Sektion 1: Biodiversität

Session 1: Biodiversity

Reintroduction of rare arable weeds under various farming practices and their influence on ecosystem services and yield

Wiederansiedlung seltener Ackerwildkräuter unter verschiedenen Anbaumethoden und ihr Einfluss auf Ökosystemdienstleistungen und Ertrag

Rosa Witty*, Matthias Schumacher, Roland Gerhards

University of Hohenheim, Institute of Phytomedicine (360), Department of Weed Science, Otto-Sander-Str. 5, 70599 Stuttgart, Germany

*rosa.witty@uni-hohenheim.de

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Abstract

Agricultural intensification and changing landscape structure led to decreasing numbers of arable flora and fauna during the last decades. To counteract these declines, weed diversity needs to be supported. It is important to promote regional weed communities including endangered species to ensure adoption to agricultural landscapes, restore their ecosystem services (e.g., pollination, weed and pest control, soil fertility) and mitigate biodiversity loss. To reintroduce rare weed species, two experiments in spring cereals were started in Renningen in 2019 and in Hirrlingen in 2021. In the first experiment, variations of weed control intensity, fertilization and row spacing were compared in regard to their influence on crop yield and biodiversity. Two different mixtures containing rare weed species were used for reintroduction: one commercially available, one self-composed regarding the former occurrences of the species in these regions. Treatments with sown rare species had on average the twice the number of weed species occurring compared to treatments without any sown weeds. Yield was significantly lower in treatments with wider row spacing, reduced fertilization, reintroduction of weed species and no herbicide use. Mechanical and chemical weed suppression did neither differ significantly in yield nor species richness in 2019. Additionally, an on-farm experiment, which started in spring 2021, examines the reintroduction success by different approaches (sowing and topsoil translocation). Besides reintroduction success the pollinator community, ground-dwelling carabid beetles and yield were investigated. The reintroduction of rare weeds was successfully accompanied by an increasing floral diversity.

Keywords: Biodiversity, crop yield, ecosystem services, rare weed species, reintroduction

Zusammenfassung

Die Intensivierung der Landwirtschaft und homogene Landschaftsstrukturen führten in den letzten Jahrzehnten zu einem Rückgang der Biodiversität. Daher ist die Förderung und Erhaltung lokaler Ackerflora und -fauna sehr wichtig. Zur Wiederansiedlung seltener Ackerwildkräuter wurden 2019 in Renningen und 2021 in Hirrlingen je einen Versuch in Sommergetreide angelegt. Im ersten Versuch werden Variationen von Reihenabstand, Düngung und Unkrautbekämpfungsmaßnahmen hinsichtlich ihres Einflusses auf Ertrag und Biodiversität verglichen. Für die Wiederansiedlung wurden zwei verschiedene Mischungen mit seltenen Ackerwildkrautarten verwendet: Eine im Handel erhältliche und eine entsprechend der früheren Ackerflora selbst zusammengestellte. Behandlungen mit eingesäten seltenen Arten zeigten im Durchschnitt die doppelte Anzahl von Ackerwildkrautarten im Vergleich zu Behandlungen ohne eingesäte Ackerwildkräuter. Der Ertrag war bei Behandlungen mit einer Mischung seltener Arten signifikant geringer als bei solchen ohne. Behandlungen mit mechanischer oder chemischer Unkrautbekämpfung unterschieden sich 2019 weder im Ertrag noch in der Artenvielfalt signifikant. Zusätzlich untersucht das zweite Experiment (Start Frühjahr 2021) den Wiederansiedlungserfolg durch verschiedene Ansätze: Aussaat und Bodenübertrag. Neben dem Wiederansiedlungserfolg wurden Bestäuber, Laufkäfer und Ertrag untersucht. Die Wiederansiedlung der seltenen Ackerwildkräuter war erfolgreich und damit wurde die pflanzliche Diversität erhöht.

