The regional weed vegetation in organic spring-sown cereals as shaped by local management, crop diversity and site

Eine regionale Analyse der Unkrautvegetation von Sommergetreideflächen auf Öko-Betrieben unter dem Einfluss von Unkrautbekämpfung, Kulturvielfalt und Standort

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Abstract

Mecklenburg Vorpommern has one of the highest percentages of organic arable production nationwide. Weeds remain to be the main challenge within this agricultural system. There is also an increase in the national support of agrobiodiversity. Weeds should therefore be continuously kept within manageable limits, while on the other side encourage a specie rich weed flora. Our objective is to investigate to which extent these two aspects can be addressed through the use of diversified crop management. In order to research this objective, weed and management data of spring sown cereal crops were obtained from organic farms in the region over the course of two years (2015-2016). The impact of the local environment and management factors on the occurring weed communities was studied in multivariate analysis approaches, followed by the separate crop diversity effects. We found a fundamental difference between the workings of the short-term management, the long-term crop diversification strategies and the more continuous site variables on the weed vegetation. Weed densities were mostly affected by direct management, while weed diversity and communities were altered through the application of crop diversity variables.

Keywords: Canonical correspondence analysis, weed communities, weed survey

Zusammenfassung

Bundesweit hat Mecklenburg Vorpommern einen sehr hohen Anteil an Ökologischer Landwirtschaft. Nach wie vor sind Unkräuter eine Herausforderung in diesen Agrarsystemen. Agrobiodiversität zu fördern, hat in Deutschland einen zunehmenden Stellenwert. Vor diesem Hintergrund sollten Unkräuter einerseits in langfristig handhabbaren Größenordnungen bleiben, andererseits aber auch eine artenreiche Flora bilden. Unser Ziel ist es, zu untersuchen, ob diese beiden Aspekte durch ein vielseitiges Management der Kulturpflanzen unterstützt werden können. Dafür wurden Unkraut und Management Daten von Sommergetreideflächen ökologisch wirtschaftender Betriebe in Mecklenburg-Vorpommern über zwei Jahre (2015-2016) erfasst. Die Auswirkungen von lokalen Umwelt- und Management-Faktoren auf die Unkrautgemeinschaften wurden multivariat analysiert und im Anschluss wurden Effekte der Variablen zur Kulturvielfalt separat untersucht. Wir fanden grundlegende Unterschiede in den Einflüssen des kurzfristigen Anbaumanagements, der langfristigen Kulturvielfaltsstrategien und den eher beständigen Standortfaktoren. Während Unkrautdichten vor allem durch direktes Management beeinflusst werden, verändern sich Unkrautartenvielfalt und –gemeinschaften, wenn Maßnahmen der Kulturvielfalt angewendet werden.

Stichwörter: Kanonische Korrespondenzanalyse, Unkrauterfassung, Unkrautgemeinschaften

Introduction

Within organic crop production weeds remain to be the main constrain on crop productivity (PENFOLD et al., 1995; CLARK et al., 1998; TURNER et al., 2007; ALROE and HALBERG, 2008). Despite many non-herbicide reduction strategies available and utilized, a total eradication of the weed flora is not to be expected. Nevertheless, a diverse weed community within arable fields increases the ecosystem services of arable fields (MARSHALL et al., 2003). The maintenance of a higher crop diversity prevents the development of a single weed species, disrupt weed communities and thus could mitigate severe weed problems on the long run (MELANDER, 2005; BLACKSHAW et al., 2007). Examples of such crop diversity strategies are: a diverse crop sequence, intercropping, cover and catch crops between cash crops and the careful choice and mixture of crop varieties (MORTENSON et al., 2000; BOND and GRUNDY, 2001; BARBERI, 2002; MELANDER, 2005). The PRODIVA project (HOFMEIJER et al., 2016) aims to study the effects of crop diversification strategies to improve weed management and still maintain a diverse weed flora. This study was conducted within the PRODIVA framework and specifically aimed to research the possible effects of crop diversity strategies on weed communities on farms, thus in practice. We do see that there are many factors of influence on weed communities, such as crop and environment (FRIED et al., 2008; ANDREASEN and SKOVGAARD, 2009; HANZLIK and GEROWITT, 2011) therefore we aim to investigate a multitude of factors, both in management and site, including crop diversity strategies.

