The impact of the new energy crop sorghum on the weed flora

Einfluss des Anbaus von Sorghumhirsen als Energiepflanzen auf die Beikrautflora

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Summary

Sorghum is one of the most promising new options for the diversification of land use and for the replacement of maize in energy cropping systems. In on-farm experiments in three different regions of Germany (Thuringian Basin, East Brandenburg and the Lake District of Mecklenburg) between 2008 and 2010, we investigated if and how the cultivation of sorghum affects weed abundances and biodiversity aspects under real farming conditions. Energy maize was used as reference crop for the comparisons with sorghum. Special regard was given to test the hypothesis that differences in the weed flora between both crops can be explained by structural and temporal characteristics of the crop stands.

In the field experiments, we found crop stands of sorghum and maize to have varying temporal (sowing time, growth dynamism) and structural traits (crop stands height and coverage). Hence, although sorghum shows a growth habit similar to that of maize, it is differing mainly in: i) the at least 3-4 week delayed sowing time, ii) a slow development during early growth stages, iii) a higher crop stand density and more intense shadowing at the end of the growing period.

According to these particularities, we found sorghum to be very sensitive to early weed infestations. The height of early weed infestation level were in dependence of the weather conditions. The weed flora (species richness and species composition) in sorghum did not differ much from that of maize. Species composition was mainly affected by the modified sowing time. The weed species composition of the later sown sorghum differed mainly in the dominance of single weed species and the share of different ecological groups. Late summer or whole year germinating weed species like e.g. species of the *Polygonaceae* family may benefit specifically while *Asteraceae* species tend to be restricted.

Keywords: Crop stand architecture, crop stand dynamism, fidelity index, general linear model, maize

Zusammenfassung

Sorghumhirsen gelten als vielversprechende Alternative zur Diversifizierung des landwirtschaftlichen Anbaus und für den parteillen Ersatz von Mais im Energiepflanzenanbau. Die Konsequenzen, die sich aus dem Anbau von Sorghumhirsen für die Beikrautregulation und Biodiversitätsaspekte unter Praxisbedingungen ergeben, waren Gegenstand von dreijährigen Felduntersuchungen in drei, naturräumlich unterschiedlichen Regionen in Deutschland (Thüringer Becken, Ost-Brandenburg und Mecklenburger Seenplatte). Mais wurde für die Erhebungen als Referenzkultur genutzt. Für die Analyse der Kulturarteneffekte wurde von der Hypothese ausgegangen, dass die Unterschiede in der Beikrautflora beider Kulturarten durch zeitliche und strukturelle Merkmale der Kulturpflanzenbestände erklärt werden können.

Im Ergebnis der unserer Felduntersuchungen konnte aufgezeigt werden, dass zwischen den von Sorghumhirsen und Mais gebildeten Kulturpflanzenbeständen deutliche entwicklungsdynamische und strukturelle Unterschiede bestehen. Die Bestandesentwicklung von Sorghumhirsen unterscheidet sich vom Mais vor allem in folgenden Eigenschaften: i.) einer um mindestens 3-4 Wochen späteren Aussaat, ii.) einer langsameren Jugendentwicklung, iii.) einem dichteren Bestand und einer höheren Beschattung gegen Ende der Vegetationsperiode.

Auf Grund dieser Besonderheiten zeigten sich Sorghumhirsen anfälliger für Frühverunkrautungen, deren Auftreten jedoch eine starke Witterungsabhängigkeit aufwies. Die Artenzahlen und Zusammensetzung der Beikräuter unterschieden sich zwischen Sorghumhirsen und Mais nicht wesentlich. Die Artenzusammensetzung variierte vor allen in Abhängigkeit vom Saattermin. Vor allem spät oder ganzjährig keimfähige Arten u.a. der Familie *Polygonaceae* können von der späten Aussaat profitieren, während z.B. Vertreter der *Asteraceae* abnehmende Tendenzen zeigten.