Stichwörter: Biodiversität, Ertrag, Ökosystemdienstleistungen, Seltene Ackerwildkräuter, Wiederansiedlung

Introduction

Promoting and preserving biodiversity is a big challenge of our times. Changing landscape structure and agricultural intensification have led to a decreasing diversity of flora and fauna within agricultural landscapes (Stoate et al., 2001; Meyer et al., 2013). Intensive agricultural management including fertiliser and herbicide use among other tools has a large negative impact on biodiversity: from plants (Meyer et al., 2013) to insects (Hallmann et al., 2013) and birds (Donald et al., 2013). Therefore, weed diversity needs to be restored and promoted because it has positive effects on other taxa. For example, Schuhmacher et al. (2020) showed arable plant diversity having a positive effect on carabid beetle diversity. To restore plant diversity Lang et al. (2018) reintroduced rare segetal plant species and Twerski et al. (2021; 2022) could show positive effects on several ecosystem services provided by some rare plant species. In our projects, the reintroduction success is also one of the main parts. Furthermore, we investigate the development of species diversity and yield under varying management systems. Additionally, our second project investigates the ecosystem services of site-adapted weed species mixtures and commonly used flowering mixtures.

Material and methods

Locations

The first experiment was set up in Renningen on the Research Station "Ihinger Hof" of the University of Hohenheim (Latitude / Longitude: 48.744273° / 8.928766°). The long-term mean annual precipitation is 742 mm and the long-term mean of temperature is 8.8 °C. The first experiment started in spring 2018 in spring barley. In autumn 2019 winter wheat was sown and in autumn 2020 rye. The second experiment is located on a farm in Hirrlingen (Latitude / Longitude: 48.387816° / 8.883128°) and started in spring barley in spring 2021. The long-term mean temperature at this location is 8.1°C with a long-term annual mean precipitation of 871 mm.

Study design

Both experiments were set up in a completely randomised block design with four repetitions. At the Ihinger Hof, each plot had 30 m^2 (3 m x 10 m) and in Hirrlingen 10 m^2 (2 m x 5 m). At the Ihinger Hof, we established nine different treatments which are listed in table 1. Two treatments contained the site-adapted flowering mixture, they differ in the frequency of sowing (every or every second year). Additionally, two treatments contain a flowering mixture provided by Rieger & Hofmann (Blaufelden-Raboldshausen): the first one was sown without any crop in 2019, the second one contained the crop in all years. In Hirrlingen, we had five different treatments: Control, single seed amount of site-adapted flowering mixture, doubled seed amount of site-adapted flowering mixture, FAKT M1 flowering mixture (species list as provided by LTZ Augustenberg (2017)) and topsoil translocation. The control treatment had no flowering mixture sown and was treated as the other treatments (no fertilisers and no weed control).

Table 1 List of treatments at Ihinger Hof. Treatments and their row distance (in centimetre) are given. Herbicide use, mechanical weed control and fertiliser use are marked with a cross. Used flowering mixtures are given as well

Tabelle 1 *Liste der Behandlungen am Ihinger Hof. Behandlungen und ihre Reihenabstände (in Zentimeter) sind angegeben. Mechanische Unkrautbekämpfungsmaßnahmen, Herbizid- und Düngereinsatz sind durch Kreuze gekennzeichnet. Verwendete Blühmischungen werden angegeben*

	Treatment	**Row distance [cm]**	**Herbicide**	**Mechanical weed control**	**Fertiliser**	**Flowering mixture**
1	*Herbicide + fertiliser*	12.5	X		X	
2	*No weed control + no fertiliser*	20				
3	*Site-adapted mixture*	20				Site-adapted flowering mixture
4	*Herbicide with insufficient weed control*	12.5	X (with insufficient weed control)		X	
5	*No weed control + no fertiliser*	12.5				
6	*Mechanical weed control + fertiliser*	12.5		X	X	
7	*Rieger & Hofmann (2019 no crop)*	20				Rieger & Hofmann flowering mixture
8	*Site-adapted mixture (sown every 2nd year)*	20				Site-adapted flowering mixture
9	*Rieger & Hofmann*	20				Rieger & Hofmann flowering mixture

Reintroduced Weed Species

The sown species mixtures within the experiments were: A flowering mixture (“Feldblumenmischung Nr. 12”) provided by the seed producer Rieger & Hofmann at the Ihinger Hof, which contains rare as well as common weed species. This mixture was chosen due to the fact that it is commercially available. In the second experiment in Hirrlingen, the flowering mixture FAKT M1 (LTZ AUGUSTENBERG, 2017) was used as a comparable, commercially used flowering mixture. The FAKT M1 mixture is part of a funding program for environment, climate protection and animal welfare (FAKT) of Baden-Württemberg (MLR, 2019). Additionally, site-adapted mixtures, which are self-composed by the authors, have been used in both experiments (Tab. 2).