This was performed in the German region of Mecklenburg-Vorpommern, with the highest percentage of area under organic production nationwide (BMEL, 2016), which primarily produces organic cereal and beef (LFA, 2017). Like in any other organic arable system, weeds are a perpetual challenge, especially in a region with crop rotations dominated by cereals and grass clover leys.

Our objectives were to: (I) compile an up-to-date list of weed species in organic farming in Mecklenburg-Vorpommern (II) test influence of site and management factors on: total weed density, species and diversity (III) investigate to which extent density and diversity can be influenced through diversified crop management.

Materials and Methods

A weed survey took place on organic farms in the region of Mecklenburg-Vorpommern in Germany. During the two years of this study (2015-2016) 42 spring sown cereal fields were surveyed at the flowering stage of the crop (Stage 61-69 of BBCH scale), after all weed management measures were finished.

Weed data

Fields were sampled for weed densities and –diversity. This was done by estimating the individual density of all weed species found in a subplot of 100 m^2, with a triple replication in each field. These subplots were located randomly in the field, keeping at least 10 meter distance from the field boundary to avoid edge effects. The density estimation was based on a classification scale, which included 10 density classes, exponentially increasing from 0.2 individuals per m^2 up to over 200 individuals per m^2. Each fields was surveyed once, the following year another spring sown cereal field on the same farm was surveyed. Some individuals could only be identified on genus level and therefore are recorded as such. Latin names are based on the Flora Europaea (EURO+MED, 2006) and in the ordination graphs displayed with EPPO-codes (EPPO, 2017).

Explanatory variables

Farmers were questioned on their overall farm management and the management of the surveyed fields. Information was taken on the current crop, preceding crops for the minimum of 5 years back in the rotation, weed management and yield. Soil type and soil quality (‘Ackerzahl’) were also inquired and subsequently soil samples were taken from the first 25 cm of the surveyed fields to determine nutrient balances. This was done in the summer of 2016. The soil samples were tested for pH, P2O5, K2O, Mg, S and the CN-ratio. Tillage was not considered, due to similar regimes between farms involved.

The explanatory variables, as shown in Table 1 include: ‘Crop Present’ which were spring sown cereals including barley, bare or under sown with white clover or peas, oats, bare or under sown with white clover or peas or rye-grass mix, summer rye , triticale and summer wheat. ‘Preceding crop’ included barley, winter barley, rye, bare or under sown with white clover, spelt, alfalfa, triticale, field beans, cabbage, oats, sunflower, winter wheat, grass glover ley mixtures and maize. ‘Other Crops’ meaning all other crops then cereals and grass clover ley. Rotation diversity was based on the presence and mixture of ‘Grass clover’, ‘Cereal’ and ‘Other crops’ for the previous 5 years in the rotation.

Statistical Analysis: R, Linear Models, Multivariate Models

Firstly, we calculated the total weed density, weed species numbers and Shannon indices of all fields. Then we conducted linear models to the data set, to find relationships between each of the explanatory variables and these total weed and diversity data.

This was followed by a canonical correspondence analysis (CCA) (TER BRAAK, 1986) on the whole data set (42 sampled fields, 94 weed species observed and 25 explanatory variables). Separate CCA's with a single explanatory variable were used to test the Gross Effects of which the significances were tested by permutation test (n=1000). This was followed by the ordination graph from this CCA. For the site conditions a separate dataset was used for the CCA, because from two sites soil nutrient data was missing. Thus, a separate ordination graph expresses these data.

All analyses were carried out using the program R 3.4.0 (R DEVELOPMENT CORE TEAM, 2013), making use of the package Vegan.

Tab. 1 Explanatory variables used in linear models and canonical correspondence analysis.

