New approaches to the conservation of rare arable plants in Germany

Neue Ansätze zum Artenschutz gefährdeter Ackerwildpflanzen in Deutschland

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DOI 10.5073/jka.2014.443.021

Zusammenfassung

Der rasante technische Fortschritt der Landwirtschaft während der letzten Jahrzehnte hat einen dramatischen Rückgang seltener Ackerwildpflanzen verursacht. Um diesem Rückgang Einhalt zu gebieten, wurden verschiedene Artenschutzkonzepte wie das Ackerrandstreifenprogramm oder das aktuelle Programm '100 Äcker für die Vielfalt' entwickelt. Für Sand- und Kalkäcker sind geeignete Bewirtschaftungsmethoden zur Erhaltung seltener Arten inzwischen gut erforscht. Für saisonal vernässte Ackerflächen, die ebenfalls viele seltene Arten aufweisen können, ist dagegen wenig über naturschutzfachlich geeignet Standortfaktoren und Bewirtschaftungsmethoden bekannt. Untersuchungen an sieben zeitweise überstauten Ackersenken bei Parstein (Brandenburg) zeigten, dass das Überstauungsregime und insbesondere die Dauer der Überstauung die Artenzusammensetzung der Bestände stark beeinflussen. Die aktuelle Bewirtschaftung zeigte dagegen weniger deutliche Auswirkungen auf Populationen der Zielarten *Myosurus minimus* und *Elatine alsinastrum*. Ein weiteres aktuelles Problem des Ackerwildpflanzenschutzes ist, dass seltene Arten oft auf Flächen vorkommen, wo ihr Überleben durch die derzeitige Bewirtschaftung akut gefährdet ist. Da die Richtlinien der ökologischen Anbauverbände intensive Bewirtschaftungsverfahren weitgehend einschränken, bietet der Ökologische Landbau günstige Voraussetzungen für den Schutz gefährdeter Ackerwildpflanzen. Wie deren Populationen erfolgreich in ökologisch bewirtschafteten Feldern etabliert werden können, wird in einem Feldversuch bei Gräfelfing in der Münchner Schotterebene untersucht. Erste Ergebnisse zu den winterannuellen Arten *Legousia speculum-veneris* und *Consolida regalis* zeigen, dass sich diese Arten erfolgreich in ökologisch bewirtschafteten Äckern etablieren lassen. Frühe Herbstsaat und eine reduzierte Kulturpflanzenkonkurrenz im Ansaatjahr erbrachten dabei die besten Erfolge. Bei reduzierter Kulturpflanzendichte führte Dinkel zu deutlich höheren Etablierungsraten als Roggen. Die Ergebnisse dieser Studie können einen wesentlichen Beitrag zur Erhaltung gefährdeter Arten in der Agrarlandschaft leisten, wenn der Transfer gefährdeter Ackerwildpflanzen in ökologisch bewirtschaftete Ackerflächen umgesetzt wird.

Stichwörter: Artentransfer, Bewirtschaftung, Ökologischer Landbau, Überstau

Abstract

Over the past decades, the rapid improvement of agricultural technology has caused a dramatic decrease of rare arable plants. This process has stimulated the development of various concepts to protect these species such as the field margin program or more recently the program '100 fields for biodiversity'. For fields with sandy or calcareous soils, management practices to conserve the specific arable flora are well explored. For occasionally wet sites, however, which may also harbour various threatened species, little is known about suitable site conditions and conservation management. Studying seven seasonally flooded field sites close to Parstein (Brandenburg) showed that the flooding regime and particularly the duration of flooding strongly affect the composition of the apparent plant communities. Effects of different arable farming practices on the populations of the two target species *Myosurus minimus* and *Elatine alsinastrum* were less pronounced. Another urgent problem of arable plant conservation is that rare species frequently grow at sites where they are threatened by current cultivation. As management is less intense under organic farming, this system could provide suitable conditions for the conservation of threatened species. However, locally extinct species need to be actively reintroduced to overcome dispersal limitations. How these plants can be successfully established in fields under organic farming was studied in a field trial at Gräfelfing (Bavaria). Preliminary results on the winter annuals *Legousia speculum-veneris* and *Consolida regalis* indicate that rare arable plants can be successfully introduced to organic fields. Early autumn sowing and a low crop competition provide the most favourable conditions for their establishment. At reduced sowing rates, winter spelt allowed a much better establishment than winter rye. If the idea of transferring rare arable plants to organic farmland establishes in practice, results of this study could substantially contribute to the conservation of rare species in arable landscapes.

