Effects of factor reduction in energy crop rotations on weed flora

Einfluss der Faktorreduktion in Energiefruchtfolgen auf die Beikrautflora

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Summary

Opportunities for reductions of fertilization and weed control efforts in energy cropping are frequently posed and contrarily discussed. Beside effects on biomass yields weed flora, increments and increased weed control requirements in subsequent years are in the focus of the discussion. As part of the research project “Site-adapted Cropping Systems for Energy Crops” (EVA), the effects of factor reductions have been analysed in a crop rotation context. The trial consisted of three different crop rotations with three levels of factor reduction: 1 - no reduction, 2 - reduced nitrogen application by 30 kg/ha per crop, 3 - reduced nitrogen application and no weed management. The whole trial was replicated with one year time difference. In order to show effects of input reduction on subsequently grown cash crops, the last crop in the rotation was winter wheat for grain production in which no input reduction was performed over all plots. The field trial has been investigated regarding the effects of: Levels of fertilization and weed control, crop rotation, crop species and year of investigation on weed cover and species composition as target variables.

The results suggest that the reduction of weed control efforts showed the main effect on the weed flora. Energy crops, like maize and sorghum, seemed to be highly sensitive to reduced weed control especially during early development stages; they showed the greatest differences between the factor levels. The reduction in fertilization resulted in no or only slight differences in the weed flora. Despite strong effects in single years and crops, there were no or only little cumulative effects observed in the final crop of the crop rotations (winter wheat). Among the differences in weed species composition, the crop species explained the largest part of variance.

Keywords: Crop species, nitrogen fertilization, species composition, weeds, weed cover

Zusammenfassung

Optionen für eine Reduktion der Intensität von Düngung und Beikrautmanagement werden insbesondere vor dem Hintergrund einer energetischen Verwertung der Biomasse häufig und auch konträr diskutiert. Neben den Effekten auf die Biomasseerträge der Kulturen wird häufig die Zunahme der Beikrautflora mit ihren potenziellen Folgewirkungen in nachfolgenden Marktfrüchten thematisiert. Im Rahmen des Verbundprojektes „Standortangepasste Anbausysteme für Energiepflanzen (EVA)“ wurden die Effekte der Faktorreduktion im Kontext verschiedener Fruchtfolgen experimentell untersucht. Im hierzu am Standort Ascha durchgeführten Feldversuch wurden drei Stufen der Faktorreduktion in drei verschiedenen Fruchtfolgen analysiert: 1 - ohne Reduktion, 2 – eine um 30 kg/ha je Fruchtart reduzierte Stickstoffdüngung; 3 – reduzierte Stickstoffdüngung und keine Beikrautkontrolle. Der Versuch wurde im Folgejahr des Startjahres als Ganzes wiederholt. Als Abschlussfrucht für alle vierjährigen Fruchtfolgen wurde einheitlich Winterweizen für die Kornnutzung ohne Faktorenreduktion angebaut, um sowohl die kumulativen Fruchtfolgeeffekte als auch die Effekte in nachfolgenden Marktfrüchten darstellen zu können. Hinsichtlich der Zielgrößen Stärke und Zusammensetzung der Beikrautflora wurden folgende Faktoren analysiert: Reduktion der Düngung und des Herbizideinsatzes, Fruchtarten- und Fruchtfolgeeffekte und Jahreseffekte. Die Ergebnisse zeigen, dass der Verzicht auf die chemische Beikrautregulation die stärksten Effekte auf den Beikrautbesatz verursacht. Insbesondere Mais und Hirsen reagieren empfindlich auf eine extensive Bestandesführung. Beide Pflanzen wiesen die höchsten Unterschiede zwischen den Faktorenstufen auf. Demgegenüber verursachte die Reduktion der Stickstoffdüngung nur geringe oder keine Veränderungen in der Beikrautflora. Trotz gravierender Unterschiede in den Einzeljahren konnten keine kumulativen und Fruchtfolgeeffekte in der Abschlussfrucht Winterweizen festgestellt werden. Die Art der angebauten Fruchtart hatte den stärksten Einfluss auf die Zusammensetzung der Beikrautflora.

Stichwörter: Artenzusammensetzung, Beikräuter, Fruchtarten, Herbizid, Stickstoffdüngung

1. Introduction

Production of biogas substrates requires lower quality standards than the production of food or feed. Therefore, the optimum intensity of factor input in energy cropping is theoretically reached at lower amounts of applied fertilizer and herbicides. Particularly the weed flora could be tolerated to a higher extent since it contributes to the total of biomass yield. Weeds have a similar energy content as crops. When the generative reproduction of weeds can be avoided, e.g. there may be real opportunities for reductions in crop protection in cereal crops (KARPENSTEIN-MACHAN, 1997).