Tab. 1 *Erklärungsvariablen im Linearen Model und in der Kanonischen Korrespondenzanalyse.*

Variable type	Explanatory variables	Categorious variable - Label	Continuous variable - Unit
Farm	**Survey year**	2015, 2016	
	Farm type	'Mixed', 'Arable'	
	Organic since	Years under organic management	
Management	**Crop present**	10 classes	
	Preceding crop	15 classes	
	Seasonal crop sequencing	Dominated by winter or summer crops	
	Yield		tons/ha
	Harrowing	number of	
	Seed density		kg/ha
Crop diversity	**Undersown**	frequency in 5 years	
	Crop mixtures	frequency in 5 years	
	Catch crop	frequency in 5 years	
	Grass clover	frequency in 5 years	
	Cereals	frequency in 5 years	
	Other crops	frequency in 5 years	
	Rotation diversity	'Low', 'Medium, 'High'	
Site conditions	**Soil quality**		points
	Sand percentage		%
	Soil pH		
	P2O5		mg/100g dry matter
	K2O		mg/100g dry matter
	Mg		mg/100g dry matter
	N		mg/100g dry matter
	C		mg/100g dry matter
	S		%
	CN-ratio		

Results

Weed species

A total of 94 weed species were found, of which 62% belonged to the group of annuals, 26% to the perennials. 12 species and/or individuals could only be determined on genus level such as hard to identify species like *Vicia* spp and *Rumex* spp or species that were rare such as *Stachys* spp or *Silene* spp. The majority belonged to the dicotyledonous (81%) with the most frequently found species being: *Myosotis arvensis* (98%), *Capsella bursa-pastoris*, *Chenopodium album*, *Fallopia convolvulus* (all 95%), *Vicia* spp (93%) and *Centaurea cyanus* (90%). The most frequently present monocotyledons were: *Elytrigia repen*s (58%), *Equisetum arvense* (53%) and *Apera spica-venti* (38%). Of all annual species 40% were known as spring- and 14% whole year germinating species, and 29% autumn germinators.

Tab. 2 Estimates ± Standard Error of the effects of the explanatory variables on weed density, species numbers, and Shannon Index. Last column shows the CCA gross effects of the variables on the weed composition. Only significant results are shown.

Tab. 2 *Schätzwerte ± Standardfehler für die Effekte der Erklärungsvariablen auf Unkrautdichte, Artenzahl und Shannon Index. Brutto-Effekte dieser Variablen in der Unkrautartengemeinschaft (CCA-Effekt). Nur signifikante Ergebnisse werden gezeigt.*

Explanatory variables	Weed densities	Species numbers	Shannon index	CCA effect
Farm				
Survey year		-3.2 ± 1.6˙		
Organic since		0.3 ± 0.2*		0.036**
Management				
Crop present	(B+Cl) 6239±3148˙ (Trit) 3687±1707*	(SR) -13.1 ± 5.3*	(SR) -0.93±0.43*	
Preceding crop	(M) 8295±2995*			
Seasonal crop seq.		(W) 4.2±1.5**		
Harrowing	-1399±649*		0.22±0.08*	
Crop diversity				
Catch crop			0.18±0.10˙	0.037*
Grass clover				0.026 ˙
Other crops		-2.0±0.9*	-0.13±0.08˙	0.027**
Site conditions				
Soil pH				0.035*
P2O5				
K2O	145±76 ˙		-0.03±0.01**	0.027*
Mg	-299±134*		0.04±0.02*	
S		24.0±14.1 ˙		

P-values associate with linear models outputs. Gross effect was calculated using separate CCAs each with one explanatory variable. P-values associate with permutation tests. ˙P<0.1, *P<0.05, **P<0.01. B+Cl = Barley with clover undersown, Trit. = Summer Triticale, M. = Maize, SR = Summer Rye, W = Winter.

Weed density, species numbers and Shannon index

The influences of the explanatory variables were tested individually on weed densities, species numbers and Shannon index of the surveyed weed flora using Linear Models (Table 2). We found that weed densities were positively influenced by Experience, certain crops like barley, triticale and maize in the previous year, and increased concentrations of potassium. However, repeated mechanical weed management and magnesium concentrations brought densities down.

In species numbers we encountered a time effect. They also increased under organic management, adding a new species every three years. A winter crop dominated rotation increases the species numbers in the field as well as increased sulfur concentrations. Summer rye as the present crop and a higher frequency of other crops in the rotation bring species numbers down.