Stichwörter: Allgemeines lineares Modell, Bestandesarchitektur, Bestandesdynamik, Mais, Treueindex

1. Introduction

The strong increase in the area grown with maize in Germany during the last years was attributed to the promotion of energy cropping systems. The one-sided focus on maize as the main crop for energy cropping lead to serious public criticism and protests and is to some extend questioning the sustainability of energy cropping systems (NABU, 2010; BN, 2010). The reasons for farmers to focus on maize are apparent: The high biomass yield, the high water and nutrient efficiency of maize and in the end the whole economic benefit of maize growing is respectively higher, partly with great differences, compared to that of most alternative traditional crops used for energy production (FNR, 2011). Due to low quality requirements, energy cropping provides many options for the introduction of new crops or intercrops into agricultural practice thereby diversifying cropping systems. The success of the introduction of new crops is highly dependent on their yield potential, yield stability and cost:benefit ratio. Sorghum crops are one of the promising new options in energy cropping systems. Sorghum millets are well adapted to the European climate. In ancient times and in the Middle Ages, they have been widely grown all over Europe. As a C_4-plant, its nutrient and water efficiency as well as drought resistance are high. In contrast to maize, sorghum plants are stocking with 4-6 stems per plant and can reach higher final plant stand heights. The very low specific requirements for soil quality or for the position in the crop rotation make a cultivation of sorghum species possible in most of the agricultural regions of Germany. Last but not least the current absence of specific epidemic plant diseases and pests promises agricultural benefits for the sequential replacement of maize with sorghum crops (KALTSCHMITT et al., 2009).

Little is known about the consequences of sorghum cultivation on the composition of the weed flora and other ecological effects in the temperate climates. Not only in the growth habit but also in the growing period and crop stand architecture there are many similarities but also dissimilarities compared to maize crop stands. The real potential of sorghum to provide more diversity and phytosanitary benefits to maize-oriented crop rotations under middle European conditions is unclear until today.

The agricultural, ecological and economic effects of various alternative energy crops, among them sorghum millets, are the subject of a series of plot and field trials within the research project "Site-adapted Cropping Systems for Energy Crops" (EVA). The project is aiming to identify the optimal strategy for an economically successful and environmentally sound production of energy crops and to search for suitable agricultural alternatives to the dominant cultivation of maize. The aim of the present study was to compare the effects of sorghum on weed cover and species composition in comparison to maize.

2. Materials and Methods

2.1 Experimental Setup

In order to integrate varying environmental conditions into the experimental design, field experiments were carried out on farms in three different geomorphological and bioclimatic regions of Germany: The Lake District of Mecklenburg (LDM), East Brandenburg (EB) and the Thuringian Basin (TB). The site conditions of the regions are described in Table 1. The experiments were conducted between 2008 and 2010 every year at the same farms, except for the LDM region, where sorghum was grown only in 2009 and 2010. The fields for the comparison between maize and sorghum have been selected with regard to the following criteria: Minimum field size of 4 ha, no external disturbing effects (distance to roads and settlements), typical climate situation, soil conditions and cropping situation typical for the region (pre-crops, soil tillage), to be located close to each other, to be located in the neighborhood of the experimental fields from the previous years. The typical farming practices are shown in Table 2. Fertilization was mainly based on the application of biogas slurry at 15-25 m^3/ha, supplemented with mineral fertilizers. The crop rotations in the LDM region were dominated by winter rye. In the EB region, crop rotations had a maize percentage of 25-50 % alternated with triticale, oilseed rape and winter rye. In the TB region, crop rotations were characterized by oilseed rape and sugar beets, and a cultivation of maize or sorghum only every 3-4 years. Most of the maize and sorghum crops were sown after winter cereals harvested as green biomass for biogas. Normally, one post-emergent herbicide application was applied in both crops by using the same active ingredients, but differing in application time due to differences in crop developments (see discussion).

Tab. 1 Description of the site conditions at the farms participating in the investigations.

Tab. 1 *Beschreibung der Standortbedingungen der im Untersuchungsprogramm beteiligten Betriebe.*

	Region		
Parameter	**LDM**	**EB**	**TB**
Location name	Groß Bäbelin	Herzfelde	Körner
Average temperature	8,4 °C	8,7 °C	9,2 °C
Annual precipitation	548 mm	541 mm	583 mm
Pre-dominantsoil type	Sand	Sand-loamy Sand	Heavy loam
Elevation	50 m	35 m	220-250 m
Soil value number	23-25	25-35	62-70

2.2 Data collection and analysis

Crop stand cover and height, overall weed cover and cover of every single weed species was determined at least four times per year with 10 replicates per date, all after the herbicide application. The plots for the weed surveys were located in the middle of the field, at least 70 m inside from the field margin following a line transect. The size of the plots was 1 m². Coverage was estimated using a modificated Braun-Blanquet scale with many intermediate values. We followed the taxonomy of WISSKIRCHEN and HÄUPLER (1998) for German vascular plants and used the EPPO-Code for tables and figures. The statistical analysis focused on the maize-crop comparison for every region separately. Except the GLM, variation between the regions was not considered.