Since fertilization and plant protections have many negative side effects on soil, surface and groundwater as well as on flora and fauna, the reduction of factor input is a central demand of nature conservation and environmental protection. A decrease in nitrogen application can help to minimize nitrogen losses into groundwater and atmosphere. In addition, a lower intensity of weed control can increase the biodiversity of agricultural ecosystems. For these reasons, the European Union (EC, 2009) as well as Germany (BMVEL, 2005) have approved directives in the last years that will promote a substantial reduction in the use of crop protection products. Due to numerous interactions (ZORNBACH, 2003) e.g. with crops and crop rotations, there are no "easy-to-handle" rules for factors reduction.

In this context, a field trial was set up within the research project "Site-adapted Cropping Systems for Energy Crops" (EVA) aiming to identify the optimal strategy for an economically successful and environmentally sound production of energy crops. Within three crop rotations nitrogen fertilization and herbicide application were varied according to three intensity levels. The present study focuses on the effects of reduced factor input on weed cover and species composition with respect to particular crop species and crop rotations.

2. Materials and Methods

2.1 Experimental setup

The field experiment was established in the foothills of the Bavarian Forest near Ascha, Germany. The experimental site is located at an altitude of 430 m above sea level with a mean annual precipitation of 807 mm and a mean annual temperature of 7.5 °C. The soil is a eutric cambisol with loamy sand and a pH of 6.4.

Three crop rotations (Tab. 1) were tested under three intensity levels as indicated in Table 2. Crop rotation A and B stand for sole biogas substrate production and integrated substrate and feed production for cattle, respectively. Crop rotation C represents a market-orientated production system with a high proportion of cash crops like grain maize and potatoes. The final component in all crop rotations was winter wheat used as a reference in order to monitor accumulated effects of the different cropping systems. Potatoes and winter wheat were treated in all intensity levels equally with optimal intensity to check for negative effects of factor reduction in preceding crops.

Tab. 1 Crop rotations for substrate production under reduced factor input; crops printed in bold were cultivated as cash crops.

Tab. 1 *Fruchtfolgen für die Substratproduktion mit reduziertem Faktoreinsatz; fettgedruckte Fruchtarten wurden als Marktfrüchte angebaut.*

Year	Number	Crop Rotation A	Crop Rotation B	Crop Rotation C
1st	1	Maize (energy)	Maize (silage)	**Maize (grain)**
2nd	2	Winter rye	Winter rye	Ryegrass
	3	Sorghum	Maize (silage)	**Potatoes**
3rd	4	Winter triticale	Winter Rye/hairy vetch	Winter wheat
	5	Ryegrass	Sorghum	Peas
4th	6	**Winter wheat**	**Winter wheat**	**Winter wheat**

Crop rotations were started in two consecutive years in 2005 and 2006 in order to account for seasonal effects. The field experiment was arranged in a split-plot block design with crop rotation as splitting factor and four replicates. Each experimental plot had an area of 49.5 m^2 with a sample area of 12 m^2.

Tab. 2 Intensity levels of factor input.

Tab. 2 *Intensitätsstufen des Faktoreinsatzes.*

RedCode	Intensity Level	Treatment
1	Intensity I (optimal)	Optimal N fertilisation; optimal pest management (PM)
2	Intensity II (-N)	N-application reduced by 30 kg/ha per crop; optimal PM
3	Intensity III (-N, no PM)	N-application reduced by 30 kg/ha per crop; no PM

2.2 Data collection and analysis

Overall weed cover and contribution of single weed species was determined in every crop for two or three times. Weed cover was estimated in percent of area covered by all weedy biomass; coverage of single species was estimated correspondingly for each present weed species. The normality of the data was tested with the Kolmogorov-Smirnov-test. To reach normality, the data were transformed and standardized.

We used the General Linear Model (GLM; SPSS 16.0) as tool for Univariate Variances Analysis in order to identify i) the main drivers for weed abundance differences and ii) to quantify the impact strength of the single factors as well the interaction between factors impacting on weed abundances. The intensity levels (RL), the crop rotation number and the crop type were defined as fix factors, the replication number of the whole trial (TR) which is an indirect measure of year effects as random factors to analyze the impacts on the weed abundance as target variable. The GLM provided the following additional outputs: i) parameter estimates (eta), which express the partial variance caused by single factors or interactions, ii) contrast tests, providing significance levels of the factor levels according a predefined baseline and iii) post hoc tests (Tukey HSD) for the fix factors.