Like species numbers Shannon indices, were negatively affected by the presence of summer rye and other crops and like weed densities, by potassium and magnesium concentrations. However, Shannon indices were positively affected by repeated harrowing and the presence of catch crops in the rotation which both increased weed diversity.

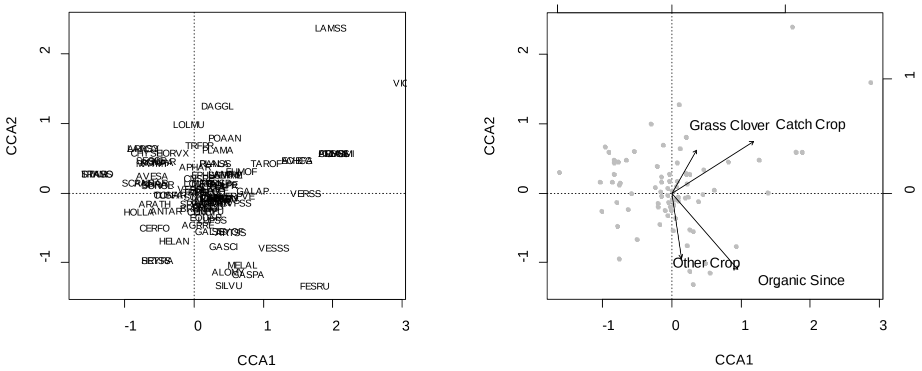

Fig. 1 Ordination plots showing the results of the CCA investigation the impact of the crop diversity variables with significant (<0.1) effects on weed communities; "grass clover frequency", "catch crop frequency", "other crop frequency" and "organic since". In the species ordination, names refer to EPPO codes.

Abb. 1 *Ordinationen der Ergebnisse der CCA und die Auswirkungen von Variablen zur Kulturvielfalt mit signifikanten (<0,1) Effekten auf die Unkrautgemeinschaften; „Kleegras-Häufigkeit", „Zwischenfrucht-Häufigkeit", „Häufigkeit anderer Feldfrüchte" und „Ökologisch seit". Artnamen in der Ordination der Unkrautarten basieren auf EPPO-Codes.*

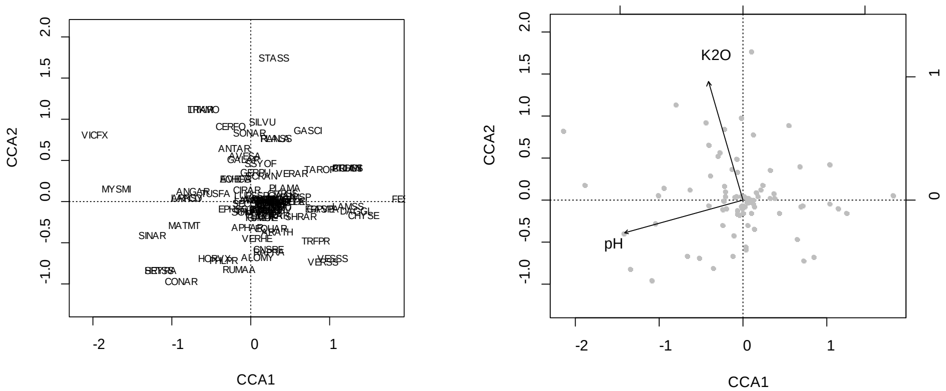

Fig. 2 Ordination plots showing the results of the CCA investigation the impact of the Site conditions variables with significant (<0.1) effects on weed communities; soil pH and K2O. In the species ordination, names refer to EPPO codes.

Abb. 2 *Ordinationen der Ergebnisse der CCA und die Auswirkungen von Variablen zu Standortbedingungen mit signifikanten (<0,1) Effekten auf die Unkrautgemeinschaften; „Boden pH", „K2O". Artnamen in der Ordination der Unkrautarten basieren auf EPPO-Codes.*

