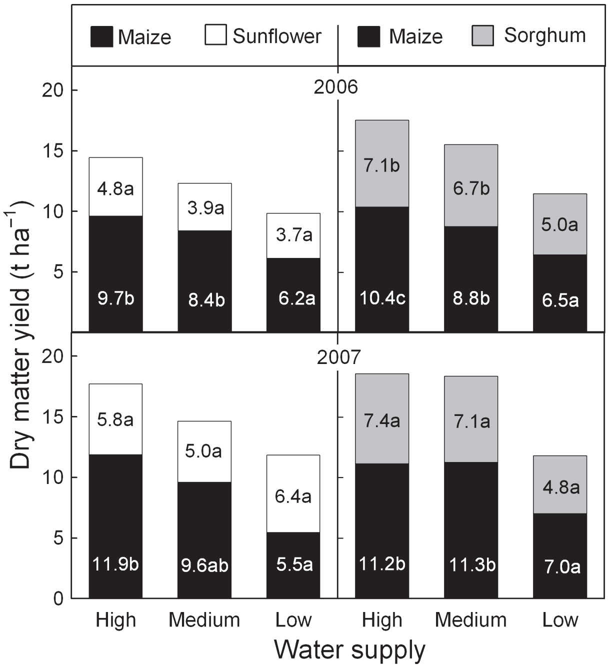

Fig. 1 Dry matter yield of the component crops in the maize/sunflower and maize/sorghum intercrops grown at different water supply under a foil tunnel. Mean values within a crop for a given intercrop and year followed by the same letter are not significantly ($P < 0.05$) different using Fisher's protected LSD.

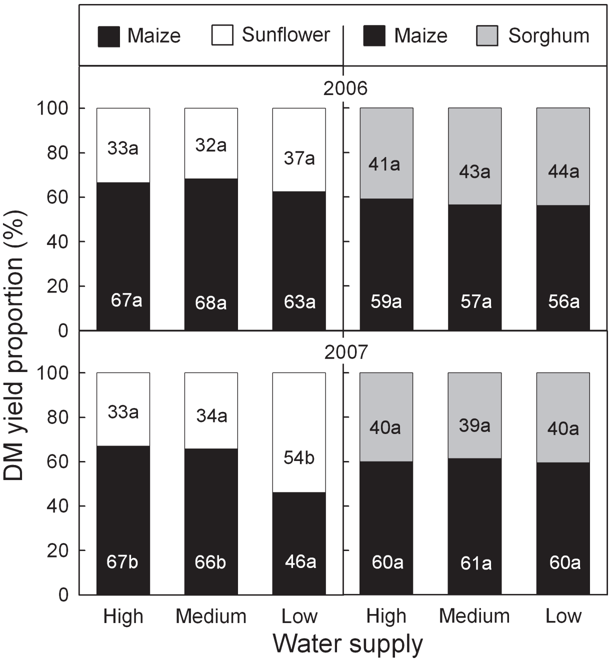

Fig. 2 Yield proportion of the component crops in the maize/sunflower and maize/sorghum intercrops grown at different water supply under a foil tunnel. Mean values within a crop for a given intercrop and year followed by the same letter are not significantly ($P < 0.05$) different using Fisher's protected LSD.

yield (18.6 t ha^{-1}). Nitrogen uptake increased with increasing water supply but this increase was statistically significant for the maize/sorghum intercrop only. For the maize/sorghum intercrop, the plant N uptake in the plots with low water supply amounted to 75 % in 2006 and 62 % in 2007 relative to the plant N uptake in the well-watered plots. The WUE increased with decreasing water supply in all intercrop × year combinations, but differences between water treatments were significant for the maize/sorghum intercrop only.

The maize plants in both intercrops and both years produced significantly more whole-plant dry matter under high than under low water supply (Fig. 1). In 2006 and 2007, sorghum produced more above-ground dry matter under high than under low water supply but this yield difference was significant in 2006 only. The sunflower dry matter yields in each year were not significantly different among the three water treatments. Despite greatly different soil moisture, the yield proportion of the two crop partners was quite stable in both intercrops (Fig. 2). Sorghum accounted for 39–44 % of the maize/sorghum intercrop dry matter yields. Except for the low water treatment, sunflower had a dry matter yield proportion of 32–34 %. Under low water supply, however, the dry matter yield proportion of sunflower increased to 37 % in 2006 and even 54 % in 2007.