Keywords: Arable weed, flooding, management, organic farming, species transfer, threatened species, wet field

Introduction

Over the past decades, the diversity of arable plant communities has severely declined and many of its characteristic species have become endangered (ALBRECHT, 1995; SUTCLIFFE and KAY, 2000; LOSOSOVÁ *et al.,* 2004; FRIED *et al.,* 2009; MEYER *et al.,* 2013). To counteract this development, conservation concepts were developed already in the 1970s. Quite successful was the Field Margin Program, initiated in North Rhine-Westphalia in 1978 by SCHUMACHER (1980) and adopted in most other federal states of Germany during the 1980s and 1990s (MEYER *et al.*, 2010). Monitoring surveys revealed that these strips harboured various threatened species, some of which were considered locally extinct. Thus, numbers of species listed in the Red List of the corresponding states were 45 for Lower Saxony (SCHACHERER, 1994), 43 for in North Rhine-Westphalia (FRIEBEN, 1995) and 47 for Rhineland-Palatinate (OESAU and JÖRG, 1994). However, factors such as weed infestation problems in parts of the fields, difficulties of enforcing contractual obligations, inflexible management agreements, insufficient financial support, difficulties of integrating the strips into the operational process of the farm, and increasing numbers of competing agro-environmental schemes (flower strips, renewable resources etc.) caused a severe decline of the number of protected field strips in Germany during the 2nd half of the 1990s (WICKE, 1998). A survey on arable plant conservation in Germany showed that only 170 sites with a main focus on arable plant conservation were left in 2007 (MEYER *et al.,* 2008), and most of these conservation projects were dependent on local activities. Therefore, a nationwide network '100 Fields for Biodiversity' was established in 2009 to conserve threatened arable plants and plant communities within their original landscape and land use context (MEYER *et al.,* 2008). Important elements of this concept are long-term financing, a regular support and supervision by experts and a management concept which is developed in cooperation with the farmers and focused on the requirements of the target species.

For fields on sandy soils, chalk or limestone, management practices to preserve the specific arable flora have been well explored (SCHNEIDER *et al.*, 1994). For seasonally wet sites, however, which can also harbour a whole series of endangered species, little is known about adaptation to the specific site conditions and agricultural management. Therefore, the sensitivity of species such as *Elatine alsinastrum*, *Limosella aquatica*, *Peplis portula* or *Myosurus minimus* to flooding, tillage, fertilization and herbicide application was analyzed to provide basic information how these communities could be promoted by arable management.

Another current problem in the conservation of arable plants is that many populations grow at sites where they are endangered by intensive cultivation. Farming practices that frequently threaten these species are the application of herbicides, strong crop competition due to fertilization and narrow crop rotations (WILSON, 1990; SCHNEIDER *et al.,* 1994). An option to maintain these populations in their specific landscapes is to transfer them to sites with a lower management intensity. As regulations of organic farming limit nitrogen input and exclude herbicide spraying, this management system could provide suitable conditions for the conservation of threatened plant populations. Moreover, a survey by WIESINGER *et al.* (2010) demonstrated that many organic farmers are willing to accept rare species in less productive parts of their arable land if their introduction does not result in significant yield losses and the spread of noxious weeds. As rare species established from transferred seeds are highly susceptible to mechanical weed control and competition (VAN ELSEN and HOTZE, 2008; ALBRECHT *et al.,* 2009), good knowledge is required of the management conditions that ensure the successful establishment of the corresponding populations. Therefore, the development of suitable methods to successfully establish rare arable plants in fields under organic management is one of the main objectives of the project 'Re-Introduction of Rare Arable Plants on Organic Farms'.