Table 2 List of species of the site-adapted mixtures. Values indicate the seed density in g / 10 m^2. For Hirrlingen, the single seed density is given. Species names are proposed by WORLD FLORA ONLINE (2021)

Tabelle 2 *Artenliste der standortspezifischen Mischungen. Werte geben Saatstärke in g / 10 m^2 an. Für Hirrlingen ist die einfach Saatstärke angegeben. Artnamen entsprechen der Nomenklatur von WORLD FLORA ONLINE (2021)*

Species	**Ihinger Hof**	**Hirrlingen**
Adonis aestivalis L.	16	
Agrostemma githago L.	2.67	
Anchusa officinalis L.	4.03	
Bromus secalinus L.		1.8
Buglossoides arvensis (L.) I.M. Johnst.		5.45
Bupleurum rotunidfolium L.	1.1	1.4
Campanula rapuncoloides L.		0.01
Consolida regalis Gray	0.3	1.1
Cyanus segetum Hill	0.53	2.7
Lathyrus tuberosus L.	10.33	
Legousia speculum-veneris (L.) Durande ex Vill.	0.87	0.2
Myosotis arvensis (L.) Hill		0.1
Papaver dubium L.	0.05	0.03
Papaver rhoeas L.	0.18	
Ranunculus arvensis L.		15.9
Scanndix pecten-veneris L.		8.8
Tessdalia nudicaulis (L.) W.T. Aiton	0.04	
Viola arvensis Murray	1.87	

These mixtures contained weed species which have been chosen based on the Red List of ferns and spermatophytes in Baden-Württemberg (BREUNIG & DEMUTH, 1999). Most species either have a status of threat or near threatened according to the list. To include a wider spectrum of species traits (e.g., in height, flowering colour) also some non-threatened species were included in the mixtures. Furthermore, the most relevant fact was the former occurrence of the species in the very same regions where the experiments are located in order to have well-adapted species to the chosen sites. In Hirrlingen, the mixture was used two times in the experiment: one treatment with the single seed amount and a second treatment with twice the seed amount. Additionally, in Hirrlingen, a topsoil translocation was performed in March 2021 according to the protocol of PIQUERAY et al. (2020) slightly modified for our purposes. We used 50 L of soil from a field under protection ("Schutzacker") in Rangendingen per plot, mixed it by hand and directly applied it to the field.

Observations

At Ihinger Hof, all treatments were observed regarding their influence on yield (harvested with plot harvester) and weed species diversity (three times counts of individuals per 0.1 m^2). In Hirrlingen, species were recorded by the extended Braun-Blanquet Scale (REICHELT & WILLMANS, 1973) within the whole plot two times in 2021 (June & July). Furthermore, an observation of the pollinators took place: per plot, two subplots (0.1 m^2) were monitored for 5 minutes each. All pollinators landing on flowers within this frame were counted and divided in taxonomic groups (honeybees, wild bees, hover flies, flies, beetles). Ground-dwelling arthropods were trapped with pitfall traps (0.3 L volume), set in three transects with four traps each. An edge and a centre transect were set up orthogonally to the experimental blocks. Additionally, a control was set up in the same field, but in distance to the block experiment within the conventionallymanaged part of the field. Just before harvest, aboveground plant biomass was cut within two subsamples (each 0.1 m^2) per plot.

