Weed seed predation in organic and conventional cereal fields

Samenfraß in Getreide auf ökologisch und konventionell bewirtschafteten Feldern

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DOI: 10.5073/jka.2012.434.033

Summary

Granivores can consume a large proportion of newly produced weed seeds in crop fields each year. If substantial, granivores can help to exhaust the seed bank and thus contribute to long-term weed control. In northern Germany, however, annual seed losses tend to be smaller and granivore density lower than elsewhere. To investigate if high land-use intensity could be involved, seed predation rates were measured using *Lolium multiflorum* Lam. as a model seed in three organic and three conventional cereal fields located close to each other. In addition, seed predation was measured at different distances from the field edge and exclosure cages were used to determine the relative contributions of vertebrates and invertebrates to seed consumption.

As expected for cereal crops, seed predation rates increased from early spring to early summer and then decreased again. Seed predation by invertebrates was comparable to that in other studies, but seed predation by vertebrates, mainly rodents, was much lower, suggesting that low seed predation rates in northern Germany may have been caused by lower mouse activity, concurring with low mouse density. Results with regard to the effect of distance to the field edge were variable and difficult to interpret. Observed responses may be linked to predator identity, with rodents foraging preferentially near field edges, and invertebrates away from field edges or indifferently. Farming system (organic *vs*. conventional) had little or no effect on seed predation rates.

Reasons for the low density of seed predators and low seed predation rates observed are unknown, but it is likely that some unidentified detrimental factor is involved in the organic fields or the impoverished landscape as a whole.

Keywords: Biological weed control, carabid beetles, distance to field edge, farming system, mice

Zusammenfassung

Samenfraß durch Granivoren kann zu hohem Verlust neuproduzierter Unkrautsamen führen. Falls dies in beträchtlichem Maße geschieht, verringert Samenfraß den Samenbankeintrag substantiell und trägt damit zur langfristigen Unkrautregulierung bei. In Norddeutschland scheinen die jährlichen Samenverluste und die Prädatorendichten jedoch geringer zu sein als anderenorts. Um zu untersuchen, ob die hohe Landnutzungsintensität hierfür ursächlich sein könnte, wurden Samenfraßraten unter Nutzung von *Lolium multiflorum* Lam. als Modellsamen auf drei ökologisch und drei konventionell bewirtschafteten, räumlich nah beieinander liegenden Getreidefeldern ermittelt. Darüber hinaus wurde der Samenfraß in unterschiedlichen Abständen zum Feldrand erfasst. Ausschlusskäfige wurden genutzt, um zwischen dem Samenfraß durch Vertebraten und Invertebraten unterscheiden zu können.

Wie im Getreideanbau zu erwarten, stieg die Samenfraßrate vom Frühling bis zum Sommer an und sank dann wieder. Der Samenfraß durch Invertebraten war vergleichbar mit dem anderer Studien. Die Samenprädation durch Vertebraten, hier hauptsächlich Nagetiere, war hingegen deutlich niedriger, ebenso die erfasste Aktivitätsdichte. Die zu beobachtenden niedrigen Samenfraßraten in Norddeutschland könnten demnach durch niedrige Vertebraten-Aktivitätsdichten beeinflusst sein. Die Ergebnisse bezüglich der Wirkung des Feldrandabstands waren unterschiedlich und schwer zu interpretieren. Die beobachteten Unterschiede könnten mit der Prädatorenart zusammenhängen, da Nagetiere bei der Nahrungssuche Feldränder und Invertebraten mehr die Feldmitte bevorzugen oder überall zu finden sind. Die Bewirtschaftungsform (ökologisch vs. konventionell) hatte wenig oder keinen Einfluss auf die Samenfraßraten.

Die Gründe für die beobachteten geringen Samenprädatorendichten und Samenfraßraten sind unbekannt, aber es ist wahrscheinlich, das gegenteilig wirkende Einflüsse auf den ökologischen Feldern oder die verarmte Landschaft als Ganzes als Ursache in Frage kommen.

Stichwörter: Abstand zum Feldrand, Bewirtschaftungsformen, Biologische Unkrautbekämpfung, Laufkäfer, Mäuse

1. Introduction

In many countries, granivores, such as birds, rodents, carabid beetles, crickets and harvester ants, consume a large proportion of the newly produced weed seeds in crop fields each year. Provided that losses are substantial (e.g. > 25-50 % per year; e.g. FIRBANK and WATKINSON, 1986), seed predators can help to exhaust the seed bank and thus contribute to weed control. Estimates of annual weed seed losses due to predation typically range from 50 to 90 % (e.g. WESTERMAN et al., 2003; HEGGENSTALLER et al., 2006; BARAIBAR et al., 2009), which corresponds to the efficiency of an herbicide application. However, preliminary data indicate that in Mecklenburg-Vorpommern in Germany, seed losses are much smaller (25-44 %) than in any other region tested so far (DAEDLOW, 2007; BARAIBAR et al., in press). Densities of granivores, such as carabid beetles and granivorous rodents, tend to be low as well (BARAIBAR et al., in press).