Effects of land use and flooding on arable plant populations of seasonally wet fields

The investigations were carried out at seasonally flooded arable field depressions close to Parstein on the Barnim Plateau in north-eastern Brandenburg. Seasonally wet fields of this region are characterized by an outstanding composition of rare plant species (FISCHER, 1983). To detect the effects of management factors such as the presence of crops, ploughing and herbicide application, two different species were studied at seven different field depressions. *Myosurus minimus* (*Ranunculaceae*) is a winter annual adapted to frequent disturbances and seasonal water logging. Arable fields are one of the major habitats of this species. *Elatine alsinastrum* (*Elatinaceae*) occurs on sites with a water table just below or above the soil surface. It usually emerges in early summer from the bare ground of drained ponds, backwater pools of rivers or even from wet arable fields (POPIELA *et al.,* 2013). In the Red List of threatened plants of Germany, *M. minimus* is classified as 'vulnerable' and *E. alsinastrum* as 'critically endangered' (category 2) (LUDWIG and SCHNITTLER, 1996).

The experimental plots were located in seven field sites where the target species were present in summer 2012. As all plots are situated in fields of one farm, they also share a common management history. Treatments: with and without 160 kg N/ha; with and without herbicide (Tribenuron 55 g/ha); and with and without cover crop (winter wheat). Field data were sampled during the summer 2013 in 1 x 1 m plots with six replicates per treatment. To test the effect of different flooding regimes, soil was taken from six field depressions and mixed to one composite sample from topographically higher sites which are scarcely flooded, and one sample within the depressions. Each of the two large mixed samples was divided in 72 portions of soil each with 1 kg fresh weight. These portions were filled in plant pots and transferred to artificial water basins at the University of Regensburg where they were exposed to the following flooding treatments for one year: Duration of flooding: never, 2 weeks, 8 weeks, permanent. Flooding depths: 0 cm, 5 cm, 15 cm and 40 cm. For each combination six replicates were tested.

During the first year of the experiment, the different treatments led to some differences in field emergence of *M. minimus* (seedling establishment in plots with application of herbicides was slightly decreased). The overall differences between the treatments, however, were not significant (Fig. 1). *E. alsinastrum,* which usually emerges long after the application of herbicides, showed a generally poor field emergence in 2013 (results not shown). This may be due to the fact that the summer of 2013 was hotter and dryer than that of 2012, when the plots were selected based on the occurrences of rare species. Hence, no statistically significant effects of the different treatments could be detected. This lack of significance and the considerable variation observed within the treatments give a first indication that other factors such as water regime may impact the rare species of this habitat type. Therefore, the effects of different flooding regimes were tested in an experiment where soil of the study area was exposed to different durations and depths of flooding.

Axis 1 of a DCA ordination (Fig. 2) show that the flooding regime clearly separated the species spectrum emerging from the soil seed bank into typical arable weeds of terrestrial sites and species well adapted to flooding. The large distance between species such as *Myosurus minimus* and *Alisma plantago-aquatica,* which both prefer (seasonally) wet soils, suggests that there is still a large variation among environmental requirements of indicators for moist or wet habitats. High correlation between the duration of flooding and the first ordination axis (Kendal Tau τ: 0.725) emphasizes that this difference was mainly caused by the duration of flooding. Axis 2 segregated samples taken from the upper and lower parts of the field depressions, reflecting the long-term flooding regime at these areas. Depth of flooding hardly affected species composition.