Tab. 2 Description of farming practice and land use measures on the investigated fields.

Tab. 2 *Beschreibung der Anbauverfahren und Betriebstypen für die Untersuchungsflächen.*

	LDM		**EB**		**TB**	
Location name	**Groß Bäbelin**		**Herzfelde**		**Körner**	
Farm type	**Cash crop - integrated**		**Cash crop - integrated**		**Mixed - integrated**	
Crop	Sorghum x. sudanense	Maize	Sorghum x. sudanense	Maize	Sorghum bicolor	Maize
Soil tillage	Disc harrow	Rotary tiller	Cultivator	Cultivator	Plough	Plough or Grubber
Tillage depth	12 cm	15 cm	18 cm	18 cm	15 cm	15-20 cm
Pre-crop	Rye	Rye	Rye	Rye	Barley	Rye
Sowing date	24-26.06.	28-30.05.	13.06*/11.05.	20-25.04.	17-20.06.	06-10.05.
Fertilization	liquid	liquid	min./liquid	liquid	liquid	liquid
Herbicide	1x	1x	1-2x	1-2x	1x	1x
Herbicide name	Click/ Buctril	Click/ Buctril	Gardo Gold	Gardo Gold/ Clio TP	n.k.	n.k.

*only 2008, n.k. name is not known

The normality of the data was tested with the Kolmogorov-Smirnov-test. To reach normality, the data was transformed and standardized. We used the General Linear Model (GLM; SPSS 16.0) as a tool for Univariate Variances Analysis in order to test the effects and interactions of the main testing factors: Region (R) and crop type (C) against interaction with the random factor year (Y) which was regarded as aggregated variation in weather and location. Correlation analyses were conducted to identify the interactions between crop stand coverage and overall weed coverage. Correlation was tested with Pearson and Spearman-Rho coefficient in parallel. The impacts of the crops on weed species composition were tested with Canonical Correspondence Analysis (CCA) using the software package CANOCO. For validity reasons only species with an overall frequency greater than 10 % have been included in this analysis. The relative promotion of single weeds by either maize or sorghum was tested by using fidelity indexes as a typical measure in ecologic vegetation analyses (CHYTRY et al., 2002).

3. Results

3.1 Temporal crop stand development and overall weed abundance

Due to higher temperature requirements during germination, sorghum is often sown later than maize, mostly in a double crop system after late harvested winter cereals. This is a distinguishing feature of energy cropping systems compared to traditional maize cultivation. Figure 1 shows the results from the field experiments at the different investigational regions. Despite of huge yearly variation it is still visible that the early development of sorghum was quite slow until the middle of July. After this period, the biomass increase of sorghum was faster than that of maize and the sorghum plants reached closer and higher crop stands compared to maize at the end of vegetation periode. In 2008, sorghum reached the crop stand densities of maize not before August. As a consequence, the dry matter content of the sorghum biomass was insufficiently low at harvest.

The average weed abundance over the three years (Fig. 1 right side) showed high differences. Except of the MLD Region, weediness in Sorghum showed the highest variation. The explanations for this finding are given in Table 3 and Figures 2 and 3. The statistical general linear model resulted in the variance explained by the different factors as shown in Table 3. Regarding the main experimental factors region (R), crop type (C) and year (Y), there was no significant effect on total weed abundances. For all three main factors, the variance within the groups was much higher as between the groups. That means that no general statistically provable single effect for the two crops was found. The crop effects became significant when considering the interactions between the factors. All three interactions were significant. The crop effect was influenced by weather (year) and site conditions (region). The reason for this relationship becomes obvious when comparing the yearly variation in total weed abundances with the weather conditions (Fig. 2 and 3). Figure 2 clearly shows that the trends within the years were similar in all regions but that trends between years were changing. While in 2008, maize had higher weed cover, the total weed cover in 2010 in sorghum was much higher compared to weediness of maize. In 2009, there were no visible differences between the two crops. The year effects are related to weather conditions during the very sensitive period of seed germination and early growth. Year 2008 was characterized by a warm spring with some deficits in the amount of rainfall more or less in all three regions (Fig. 3). In 2010, especially the period around sowing was cold and cloudy with normal rainfall. In 2010, crop coverage of sorghum was significant lower compared to maize till the 200th calendar day whereas the total weed cover was significant higher.