The impacts 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. Variance Partitioning was performed by running the CCA with all combinations for input factors and covariates, starting from a full model (all factors as input factors) and changing the inputs stepwise to covariates in the model. Additionally, the relative promotion of single weeds by single factors was tested by using fidelity indexes as commonly used in ecologic vegetation analyses (CHYTRY et al., 2002).

3. Results

3.1 Identifying and quantifying the main impact factors

The overall analysis with the General Linear Model resulted in the variance parts explained by the different factors as shown in Table 3. The intensity level (RL) caused the highest impact on total weed coverage (34 % of variance). Together with the crop species (CS) and the interaction between RL and CS, both factors explained nearly two third of the overall variance. The impact of crop rotation and year effects for the trial replications remained very low (1.2 respectively 1.8 %) and can therefore be neglected.

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

Tab. 3 *Ergebnistabelle des statistischen allgemeinen Modells (GLM) zur Charakterisierung der Varianzquellen und der partiellen Beiträge (Eta) der Prüffaktoren.*

Source	Type III Sum of Squares	df	F	Sig.	Partial Eta Squared
Intercept	1252.527	1	102.962	0.056	0.990
CropRotation (CR)	11.894	2	5.635	0.004	0.012
IntensityLevel (RL)	503.272	2	238.434	0.000	0.338
TrialReplication (TR)	16.918	1	16.030	0.000	0.017
CropSpecies (CS)	104.838	8	12.417	0.000	0.096
Interaction CR * RL	18.090	4	4.285	0.002	0.018
Interaction RL * CS	248.001	16	14.687	0.000	0.201
Error	984.659	933			

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

Figures 1-3 show the average weed coverage of every single crop rotation element and the weed dynamic over the years for the three intensity levels. Three details should be highlighted: 1.) Differences between intensity levels were mainly caused by higher weed infestation in factor level 3 (-N, no PM). Only these differences were significant. There were no or no significant differences between level 2 (-N) and the control level 1. 2.) There was no accumulative effect of the reduced factor input visible or provable in the last year of the crop rotation (winter wheat with weed control in all intensity levels). 3.) There were hardly any differences in weed infestation between the three tested crop rotations in the last crop of the rotation (winter wheat).

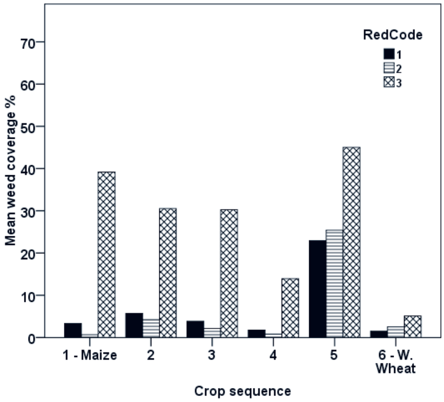

Fig. 1 Average weed coverage in all crop species included in crop rotation A as affected by factor reduction levels (=RedCode) (Average over the trial replication and three investigation dates per year).

Abb. 1 *Mittlere Beikrautbedeckung in den einzelnen Fruchtfolgegliedern der Fruchtfolge A als Effekt der untersuchten Faktorstufen (=RedCode) (Mittelwerte über zwei parallele Versuchsanlagen, drei Boniturtermine).*

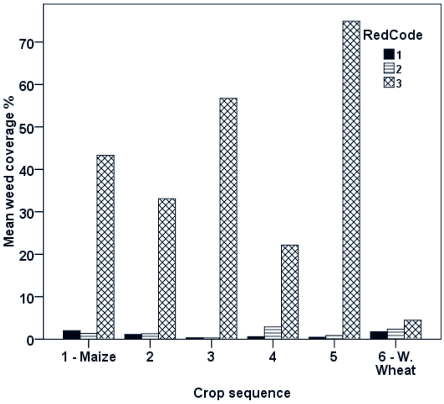

Fig. 2 Average weed coverage in all crops species included in crop rotation B as affected by factor reduction levels (=RedCode) (Average over the trial replication and three investigation dates per year).