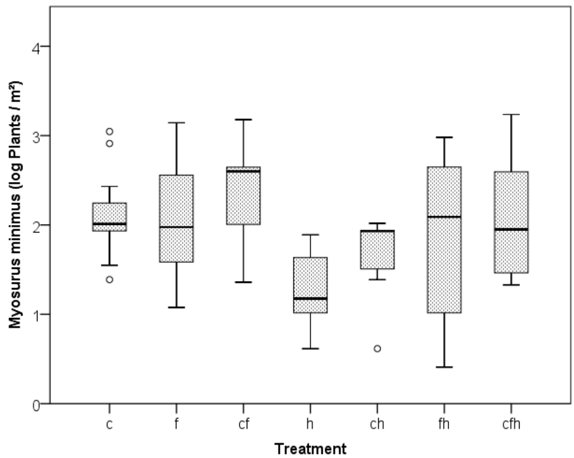

Fig. 1 Effect of cover crop (wheat) (c). fertilization (f) and herbicide application (h) on establishment of *Myosurus minimus* in field plots. Fertilization: 0 or 160 kg N/ha; herbicide: 0 or 55 g Tribenuron/ha at BBCH 34; and crop: with or without winter wheat cv. Akteur. Kruskal-Wallis test indicates no significant differences among the treatments ($P < 0.05$).

Abb. 1 *Wirkung von Deckfrucht (Weizen) (c), Düngung (f) und Herbizidbehandlung (h) auf das Auflaufen von* Myosurus minimus *in den Behandlungsplots. Düngung: 0/160 kg N/ha; Herbizid: 0/55 g Tribenuron/ha in BBCH 34; und Kultur: mit/ohne Winterweiten Sorte Akteur. Nach Kruskal-Wallis-Test keine signifikanten Unterschiede zwischen den Behandlungen ($P < 0.05$).*

Our results suggest that flooding regime and particularly the duration of flooding strongly affected the composition of the plant communities emerging from the soil seed bank. Effects of different arable farming practices on the populations of rare species were less pronounced. This may be – at least for *E. alsinastrum* – due to the dry and hot summer in 2013 which negatively affected field establishment. To which extent these treatments control the establishment of rare species on temporarily wet soils in general remains to be seen. Further field investigations and seed bank analyses may reveal the long term development of the populations.

Establishment of threatened arable plants in organic farmland

The investigations were carried out in the northern Munich Plain. This landscape is characterized by a high percentage of arable farming and formerly harboured various rare species, specifically adapted to calcareous soils.

During the past decades, however, these species significantly declined (ALBRECHT, 1989) and some of them are now close to regional extinction. Therefore, the arable field reserve 'Kastner Grube' was established in 1999 to conserve the remaining populations of rare arable plants in the northern Munich Plain (MATTHEIS, 2003). Seeds from this reserve were propagated by a regional seed producer and transferred to experimental field plots of the Seidlhof Stiftung, close to Gräfelfing to the west of Munich. The investigated species were the comparatively large-seeded and tall Ranunculaceae *Consolida regalis* and the small-growing and small-seeded Campanulaceae *Legousia speculum-veneris*. Both species are classified as 'endangered' (category 3) in the Red List of endangered plants in Germany (LUDWIG and SCHNITTLER, 1996). In addition, they are also listed among the 40 species that are of particular importance for arable plant conservation throughout Europe (STORKEY *et al.,* 2012). In a preliminary survey none of these species occurred at the plots prior to sowing.