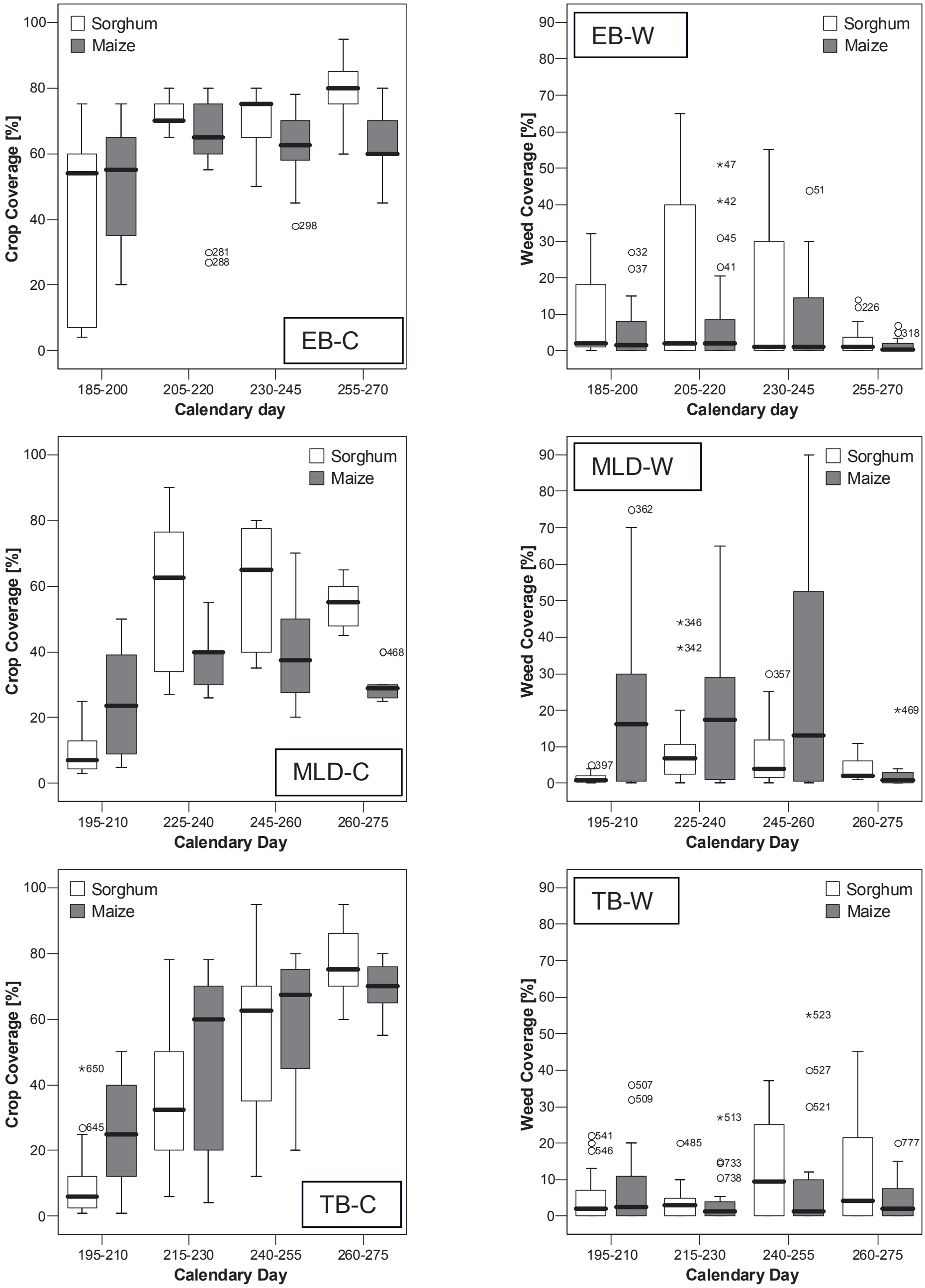

Fig. 1 Differences in crop (C) and weed (W) coverage between Sorghum and Maize over time at the three investigational regions (Average from 10 replications and three investigational years).

Abb. 1 *Unterschiede in der Bedeckung durch die Kultur (C) und Beikraut (W) zwischen Hirsen und Mais über die Vegetationsperiode (Mittelwerte über jeweils 10 Wiederholungen und drei Untersuchungsjahre).*

Tab. 3 Statistical parameters of the factors influencing total weed coverage together with the size of their partial variance explanation (eta-value) (output of the General Linear Model; GLM).