The chemical composition of the whole-plant biomass was markedly different among the three crop species (Table 2). In each of the two experimental years, sunflower had a higher concentration of crude ash, crude fat, crude protein and crude fibre, but lower NFE than either maize or sorghum. The nutrient concentrations of maize and sorghum were more similar than for maize and sunflower. Maize differed from sorghum mainly by a higher level of NFE and a lower level of crude fibre. The calculated methane-producing potentials of maize and sunflower were similar and considerably higher than that of sorghum. There was much more variation in chemical composition among the three crops than across the water regimes within the crops. The amount of water supply had some significant effects on the nutrient concentration of the two partners of the maize/sunflower intercrop in 2006 but almost no such effect in 2007. In 2006, sunflower under low water supply had significantly lower crude ash, higher crude fat and higher specific methane yield than under medium or high water supply. Maize in 2006 also had significantly higher specific methane yield under low and medium than under high water supply.

Water supply had little effect on the nutrient concentration of the maize/sorghum intercrop (Table 3). In the maize/sunflower intercrop, however, especially the low water supply exerted strong effects on the chemical

Table 2 Whole-plant nutrient concentration and specific methane yield of maize/sunflower and maize/sorghum intercrop partners grown at different water supply under a foil tunnel

	2006				2007			
Water supply	Maize	Sunflower	Maize	Sorghum	Maize	Sunflower	Maize	Sorghum
Crude ash [g (kg DM)$^{-1}$]								
High	45 a[1]	148 b	47 a	55 a	58 a	140 b	60 a	49 a
Medium	49 a	146 b	49 a	52 a	56 a	142 b	57 a	50 a
Low	44 a	127 a	52 a	48 a	56 a	116 a	60 a	46 a
Crude fat [g (kg DM)$^{-1}$]								
High	26 a	106 a	29 a	22 a	14 a	156 a	18 a	14 a
Medium	29 b	113 a	30 a	22 a	18 a	128 a	16 a	17 a
Low	26 a	165 b	26 a	23 a	24 a	185 a	22 b	18 a
Crude protein [g (kg DM)$^{-1}$]								
High	58 a	112 a	66 a	76 a	65 a	101 a	80 a	70 a
Medium	65 a	111 a	63 a	75 a	71 a	93 a	72 a	64 a
Low	82 a	112 a	77 a	84 b	78 a	102 a	75 a	72 a
N-free extract [g (kg DM)$^{-1}$]								
High	642 a	329 a	647 a	562 a	666 a	283 a	653 a	624 a
Medium	668 b	338 a	664 b	593 a	656 a	320 a	642 a	621 a
Low	668 b	328 a	646 a	606 a	645 a	329 a	635 a	620 a
Crude fibre [g (kg DM)$^{-1}$]								
High	230 a	306 a	211 a	285 a	197 a	320 a	190 a	243 a
Medium	189 a	293 a	194 a	259 a	199 a	318 a	214 a	248 a
Low	181 a	268 a	199 a	239 a	197 a	268 a	208 a	245 a
Specific methane yield [l (kg VS)$^{-1}$]								
High	306 a	288 a	308 a	244 a	295 a	297 a	300 a	241 a
Medium	309 b	291 a	309 a	243 a	296 a	292 a	294 a	242 a
Low	308 b	305 b	307 a	243 a	293 a	309 a	292 a	242 a

[1] Mean values within a column for a given character followed by the same letter are not significantly ($P < 0.05$) different using Fisher's protected LSD.

composition. The crude fat concentration of the maize/sunflower intercrop in its range from 52 to 111 g (kg DM)$^{-1}$ depended closely on the water supply. In each year, this intercrop attained its maximal crude fat concentration at low water supply. The specific methane yield was not affected by water supply except for the maize/sunflower intercrop in 2006.

Discussion

The effect of water supply on the methane-producing potential of intercrop biomass can either result from changes in the nutrient concentration of the partner crops themselves, or from a shift in the relative yield proportion of the partner crops, that is, from changed intercrop competition. In the maize/sorghum intercrop, the differences in water supply had only little effect on nutrient concentration and yield proportion of the two companion crops. In the maize/sunflower intercrop in contrast, both aforementioned effects were operating. The crude fat concentration increased with decreasing water supply, both in sunflower and in the maize/sunflower intercrop. Under severe drought stress, sunflower contributed significantly more to the total intercrop dry matter yield than under moderate and no drought stress. The higher yield proportion of sunflower with increasing drought stress was paralleled by an increased substrate quality for biogas production of the maize/sunflower intercrop. However, in comparison with the large difference existing for the methane-producing potential between the two types of intercrop, the effect of water supply on the substrate quality was small.