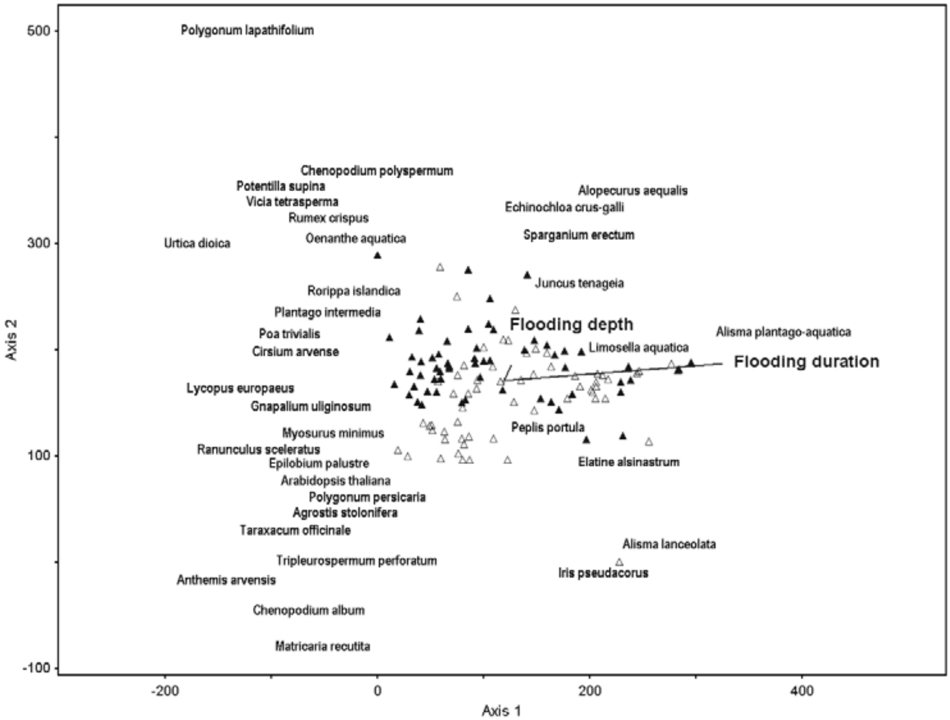

Fig. 2 DCA ordination biplot of the species composition emerging from the soil seed bank of six field depressions which are regularly affected by flooding. Samples come from frequently (▲) and scarcely (△) flooded parts of the depressions. Duration of flooding: never, 2 weeks, 8 weeks, and permanent. Flooding depths: 0 cm, 5 cm, 15 cm and 40 cm. Species occurring in less than six samples were removed. Before the ordination data were square root transformed. Length of gradient for Axis 1 is 2.96. Percentages of variance explained: Axis 1 36.1%, Axis 2 13.6%.

Abb. 2 *DCA-Ordination Biplot der aus Samenbankproben von sechs saisonal überfluteten Ackersenken aufgelaufenen Artenzusammensetzung. Die Probeflächen stammen von häufig (▲) und selten (△) überstauten Bereichen der Senken. Überflutungsdauer: nie, 2 Wochen, 8 Wochen sowie permanent. Überstautiefen: 0 cm, 5 cm, 15 cm und 40 cm. Arten mit weniger als sechs Vorkommen wurden ausgeschlossen. Vor der Ordination erfolgte eine Quadratwurzel-Transformation. Gradientenlänge von Axis 1 war 2,96. Anteil der durch die Achsen erklärten Varianz: Axis 1 36,1%, Axis 2 13,6 %.*

As winter annual crops are known to provide the most favourable establishment conditions for the target species (SCHNEIDER *et al.,* 1994; GÜNTER, 1997), winter rye and winter spelt were used to test how the presence and density of crops affected arable plant establishment. The sowing rates usually applied in organic fields of the region are 160 kernels/m² for hulled spelt and 350 seeds/m² for rye. To detect how the rare species establish under reduced crop competition, these 'normal' sowing rates were complemented by two treatments with reduced sowing rates and one variant without any crop. Reduced sowing rates were a quarter of the usual seed numbers, i.e. 40 kernels/m² for spelt and 88 seeds/m² for rye.