Crop management in Mecklenburg-Vorpommern is generally intense. Average field size is 75 ha with little or no non-crop vegetation between fields. The typical oilseed rape - winter wheat - winter barley or winter wheat rotation is short and without much crop diversity. Treatment indices for herbicides, fungicides, insecticides, growth regulators are high, namely in oil seed rape 1.7, 0.9, 2.5 and 1.0, respectively, and in winter wheat 1.9, 2.0, 1.1, and 1.0, respectively (ANONYMUS, 2009). Tillage intensity is high, involving yearly operations with chisel and mouldboard plough. It is likely that one or more of these factors are responsible for the observed low predation rates and low densities of granivores, but it is unknown which. In this study, seed predation rate was measured in three organic and three conventional cereal fields at different distance from the field edge. The null hypothesis was that farming system (organic *versus* conventional) and the vicinity of field edge vegetation would have no effect on predation rate (% seeds/week). In addition, selective exclusion was used to determine the relative contributions of vertebrates and invertebrates to seed consumption.

2. Materials and methods

2.1 Experimental design

Trials involved five temporal replications from 6 May to 8 July 2011 on six cereal fields near Rostock Mecklenburg-Vorpommern, northern Germany. The climate is influenced by the Baltic Sea; hence it has milder autumns and colder springs compared with other areas at the same geographical latitude. Average annual temperature is 8.4 °C (2011: 9.3 °C) and average annual rainfall is 591 mm (2011: 732 mm), (ANONYMUS, 2011). Weather conditions during the experiment were typical except for very high precipitation from 8 June onward (cumulative amount of rainfall 2-9 June 36 mm; 17-25 June 34 mm; 1-8 July 40 mm).

Predation was measured in three organically (fields 1, 2 and 3) and three conventionally (fields 4, 5 and 6) managed fields which were at least 2 km away from each other. All fields were sown with winter wheat (*Triticum aestivum* L.) except field 1, which was sown with spelt (*Triticum aestivum* subsp. *spelta* L.). The preceding crop on the organic fields was peas (field 1), potatoes (field 2), and a grass-clover mixture (field 3). On the conventional fields, the preceding crop was winter oilseed rape (field 4), winter wheat (field 5), and potatoes (field 6). In the organic fields the crop rotation also included barley, rye, oats and lupines. Field size was approx. 75 ha, similar to the average size of fields in the region. All fields had at least one field edge next to areas with natural ground vegetation, shrubs and trees.

Lolium multiflorum Lam. seeds (4.22 ± 0.03 mg/seed; mean ± SE) were exposed to predators for seven days each 14 days. This species was chosen because of its demonstrated palatability to vertebrate and invertebrate seed predators (BARAIBAR et al., 2009).

Per field, an area of 100 x 100 m was selected adjacent to natural vegetation. Seed predation was measured using a regular grid of six rows and six columns of seed cards, 20 m apart, prepared after WESTERMAN et al. (2003). Half of the cards were covered by vertebrate exclosure cages (mesh size: 10 mm). The position of the exclosure cages were randomized in both x- and y–direction, such that three open cards and three enclosed seed cards were present in each row and each column. After exposure, seed cards were collected and the remaining seeds counted. To determine losses due to reasons other than seed predation, four seed cards per field were placed under fine-meshed exclosure cages (2.8 mm) and served as controls. Activity density of vertebrates (rodents) and invertebrates was measured using 18 Sherman life traps per field over three nights from 29 May to 1 June, baited with dough made out of oats, flour, peanut butter, oil and water. To estimate invertebrate activity density, six pitfall traps per field were for 48 hours from 31 May to 2 June. Each consisted of an 8 cm wide plastic container filled for 20 % with a 10 % ethylene glycol solution.

2.2 Statistical analyses

The percentage of seeds predated, Q, was estimated for each exposure period separately. *Q* was calculated as:

$$Q = \frac{S_i - S_f}{S_i} \times 100\% \qquad [week^{-1}] \qquad [1]$$

with S_i, the initial number of seeds per card, and S_f, the final number of seeds left after exposure. Results from control cards were referred to as Q_c; those of cards exposed to predators as Q_m. The requirement of normality was met by a logit-transformation as confirmed by the Shapiro-Wilk normality test. The requirement of homogeneity of variance was checked by visual detection in the residual plots of the chosen models. Due to counting errors, *Q* was < 0 % in a number of cases. To enable logit-transformation, all data were corrected by adding 3 % (1st and 2nd period), or 1 % (other periods). In cases where the correction led to $Q_m > 100$ % these were set to 99 %.