Water supply affected the substrate quality of the maize/sunflower intercrop via the specific seasonal growth patterns of the partner crops. Because of its rapid early season growth, sunflower exploited the soil moisture rapidly. At the time when the thermophilic maize encountered favourable growth conditions, sunflower had already depleted a substantial portion of the winter soil moisture. The water from winter rainfall constituted a considerable quantity of the water available to the intercrop. In the severe drought stress treatment for example, the proportion of water from winter rainfall in 2006 and 2007 made up 35 % and 68 %, respectively, of the total

Table 3 Whole-plant biomass nutrient concentration of maize/sunflower and maize/sorghum intercrops grown at different water supply under a foil tunnel

	2006		2007	
Water supply	Maize/Sunflower	Maize/Sorghum	Maize/Sunflower	Maize/Sorghum
Crude ash [g (kg DM)$^{-1}$]				
High	79 a[1]	51 a	85 a	55 a
Medium	79 a	50 a	85 a	55 a
Low	75 a	50 a	88 a	55 a
Crude fat [g (kg DM)$^{-1}$]				
High	52 a	26 a	61 a	16 a
Medium	56 a	26 a	55 a	16 a
Low	78 a	25 a	111 b	20 a
Crude protein [g (kg DM)$^{-1}$]				
High	76 a	70 a	77 a	76 b
Medium	79 a	68 a	78 a	69 a
Low	93 b	80 a	91 b	74 ab
N-free extract [g (kg DM)$^{-1}$]				
High	537 a	612 a	539 b	642 a
Medium	564 a	634 a	542 b	633 a
Low	540 a	629 a	475 a	629 a
Crude fibre [g (kg DM)$^{-1}$]				
High	255 c	241 a	237 a	211 a
Medium	222 b	222 a	240 a	227 a
Low	214 a	216 a	235 a	223 a
Specific methane yield [l (kg VS)$^{-1}$]				
High	300 a	282 a	296 a	277 a
Medium	304 b	281 a	295 a	274 a
Low	307 b	279 a	302 a	272 a

[1] Mean values within a column for a given character followed by the same letter are not significantly ($P < 0.05$) different using Fisher's protected LSD.

seasonally available soil water. Thus, the conditions prevailing in the severe drought stress treatment resemble the climatic conditions with wet winters and dry summers predicted in climate change scenario for Germany (EEA, 2008). Anil et al. (2000) also reported that sunflower dominated the maize in a maize/sunflower intercrop. In their study, sunflower depressed the ear and grain development of maize through induction of drought stress with the consequence of a low starch content of the maize partner crop. It has been shown in several studies that sunflower because of a remarkably high water use causes greater soil water depletion than other crops (Nielsen et al. 1999, Miller et al. 2002, Merrill et al. 2007).

Fukai and Trenbath (1993) noted that intercrops are most productive when their component crops differ greatly in growth duration so that their maximum requirements for growth resource occur at different times. As shown for the maize/sunflower intercrop in the present study, high yield of maize was inhibited because sunflower as the earlier-maturing partner crop depleted most of the available soil water. It thus appears a doubtful strategy to increase intercrop productivity in drought stress environments by combining crop species of different phenology.

In 2006, sorghum already attained its maximum biomass yield at medium water supply, whereas maize needed high water supply for maximal yield. This is an indication for a higher drought tolerance of sorghum in comparison with maize. Superior biomass yields of sorghum over maize under moderate to strong drought stress also have been reported for semiarid environments of Australia (Muchow, 1989), India (Singh and Singh, 1995) and Spain (Farré and Faci, 2006). The higher drought tolerance was attributed to the ability of sorghum to extract water from deeper soil layers (Singh and Singh, 1995, Farré and Faci, 2006).

In 10 published intercropping studies examined by Morris and Garrity (1993), the water uptake by monoculture crops and intercrops was almost the same, whereas the intercrops greatly exceeded the WUE for monoculture crops. The values for WUE in the aforementioned studies (0.2–21.4 kg ha^{-1} mm^{-1}) were much lower than the values obtained in the present study (37–76 kg ha^{-1} mm^{-1}). This supposed discrepancy is probably attributable to the fact that the intercrops examined by Morris and Garrity (1993) contrary to this study involved low-yielding legume crops and that the yield measure was mostly grain yield instead of total biomass production.

Conclusions

The results of this study indicate that growing of maize/sunflower and maize/sorghum in alternating double rows under varying seasonal water supply has little effect on nutrient composition and methane-producing potential of the intercrops. The relatively constant biomass yield proportion of maize and sorghum under varying water supplies shows that these two crops have a similar ability to acquire soil water. The significantly higher yield proportion of sunflower as compared with maize under low water supply indicates that sunflower is a highly competitive intercrop partner in dry summers because of its rapid early season growth, and thus strong ability to acquire the residual winter soil moisture. Concomitant with a higher yield proportion of sunflower under drought stress is a higher specific methane yield of the maize/sunflower intercrop. Therefore, without opportunity for supplemental irrigation, the operators of agricultural biogas plants at sites with frequently limited water supply will certainly be faced with the problem of poor yield stability. However, in maize/sunflower intercrops drought-induced losses in dry matter yield will be partially compensated by the higher methane-producing potential under low water supply.

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