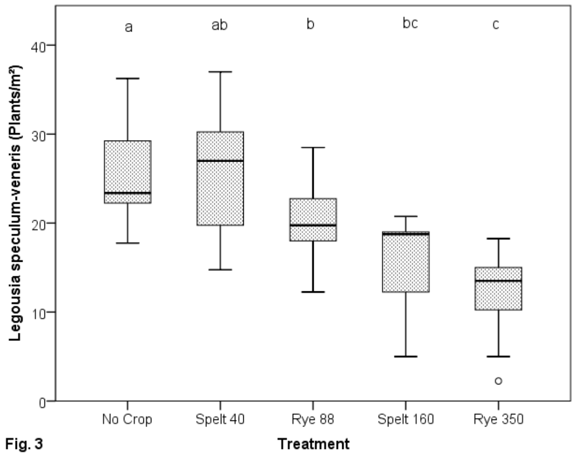

Fig. 3 Effects of crop species and sowing densities on the number of established *Legousia speculum-veneris* plants. Sowing rates: *L. speculum-veneris* 500 seeds/m²; spelt 40, 160 spelt seeds with husk/m²; and rye 88, 350 seeds/m². Different letters (a,b,c) indicate significant differences between treatments (Kruskal-Wallis test and Mann-Whitney U-test; $P < 0.05$). To correct alpha error by multiple comparison HOCHBERG (1988) correction was used.

***Abb. 3** Effekt von Art und Saatstärke der Kulturpflanzen auf die Individuendichte von Legousia speculum-veneris. Saatstärke: Spelt 40, 160 Dinkelfesen/m²; Rye 88, 350 Roggensamen/m²; and* L. speculum-veneris = *500 Samen/m². Verschiedene Buchstaben (a,b,c) kennzeichnen signifikante Unterschiede (P < 0.05) beim generellen (Kruskal-Wallis Test) und paarweisen (Mann-Whitney U-Test) Behandlungsvergleich. Eine Alpha-Fehlerkorrektur erfolgte nach HOCHBERG (1988).*

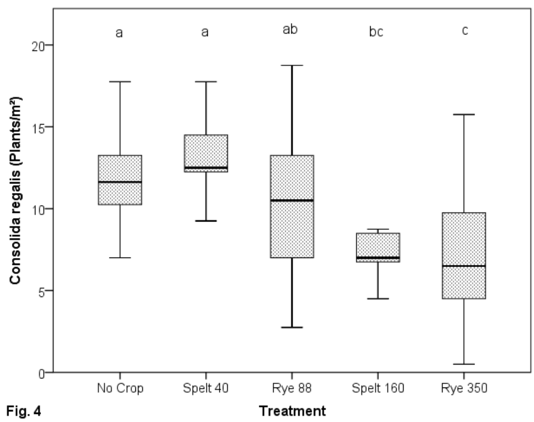

Fig. 4 Effects of crop species and sowing densities on the number of established *Consolida regalis* plants. Sowing rates: *C. regalis*: 200 seeds/m²; spelt 40, 160 spelt seeds with husk/m²; and Rye 88, 350 seeds/m². Statistical analysis see Figure 3.

***Abb. 4** Effekt von Art und Saatstärke der Kulturpflanzen auf die Individuendichte von* Consolida regalis. *Saatstärke: Dinkel (Spelt) 40, 160 Fesen/m²; Roggen (Rye) 88, 350 Samen/m², C. regalis 200 Samen/m². Statistische Auswertung wie in Abbildung 3.*

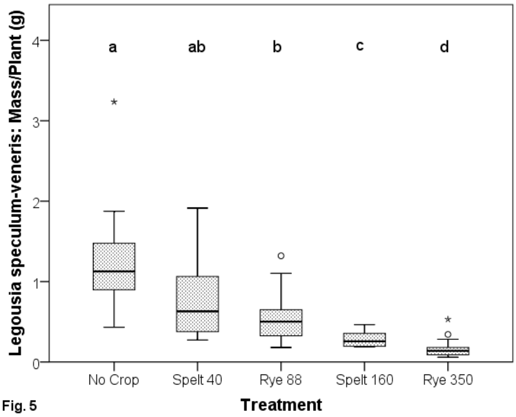

Fig. 5 Effects of different crop species and sowing rates on the biomass of *Legousia speculum-veneris* plants. Sowing rates (seeds/m^2): Spelt 40, 160 = spelt seeds with husk; and Rye 88, 360 = rye seeds. 500 seeds of *L. speculum-veneris*. For statistical analysis see Figure 3.