Weed community

The permutation test found an influence of organic since, catch crops, grass clover frequency, other crop frequency, pH, and potassium content (Tab. 1). The CCA of the farm/management/crop diversity data set resulted in the ordination shown in Figure 1. The axis of 'Grass Clover' indicated the frequency of grass clover ley used in the rotation which supports monocotyledonous weed species: *Dactylis glomerata*, *Lolium multiflorum* and *Poa annua* and voluntary red clover *Trifolium pratense*. The second axis of 'Catch Crops' related to the family of *Vicia*, often used in cover crop mixtures. The third axis of 'Organic Since' shows the positive influence on species numbers by the increase of the less common weed species: *Silene latifolia* and other members of the Silene family. The forth axis of 'Other Crop' shows a less clear relationship with the weed composition other than the occurrence of voluntary crop species of "other crops" such as *Lupinus* spp and *Helianthus annuus* which do not occur in rotations that lack the cultivation of these crops. This is however a broad explanatory variable. Most common weed species clustered mostly in the center, seemingly unaffected by researched variables.

The second ordination (Fig. 2) is based on the CCA data set specifically adapted to host the site variables. Here the variables of potassium and pH had a significant effect on the weed composition. The first axis of Potassium appears to relate to species that prefer nutrient rich soils like *Stachys* spp, *Sonchus arvensis* and *Cerastium fontanum*. The second axis of 'pH' associates broadly with species that prefer a light to moderate alkaline soil such as *Sinapis arvensis*, *Matricaria discoidea* and *Setaria* spp.

Discussion

Weed species

The weed species found in the survey reflect the situation of Mecklenburg-Vorpommern and its agricultural system. The most frequent species were spring- or opportunity based emerging, typical for cereal dominated systems and adapted to the local slightly poorer sandy-loam soils. There was also the occurrence of weeds more often associated with grassland systems, such as *Taraxacum officinale*, *Plantago major* and *Rumex acetosella*, possibly because of the frequent cultivation of grass clover leys. *Centaurea cyanus* is typically associated with autumn germination and thus autumn sown cereals, it however occurred in high densities in the surveyed spring sown cereals. This species has increased in the last decade in Mecklenburg-Vorpommern and seems to have adopted a more opportunistic lifestyle.

Weed density, species numbers and Shannon index

The most interesting finding on farm level is the increase of species numbers with a longer time under organic management, reaffirming that organic management does over time indeed support species richness (HALD, 1999). Also promising is that the duration of organic management does not increase weed densities. When we look at management effects, a definite effect of crop present was found, both on densities, where some crops are linked with increased densities, and on diversity level. Here we see an effect of summer rye: although densities were not affected, species richness and diversity responded negatively. Rye crops are described to have allelopathy effects on some weed species (BARNES and PUTMAN, 1986). On the other side: the open nature and late harvest of maize as a precrop seems to increase densities the next year. Other authors also record a high impact of crop and pre-crop (FRIED et al., 2008; HANZLIK and GEROWITT, 2011). Weeding actually decreases weed densities, but stimulates diversity, an effect also reported by ARMENGOT (2013). The harrowing could weed out early dominant species and stimulate a secondary flush of emergence. Thus, direct management has impact on the densities of weeds in the field, but, a much smaller effect on the weed diversity and non on the weed community as a whole.

In contrast, crop diversity strategies had no effects, positive or negative, on densities, but did on species richness and diversity. Catch crops encouraged diversity, but additional other crops in the rotation decreased it. However, high or low rotation diversity showed no influence. This might be unusual, contradicting research (ULBER et al., 2009), but surveyed rotations also tended to be structurally similar.

Again different were the influences of site variables. The concentrations of the soil nutrients potassium, magnesium and sulfur affected both densities and diversity - reflecting the more complex and intricate effects soil nutrient availability has on densities and specific species (ANDREASEN and SKOVGAARD, 2009).

Weed community

If we then look to the CCAs it is promising to find the degree of influence the crop diversity variables have on weed communities. Winter catch crops, grass clover leys and other crops frequency in the rotation all affected the weed population significantly. This however is in stark contrast to the management variables who, with exception for organic since, do not have any effect on the weed composition. In the soil category the variables affecting are pH and potassium, reflecting the effects from the linear models. However, the more common weed species seemed the least affected by the explanatory variables. Therefore, it is of interest to study these effects on species level in future analysis.

To summarize, most fascinating are the shifted effects from densities that react to direct short-term management and diversity resp. communities that reacts to indirect long-term management. The results are both classical and intriguing and beg for further and deeper research, which will take place within the PRODIVA project.

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