Statistical analysis

Statistical analysis was performed with R (R CORE TEAM, 2018). Species richness data from Hirrlingen and the yield in 2019 at the Ihinger Hof were analysed with the standard analysis of variance (ANOVA) and treatment means were compared with a Tukey HSD test. Assumptions for the ANOVA were tested by the Shapiro test for normal distribution and Levene's Test for homogeneity of variance. The data of species richness and yield in 2020 at the Ihinger Hof did not show normal distribution and homogeneity of variance, therefore, a non-parametric test (Kruskal Wallis test) and the Conover-Iman test for pairwise comparison were used. A significance level of $p = .05$ was used for all statistical tests.

Results

Ihinger Hof

The two mixtures at the Ihinger Hof showed quite similar success rates regarding the number of emerged species from the mixtures: on average 10 out of 12 and 14 out of 17 sown species emerged of the site-adapted and the commercial mixture, respectively. Additionally, some species managed to spread to other treatments, for example *Agrostemma githago* L. was spotted at least once during all three years in all treatments without a flowering mixture. The overall species richness significantly differed (Kruskal Wallis test: Chi sq (8) = 41.592, $p < .001$) between the various treatments. As shown in Figure 1, the number of species was almost twice as high in treatments with sown rare species compared to the other treatments.

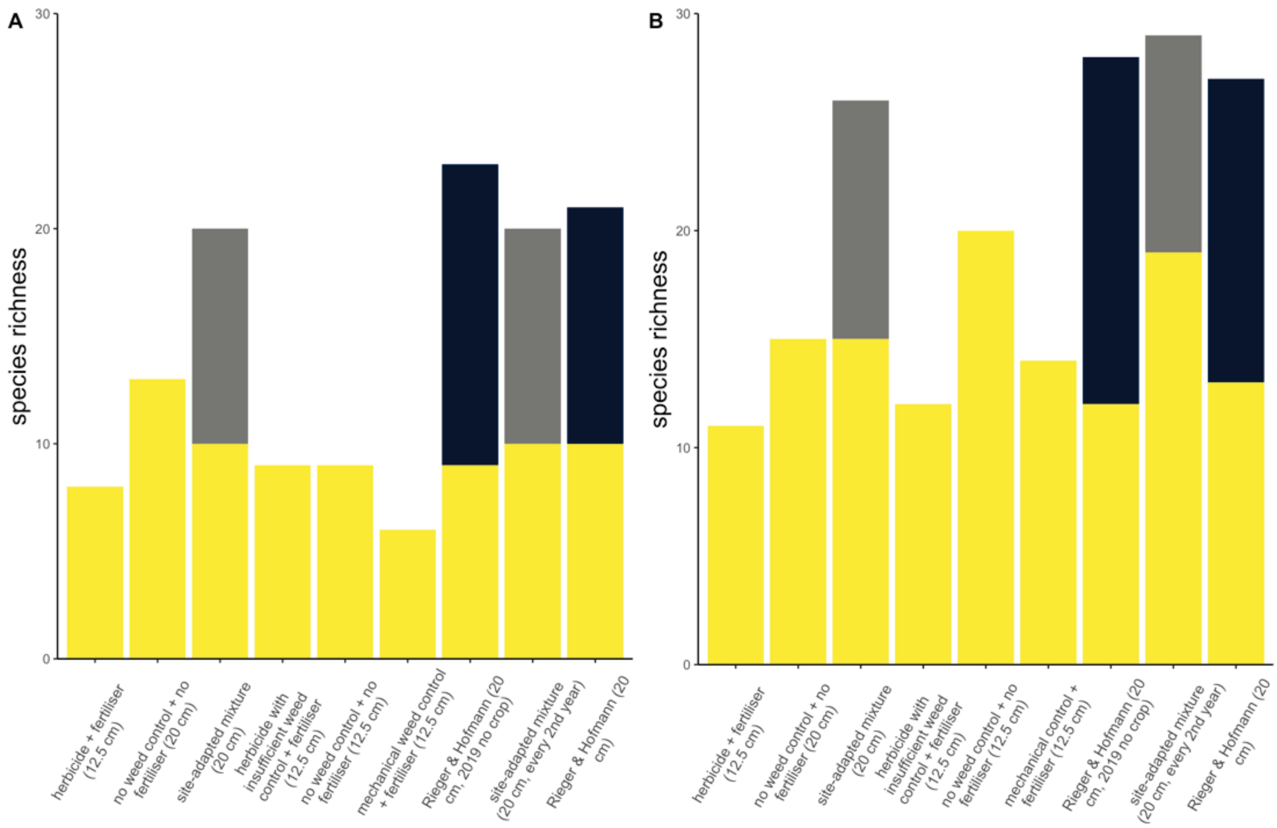

Figure 1 Plant species richness at Ihinger Hof. Species belonging to the site-adapted flowering mixture are highlighted in grey and species of the Rieger & Hofmann flowering mixture in dark blue. In parentheses, the row distance of the cereal crop is given. The site-adapted mixture treatments differ in the frequency of sowing rare arable plants (every or every second year). The first treatment with the Rieger & Hofmann flowering mixture had no crop in 2019. A is the data of 2019 in spring barley and B of 2020 in winter wheat.

Abbildung 1 *Artenreichtum der Flora auf dem Ihinger Hof. Arten, welche zur standortspezifischen Blühmischung gehören, sind in Grau hervorgehoben, und Arten, welche zur Blühmischung von Rieger & Hofmann gehören, in Dunkelblau. In Klammern sind die Reihenabstände des Getreides angegeben. Die Behandlungen mit der standortspezifischen Blühmischung unterscheiden sich in der Frequenz der Aussaat (jedes oder alle zwei Jahre). Die erste Behandlung mit der Blühmischung von Rieger & Hofmann wurde 2019 ohne Getreide ausgesät.* ***A*** *stellt die Daten für 2019 in Sommergerste dar und* ***B*** *die Daten von 2020 im Winterweizen.*