Fig. 5 *Effekt verschiedener Arten und Saatstärken von Kulturpflanzen auf die Biomasse von* Legousia speculum-veneris. *Saatstärken: Dinkel (Spelt) 40, 160 Fesen/m²; Roggen (Rye) 88, 350 Samen/m² und* L. speculum-veneris *500 Samen/m². Statistische Auswertung wie in Abbildung 3.*

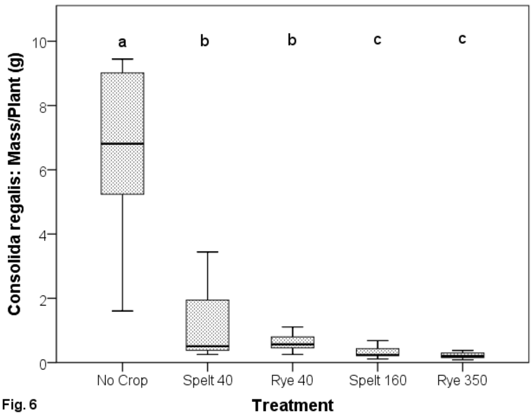

Fig. 6 Effects of different crop species and sowing rates on the biomass of *Consolida regalis* plants. Sowing rates (seeds/m^2): Spelt 40, 160 = spelt seeds with husk; Rye 88, 360 = rye seeds. 500 seeds of *L. speculum-veneris*. Statistical analysis see Figure 3.

Fig. 6 *Effekt von Art und Saatstärke der Kulturpflanzen auf die Biomasse von Consolida regalis. Saatstärken: Dinkel (Spelt) 40, 160 Fesen/m²; Roggen (Rye) 88, 360 Samen/m²; und C. regalis 200 Samen/m². Statistische Auswertung wie in Abbildung 3.*

For both *L. speculum-veneris* and *C. regalis* Figures 3 - 6 showed that plant density and the phytomass per plant significantly declined at increasing sowing rates of the crop. These results indicate that both species are highly susceptible to crop competition. As plant phytomass is closely correlated with seed production (corresponding results by LUTMAN *et al.* (2011) were also confirmed for the target species; data not published), the impact of competition on plant number and fitness is particularly important. It suggests that crop competition may essentially affect seed production and thus the establishment and long-term survival of populations. Despite the differences in plant and seed size, this seems to apply for both species. In order to establish threatened species successfully, this means that reduced crop sowing rates favour establishment and survival of the target species. If crops shall be sown, spelt may be preferred over rye, which showed a higher competitiveness even at reduced sowing rates.

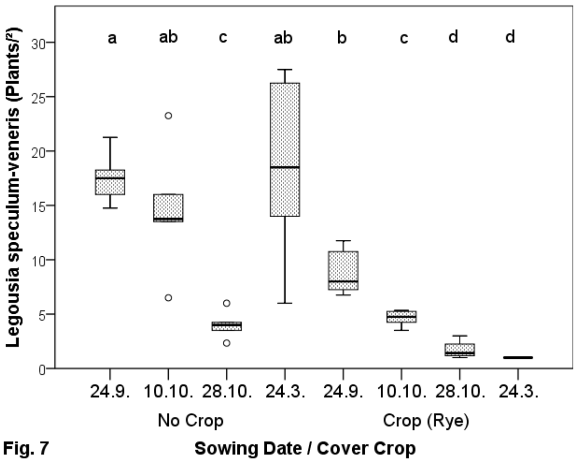

Fig. 7 Effects of different sowing dates on the number of established plants of *Legousia speculum-veneris*. Sowing rates: *L. speculum-veneris* 500 seeds/m², and winter rye 360 seeds/m². For statistical analysis see Figure 3.