In addition, the Abbott-corrected (ABBOTT, 1925) total percentage of seed predation, Q_{total}, was calculated as:

$$Q_{total} = \frac{S_i \times C - S_f}{S_i \times C} \times 100\% \qquad [week^{-1}] \qquad [2]$$

With *C*, the proportion of seeds recovered from control cards. Derived from Q_{total} is the percentage of seeds predated by vertebrates only (Q_{vert}), which was calculated as:

$$Q_{vert} = \frac{S_i \times C - S_f}{S_i \times C} \times 100\% - Q_{inv\_field} \qquad [week^{-1}] \qquad [3]$$

with Q_{inv_field} the field-specific, average percentage of seed predation by invertebrates .

Generalized linear mixed effects models (GLMM) were used to test if the response variable Q_m was influenced by the fixed effects of farming system, exclosure treatment or distance from the field edge using the package nlme of R, v 2.12.0 (PINHEIRO et al., 2010; R DEVELOPMENT CORE TEAM, 2010). Field and position of seed cards in a row were included as random effects. All-possible-subset regression was conducted in two steps to find the model that best described the random and fixed effects. First, results from both exposed and control cards were included to test if Q_m differed significantly from Q_c. If so, seed losses were due to seed predation. Next, all-possible-subset regression was conducted to find the models that best described Q_m. Akaike's information criteria (AIC) was used as a selection criterion. All-possible-subset regression resulted in a random intercept mixed effects model with field as random factor.

3. Results

3.1 Seed predation rates

Regression analysis (GLMM) of the proportion of seeds removed from open seed cards and seed cards covered by cages, relative to control cards, indicated that seeds were removed through predation, except in the first exposure period, where seeds were lost mainly due to other causes ($p = 0.059$, Tab. 1).

Tab. 1 Significance of seed predation, the number of observations (*N*) and the effect of farming system (organic/conventional), distance from the field [m], exclosure treatment (caged/open), and interaction terms on the percentage of seeds predated, per observation period (back-transformed parameter estimates of random intercept mixed models with field as random factor).

Tab. 1 *Signifikanz der Samenprädation, Anzahl der Beobachtungen (N), Einfluss der Bewirtschaftungsform (ökologisch/konventionell), Entfernung vom Feldrand [m], Ausschluß (Käfig/offen) und die Wechselwirkungen bezüglich des prozentualen Anteils gefressener Samen je Beobachtungsperiode (rücktransformierte Parameterschätzwerte des jeweilig besten random intercept mixed models mit Feld als Zufallsfaktor).*

Exposure period	**6-13 May**		**20-27 May**		**3-10 Jun.**		**17-24 Jun.**		**1-8 July**	
Significance seed predation	**0.059**		***		***		***		***	
N	**216**		**216**		**216**		**168**		**204**	
Fixed effects										
Intercept	0.06		0.68		0.95		0.67		0.88	
Farming system			-0.53		-0.11		-0.4		-0.61	*
Distance [m]	- 9.1 e^{-4}	**	-2.3 e^{-3}		7.9 e^{-5}		0.17	***	- 1.2 e^{-3}	*
Exclosure treatm.	- 0.06	***	-0.43	***	-0.40	***	-0.17	*	- 0.56	***
Exclosure treatm. x distance	1.0 e^{-3}	*	-		8.0 e^{-4}	*	-		2.2 e^{-3}	*
Farming system x distance	-		3.4 e^{-3}	*	-7.7 e^{-4}	*	-		-	
Farming system x exclosure treatm.	-		0.22	**	-		-		-	

Significance level; * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$

The effect of exclosure treatment was (highly) significant during all exposure periods, with consistently more seeds predated from the open cards than from cards underneath vertebrate exclosure cages (Tab. 1). The effect of farming system was not significant, except during the last observation period when seed predation was lower in the organic fields. However, some interaction terms involving farming systems were significant, e.g., the interaction between farming system and exclosure treatment during the second observation period, which indicates that more seeds were predated by invertebrates in organic fields. For the sake of simplicity, seed predation rates were averaged over organic and conventional fields to produce Fig. 1A, which shows the percentage of seed predation increasing from early May (6 %) to early June (63 %). After June, seed predation decreased again such that by the end of the trial, early July, the percentage of seed predation was 37 %. The percentage of seeds predated by vertebrates was 87 %, 36 %, 34 %, 6 % and 44 % in the first, second, third, fourth, and fifth observation period (Fig. 1A).

The effect of the distance from the field edge was significant during the first, fourth and final observation period (Tab. 1). In addition, some interaction terms involving distance were significant, i.e., farming system × distance (2nd and 3rd period) and exclosure treatment × distance (1st, 3rd and 5th period). The latter signifies distinctive trends for vertebrates and invertebrates, as illustrated by seed predation rates during the 3rd observation period in Figure 1B. However, most of these effects were non- or weakly significant.