Bupleurum rotundifolium L. reached an average density of 11.55 plants per m^2 in all treatments containing flowering mixtures in 2019 and 2020. Even *Bupleurum rotundifolium* spread to the treatment with 20 cm row distance of the crop and no herbicide nor fertiliser use in 2020. Whereas *Papaver dubium* L. only occurred in winter wheat (2020) with an average density of 1.11 plants per m^2 in three of four treatments with flowering mixtures. The yield, however, does not significantly differ between the treatments where rare arable plants have been sown and the two treatments without weed control and no fertiliser use in 2019. Still, these treatments differ significantly from treatments with weed control and fertiliser use in 2019 and 2020. Weed control (chemical or mechanical) did not have any significant differences in species richness (8 and 6 species, respectively) and spring barley yield (5.14 t/ha and 5.24 t/ha, respectively) in 2019. The sowing of the commercially used mixture without a crop in the first year caused higher weed densities per square meter and significantly lower winter wheat yields (2.21 t/ha) in 2020. This is true even compared to the other three treatments containing rare species (2.92 t/ha). The highest species richness was achieved by a site-adapted mixture (29 species) in 2020.

Hirrlingen

In Hirrlingen, the reintroduction success differed considerably. The topsoil translocation treatment resulted only once in an occurrence of *Buglossoides arvensis* (L.) I.M. Johnst. We could not find a significant difference of species richness comparing the single seed amount mixture to the doubled one. Nevertheless, nine species out of 11 species included in the site-adapted flowering mixtures germinated and flowered in 2021. The commercial flowering mixture had on average a higher species richness compared to all other treatments. However, both the site-adapted flowering mixture (single amount) and the commercial flowering mixture have on average a significantly higher species richness compared to the control and the topsoil translocation (Fig.2). Yet, the alpha diversity did not differ significantly between all treatments. Both, *Legousia speculum-veneris* (L.) Durande ex Vill. and *Scandix pecten-veneris* L., had on average an abundance of 2.2% within each treatment containing the sown rare species. The amount of trapped carabid beetles was significantly higher in the edge transect compared to the control. The number of observed pollinators did not differ between our treatments; however, honey bees had their highest count in the site-adapted mixture with the doubled seed amount.