Abb. 7 *Auswirkung verschiedener Saattermine auf die Individuendichte von* Legousia speculum-veneris. *Saatstärken:* L. speculum-veneris *500 Samen/m², und Winter-Roggen 360 Samen/m². Statistische Auswertung wie in Abbildung 3.*

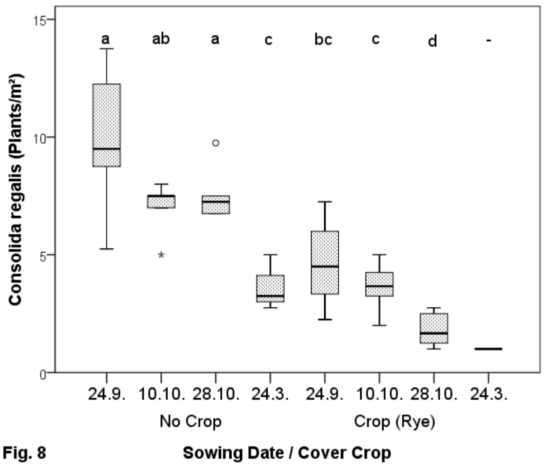

Fig. 8 Effects of different sowing dates on the number of established plants of *Consolida regalis*. Sowing rates: *C. regalis* 200 seeds/m², and winter rye 360 seeds/m². Statistical analysis see Figure 3.

Fig. 8 *Auswirkung verschiedener Saattermine auf die Individuendichte von Consolida regalis. Saatstärken C. regalis 500 Samen/m², und Roggen 360 Samen/m². Statistische Auswertung wie in Abbildung 3.*

Another important factor affecting arable plant establishment is the time of sowing. As most threatened arable plant species are winter annuals (ALBRECHT and MATTHEIS, 1998), an early, an intermediate and a late autumn sowing date as well as one date in spring were compared (Fig. 7 and 8). Early sowing in autumn significantly increased the establishment of both species. In contrast to *C. regalis*, *L. speculum-veneris* also showed substantial emergence when sown in a pure stand without cover crops in spring. These individuals, however, did not develop flowers before harvest (results not shown). Both species produced more biomass when winter spelt was used as the crop.

These results indicate that rare arable plants can be successfully introduced into fields under organic management when certain constraints are considered. Hence, early autumn sowing and reduced crop competition may provide the most favourable conditions for a successful establishment of threatened winter annual plants. With reduced crop sowing rates, winter spelt allows a much better seedling establishment than winter rye. In future experiments, the effects of grass-clover mixtures in crop rotations, of modified sowing densities of the arable plants and the establishment of other rare species will be studied. If the idea of transferring rare arable plants from their original habitats to organic farming fields finds its way into practice, results of this study could contribute substantial information on how species diversity of arable landscapes could be developed in the future. Compared to isolated field reserves, this seeding method has also the advantage that populations from a number of farms can be transferred to sites with different management conditions. Diverging selection mechanisms at these sites may maintain or even increase morphological, phenological and genetic diversity within a landscape.

Acknowledgements

Funding was provided by the Deutsche Bundesstiftung Umwelt (DBU) for the project 'Development of a conceptual framework to conserve the vegetation of seasonally wet field depressions' (DBU No. 29317-33/0) and by the Bundesprogramm Ökologischer Landbau for 'Re-introduction of rare arable plants on organic farms' (No. 06OE355). Many thanks to the Seidlhof-Stiftung for contributing the site and the personal stuff to perform the field trial at Gräfelfing and to Prof. Dr. Peter Poschlod, University of Regensburg for providing the water basins for the flooding experiment. Invaluable support to perform the DBU project was given by Uwe Raabe (Marl), Andreas Herrmann (Potsdam) and Frank Gottwald (Brodowin).

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