Tab. 3 *Ergebnistabelle des General Linear Models (GLM) für den Gesamt-Beikrautdeckungsgrad zur Charakterisierung der Varianzquellen und der partiellen Beiträge (Eta) der Prüffaktoren.*

Source	Type III Sum of Squares	df	F	Sig.	Partial Eta Squared
Constant term	1501062.1	1	298.8	0.034	0.997
Region (R)	22127.8	2	0.928	0.485	0.381
Crop (C)	2088.2	1	1.214	0.385	0.376
Year (Y)	6740.2	2	0.228	0.808	0.124
Interaction R * C	3735.2	2	6.982	0.001**	0.018
Interaction R * Y	26044.8	3	48.642	0.000**	0.163
Interaction C * Y	1731.7	2	3.234	0.040**	0.009
Error	535.4	747			

(df – degrees of freedom; F - F-value; Sig. – Significance level)

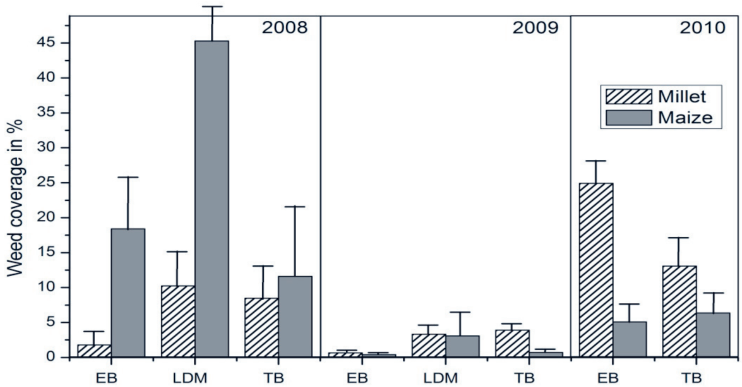

Fig. 2 Average weed coverage in maize and sorghum millets in the three experimental years (4-7 investigation dates per year).

Abb. 2 *Mittlere Beikrautdeckung in Mais und Sorghumhirse in den drei Versuchsjahren (jeweils 4-7 Boniturtermine je Jahr).*

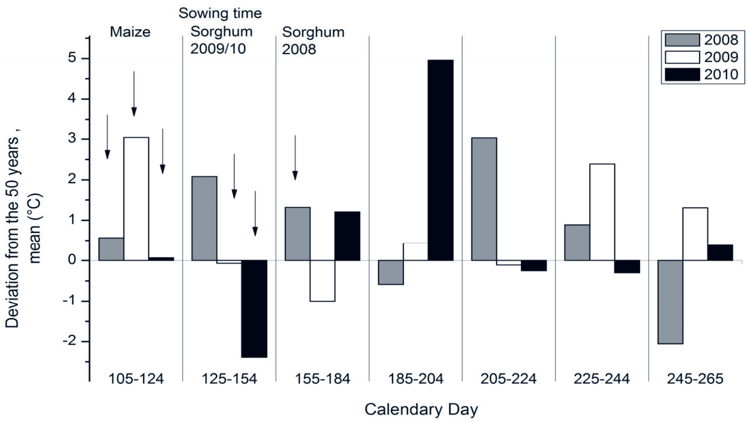

Fig. 3 Deviation from the averaged daily annual temperature from the last 50 years mean (zero line) at East Brandenburg (EB) in the years 2008-2010 (averaged daily temperature).

Abb. 3 *Abweichung der gemittelten Tagestemperatur vom 50-jährigen Mittel in der Untersuchungsregion Ost-Brandenburg (EB) in den Jahren 2008-2010.*

The results from the correlation analysis between crop and total weed coverage showed that no significant correlation could be found for the two factors in the TB region and in the year 2009 in all regions, respectively. In the regions EB and LDM, competition between crop and weeds started only around calendar day 225-240 and significant correlations could be found only when the longitudinal growth of the crop stands started.

3.2 Effects on species composition

As result of our surveys, we could not detect any significant difference in species number between sorghum and maize. Annual species number varied in both crops between 4 and 20 (maize) respectively 5 and 22 species (sorghum). Variance explanation in species composition regarding the crop type was 5.1 % in EB region, 17.5 % in LDM region and 5.4 % in TB region as found in the Canonical Correspondence Analysis (CCA). During the whole experimental period, only one or two species were found which showed a high relation (fidelity) to only one of the two crop types, sorghum or maize. The species fidelity varied among the regions (Tab. 4).