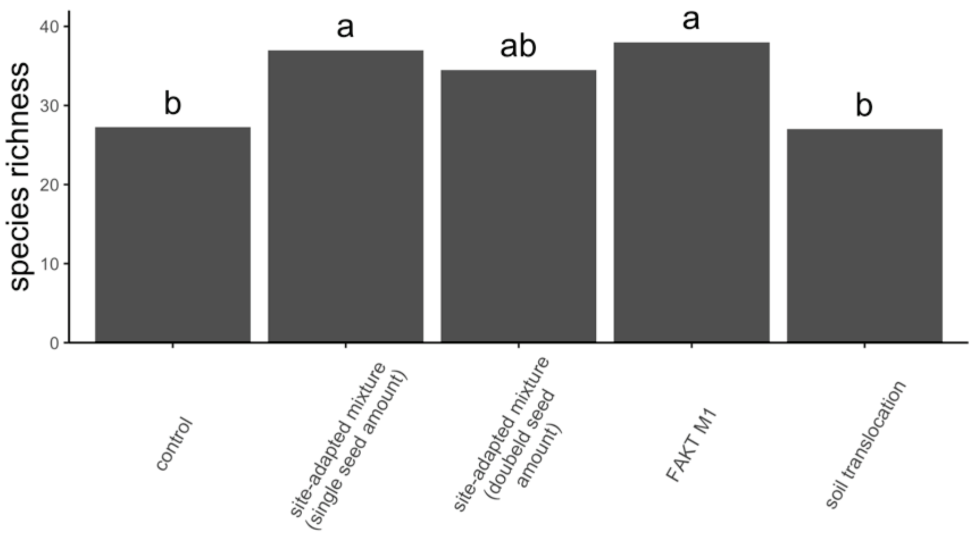

Figure 2 Plant species richness at Hirrlingen. Different letters indicate significant difference (Tukey HSD test; p ≤ .05).

Abbildung 2 *Artenreichtum der Flora in Hirrlingen. Unterschiedliche Buchstaben weisen auf signifikante Unterschiede hin (Tukey HSD Test: p ≤ .05).*

Discussion

The summer 2021 had a high amount of precipitation and the segetal plants in Hirrlingen started flowering quite late, hence, the first observation of the pollinators was quite difficult due to the fact that barely any plants flowered. But usually the prolonging of flowering season (early as well as late) as well as a diversity of the food resources is increasing the wild bee richness (NEUMÜLLER et al., 2021). Additionally, a determination to species level is needed to state an effect of the more diverse arable plant community on wild bee species. Furthermore, the experiment in Hirrlingen needs observations in the following years to evaluate the reintroduction success. Therefore, we will monitor the seed dispersal along the sowing direction and the soil seed bank as suggested by LANG et al. (2018) for the evaluation of reintroduction. Reintroduction of rare arable plants can be a very good tool to restore diversity (LANG et al., 2018; TWERSKI et al., 2021) which can further increase carabid beetle diversity (SCHUMACHER et al., 2020). Comparing different farming practices at the Ihinger Hof showed that rare weed species reintroduction does not have a negative impact on the yield compared to farming without herbicide and fertiliser use. This corresponds with the results of TWERSKI et al. (2021). The treatments with herbicide and fertiliser use have a higher yield, however, they are less species-rich compared to the treatments with flowering mixtures. Therefore, the reintroduction process needs some political support (compensation money) to be economically interesting to farmers. Probably a future agricultural landscape should contain a heterogenic structure including fields with high yields, but also refugia with higher plant diversity. A higher plant diversity can promote several ecosystem services ranging from pollination to pest control (STORKEY & NEVE, 2018; SCHUMACHER et al., 2020; TWERSKI et al., 2021). Often commercially available flowering mixtures contain only few species, are composed to provide food resources for honeybees and flower too late for some wild bee species (SCHMID-EGGER & WITT, 2014). They are, however, fast growing and especially mixtures with a higher species richness which might contain even perennial plants can help to increase biodiversity and heterogeneity within landscapes (NEUMÜLLER et al., 2021). Moreover, TWERSKI et al. (2022) showed a positive effect on wild bee richness and abundance of rare arable plants. Hence, ways to sustainably implement conservation and promotion of biodiversity in agricultural landscapes need to be explored; in particular practical approaches.

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