Abb. 2 *Mittlere Beikrautbedeckung in den einzelnen Fruchtfolgegliedern der Fruchtfolge B als Effekt der untersuchten Faktorstufen (=RedCode) (Mittelwerte über zwei parallele Versuchsanlagen, drei Boniturtermine).*

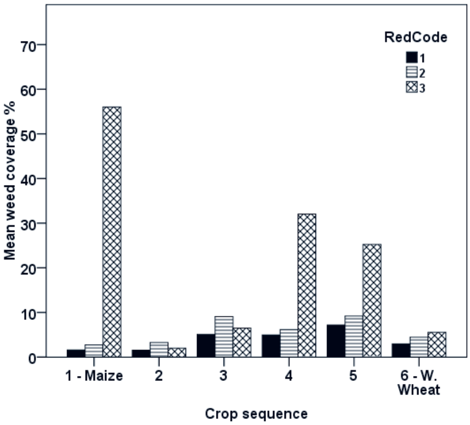

Fig. 3 Average weed coverage in all crops included in crop rotation C as affected by factor reduction levels (=RedCode) (Average over the trial replication and three investigation dates per year).

Abb. 3 *Mittlere Beikrautbedeckung in den einzelnen Fruchtfolgegliedern der Fruchtfolge C als Effekt der untersuchten Faktorstufen (=RedCode) (Mittelwerte über zwei parallele Versuchsanlagen, drei Boniturtermine).*

3.2 Interaction between factor reduction and crop species

The onserved interaction between factor reduction and crop species can be attributed to two reasons. Firstly, not all crop species have been treated with different intensity levels. Secondly, the differences between intensity level 3 (-N, no PM) and the other two levels were nearly double in size in crops with weak competitive ability like maize and sorghum (Fig. 4).

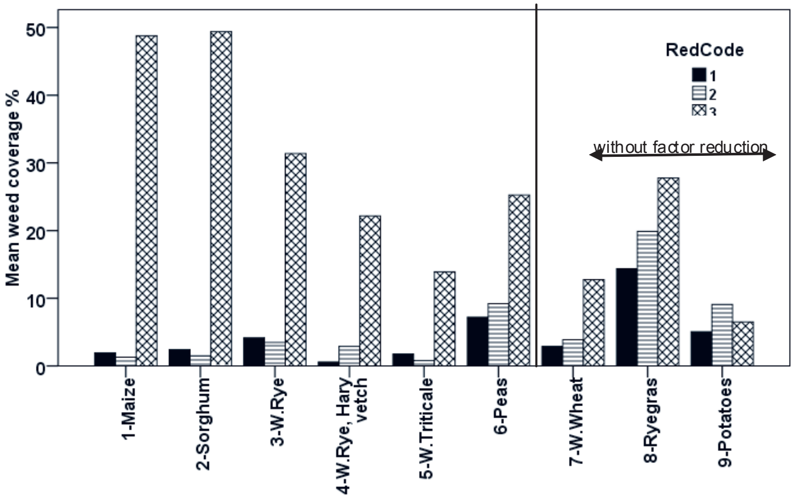

Fig. 4 Average weed coverage as function of crop species and factor reduction levels (=RedCode) (Average over crop rotations, the trial replication and three investigation dates per year).

Abb. 4 *Mittlere Beikrautbedeckung als Wechselwirkung zwischen Fruchtart und Faktorreduktionsstufen (=RedCode) (Mittelwerte über alle Fruchtfolgen, zwei parallele Versuchsanlagen, drei Boniturtermine).*

Under intensity level (RL) 1 (control) or 2 (-N), maize, sorghum, winter triticale and winter rye with hairy vetch had the lowest weed abundances, which were significantly lower compared to weed infestation in peas and ryegrass. Under intensity level 3 (-N, no PM), maize and sorghum showed the highest weed coverage. The differences in weed coverage between maize and each of the other crops (except of sorghum) were significant at intensity level 3. In sorghum, the weed coverage was not significantly different to the weed coverage in winter rye, winter triticale, winter rye with hairy vetch and peas at RedCode 3.

3.3 Effects on species composition

The investigated four factors: Intensity level (RL), crop rotation (CR), crop species (CS) and trial replication (TR = year effects) explained in average for both trial replications 79.1 % of overall variance in species abundances. The crop species was the single factor with the highest lonely impact on species composition (38.5 % of variance). The intensity level (RL) and the crop rotations had only very small impacts as single factors (1.3 % respectively 0.3 % of variance). The interaction between Intensity level (RL), crop species (CS) and crop rotation (CR) was related to 76.1 % of the variance. The differences caused by year (trial replication) can be ignored (3.4 %).