Tab. 4 Result table for the fidelity indices expressing the close relationship between high abundances of certain species and the tested crops (species with Phi-Values > 0.2).

Tab. 4 Ergebnistabelle für die Berechnung des Treue-Index als Ausdruck der Förderung hoher Abundanzen einzelner Arten durch die geprüften Fruchtarten (Arten mit Phi-Werten > 0.2).

EB region		**LDM region**		**TB region**	
Sorghum	**Maize**	**Sorghum**	**Maize**	**Sorghum**	**Maize**
CHEAL	AGRRE	POLCO	CHEAL	THLAR	BRSNN
SSYAL		HORVX		HORVX	POLPE

Abbreviations are EPPO-codes for weed species, exemplarily: POLPE - *Polygonum persicaria*, SSYAL – *Sysimbrium altissimum*; AGRRE – *Elymus repens*; CHEAL – *Chenopodium album*, for more see: http://de.wikipedia.org/wiki/EPPO-Code

Taking into account the findings for the overall weed cover, it is reasonable to assume that similar to weed abundance, species composition was also influenced by weather variation and different sowing time. Calculating the impact of these factors on several ecological groups of the weed flora with GLM showed that variation in yearly temperature had some impact on the coverage of species from the families *Brassicacea, Poaceae* and *Polygonaceae*. Sowing date impacted the abundance of the late summer annual species (increasing), the typical noxious maize weeds (increasing) and species from the *Asteraceae* family (decreasing – but not significantly).

4. Discussion

The field surveys under on-farm conditions showed an overarching impact of the weather conditions in the period from the sowing date until the beginning of the longitudinal growth for both crops. This has already been reported from an agronomic point of view for sorghum (TFZ, 2007). Maize seemed to be more sensitive to drought at early development stages (as observed in 2008). Sorghum in contrast was more sensitive to temperature than water availability (results of 2010). The most important tool of farmers for influencing growth processes of the two crop species is the choice of the appropriate sowing time. Since the optimal sowing time for sorghum will vary between regions and actual year, there is a great uncertainty among farmers.

Due to the higher temperature demands, the germination of sorghum is slow and its early growth requires a longer time compared to maize. In our investigations, the development of sorghum stands achieved the level of maize stands not before the mid of July. The consequence of this was a higher sensitivity to other external effects (e.g. weather) that may promote weed growth and spread. In the experimental year 2010, the cold temperatures in May delayed sorghum germination and growth but not the germination and growth of the weeds. This is contrary to reports from the warmer climates of Africa and America where sorghum is regarded as highly competitive against weeds and shows positive sanitary effects on crop rotations (EINHELLIG and RASMUSSEN, 1989). GEHRING and THYSSEN (2011) reported on damages of sorghum crops caused by herbicides in constellations of limited crop development due to low temperatures. Sorghum crops are at least partly sensitive to herbicide agents before reaching the three-leaf development stage (TFZ, 2007). Another drawback for sorghum in this relation is the limited herbicide spectrum available for this crop actually in Germany. Only five herbicides (typical maize herbicides) are registered for the application in sorghum (GEHRING and THYSSEN, 2011). The delayed application date of these agents together with higher temperatures may also influence the herbicide efficiency.

Crop stand densities of sorghum and maize have a temporarily limited influence on weed abundance. As shown by our statistical analyses, significant correlations between crop and total weed cover could be found from calendar day 225-240 on and in case of serious preliminary weed coverage. The time span before this period is defined as the critical stage for weed control. According to KNEZEVIC et al. (2002) we found the weed management at this stage to be crucial for the final weed cover and the crop stand densities. This is in accordance with findings of PAOLINI et al. (1998) for other crops. The more intensive growth of sorghum at later time may reduce weediness partly but not change the general trends.

Our results indicate that there was only limited variation (5-17.5 %) in species composition of the weed flora attributed to the kind of crop species: Sorghum and maize. Moreover, the interaction with sowing date has to be taken into account. Since most of the established weeds in Central Europe are adapted to winter cereals or early summer crops, some of them will not be able to germinate and reproduce in late sown crops. According to this, effects of sorghum on weed flora diversification will be very low or even negative. The set of our experimental farms was too small to draw general trends regarding selective effects of the late sowing dates on sorghum growth. Only some first trends can be presented as basis for discussion. The abundance of species from the *Asteraceae* family decreased in our dataset with late sowing dates, while the abundances e.g. of the *Polygonaceae* species and other species germinating all over the year seem to be unaffected.

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