The used fidelity indices measure "the degree to which a species is concentrated in a given vegetation unit" (here: factor combination) (BRUELHEIDE, 2000). Table 4 presents the weed species which can be regarded as highly related and promoted by the tested factors. As higher the Phi-value, the stronger is the relation of a single species to a certain factor. Here, we were mostly interested to highlight the promotional effects of the factor reduction, mainly for intensity level 3 (-N, no PM) and the effects of the maize and sorghum growing.

Tab. 4 Result table for the fidelity indices expressing the close relationship between high species abundances and the tested impact factors (species with Phi-Values > 0.2, TR – TrialReplication).

Tab. 4 *Ergebnistabelle für die Berechnung des Treue-Index als Ausdruck der Förderung hoher Artabundanzen durch ausgewählte Einflussfaktoren (Arten mit Phi-Werten > 0.2, TR – Anlagenummer des Versuches).*

Tested factor	**TR 1**	**TR 2**
Intensity level (RL) 3	CHEAL	POLPE
	GASCI	STEME
	MATCH	MATCH
	POLPE	GASCI
	STEME	CHEAL
Maize crop	CHEAL	POLPE
	POLPE	CHEAL
Sorghum crop	GASCI	CHEAL

Abbreviations are EPPO – Codes for weed species, exemplarily: POLPE - *Polygonum persicaria*, STEME – *Stellaria media*; MATCH – *Matricaria chamomilla*, GASCI – *Galinsoga ciliata*; - CHEAL – *Chenopodium album*, for more see: http://de.wikipedia.org/wiki/EPPO-Code

4. Discussion

The most evident effect of reduced factor input was observed in maize and sorghum at intensity level 3 (-N, no PM). In these crops, weed infestation tended to increase over the time period of three years in the variant without herbicide application.This was mainly visible in crop rotation B, where maize or sorghum were grown yearly with varying winter catch crops. The occurring summer annual weed species *Chenopodium album*, *Polygonum persicaria* and *Galinsoga ciliata* perform their development cycle very fast and reach ripeness of seeds before harvest of maize or sorghum. Thus, the growing seed bank of these weed species will lead to an increasing need for weed control in subsequently grown summer crops. Since maize and sorghum respond very sensitively to weed flora with yield losses of 30 %, weeds cannot be tolerated in these crops and need to be controlled either chemically or mechanically (DEIGLMAYR et al., 2009). Due to their slow development in early phenological stages, maize and sorghum crops are in particular highly sensitive to weed competition and weed spread (KNEZEVIC et al., 2002). Nevertheless, the reduction of chemical weed control is possible also in these crops, but it requires a compensation with alternative weed control measures like undersowing, mulching or mechanical weed control (BRUST et al., 2011).

Winter crops in general showed lower weed cover and no rise in weed infestation. Winter annual weed species are either less competitive as for example *Stellaria media* or exhibit a simultaneous development with the cultivated crops. Hence, weed species as *Matricaria chamomilla* are harvested before ripeness of their seeds and consequently seeds do not accumulate in the soil. Our results support the assumption of KARPENSTEIN-MACHAN (1997) according to low effects of weed control reductions in cereal crops harvested as green biomass. We found no or only slight effects in winter cereal catch crops. This suggests that the tolerance level for weeds in winter catch crops for biogas production can be set rather high.

Despite huge increments in the weed cover in plots without weed control in single years, we could not observe cumulative effects in the subsequent conventional cereal crop. Winter cereals combine a relative high competitive ability with a distinguished growing period. Therefore, the increase in summer annual weeds was not manifested in winter wheat. This “cleaning effect” of winter cereals indicates the high importance of crop changes within energy crop rotations and suggests that factor reductions options are interacted with the diversity of crop rotations. Crop rotations can be used to cure single year problems.

Our results indicate that the options for factor reductions in energy cropping are interacted by the crops grown for biomass. Particularly in maize and sorghum, weeds must be carefully controlled. Other experiments have shown that there are also options for reducing herbicide doses by 29-40 % in maize but only as part of an integrated management (DOGAN et al., 2005) or new innovative cropping systems (MÜLLER-SÄMANN et al., 2006). A survey on current practice in weed management in Lower Saxony in Germany (KARPENSTEIN-MACHAN and WEBER, 2010) has shown a trend to higher post-emergent herbicide applications in energy maize compared to whole crop cereals. Concerning winter crops, further research is needed to evaluate the long-term effect of reduced weed control. The options of reduction in dose or rates of application for the special cropping requirements of energy crops (e.g. late sowing of maize and sorghum) should be evaluated by future research projects.

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