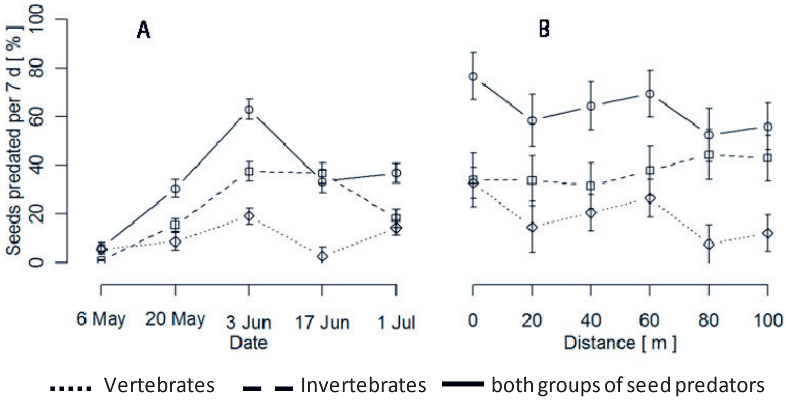

Fig. 1 Percentage of seed predation caused by vertebrates, invertebrates and both groups of seed predators in small-grain cereal fields averaged over all fields (mean ± SE, n = 6), in the municipality of Rostock, Mecklenburg-Vorpommern, Germany, over the course of the season (A) and (B) as a function of the distance from the field edge (3-10 June 2011). The location of the symbol in figure (A) indicates the start of a 7-day observation period.

Abb. 1 *Prozentualer Anteil des Samenfraßes durch Vertebraten, Invertebraten und beiden Prädatorengruppen gemittelt über alle Getreidefelder (Mittelwert ± SE, n = 6) in der Umgebung von Rostock, Mecklenburg-Vorpommern, Deutschland, im Verlauf einer Saison (A) und (B) als Funktion des Feldrandabstands (3.-10. Juni 2010). Die Datumsangaben in Abbildung (A) markieren den Beginn eines 7-tägigen Beobachtungszeitraums.*

3.2 Seed predator identity

A total of 18 unique individuals of the striped field mice, *Apodemus agrarius* (Pallas), five unique individuals of wood mice, *A. sylvaticus* (L.), and one *Microtus* spp. were captured in six fields, during 324 trapnights (6 fields × 18 traps × 3 nights). The highest numbers of mice, namely six and eight, were caught in the conventionally managed fields 4 and 5, respectively. The number of rodents caught was extremely low in the organic fields, namely two, two and three, in fields 1, 2 and 3, respectively. Analyses of the pitfall trap catches are in progress, but preliminary results indicated that densities of typical granivorous carabids, such as *Amara* spp. and *Harpalus* spp., were low. Most individuals belonged to common, omnivorous species, such as *Poecilus cupreus* (L.) and *Pterostichus melanarius* (Illiger).

4. Discussion

The course of seed predation over the season, namely increasing rates from early spring to early summer and then decreasing again, is typical of small grain cereals and has previously been reported, e.g., in the Netherlands (WESTERMAN et al., 2003), UK (MAUCHLINE et al., 2005), USA (HEGGENSTALLER et al., 2006), and southern Germany (BANHARDT, 2011). The pattern appears to be related to canopy cover which increases with crop growth and decreases with crop maturation (HEGGENSTALLER et al., 2006).

The level of seed predation (max. 63 % per 7 days) was lower than in most other studies which concurs with rates previously observed in the area (e.g., BARAIBAR et al., in press). It could at least in part be explained by the shorter exposure period used here, namely 7 instead of 14 days, as seed predation rate increases with exposure time (DAEDLOW, 2007). Although seed predation by invertebrates was more or less comparable to that observed in other studies, seed predation by vertebrates was much lower. The main vertebrate predators in Rostock were rodents; birds were seldom seen in any of the fields. This suggests that in northern Germany the relatively low seed predation rates by all predators combined may have been caused by a lower mouse activity. The lower foraging activity by granivorous mice would concur with the low number of mice present, as compared to other studies (e.g., WESTERMAN et al., 2011). The number of rodents caught was slightly higher in the conventional fields 4 and 5, than in the other fields. Interestingly, these two fields were the only ones that had been managed with less tillage. Field 4 was mouldboard ploughed prior to seeding of wheat in 2010, but no tillage was applied in the preceding year. Field 5 was managed without tillage prior to seeding of winter wheat in 2010. This suggests that tillage may have affected rodent densities. We, therefore, reanalysed the data with the inclusion of an extra factor 'tillage'. However, results were not significant (data not shown).

Fields 4 and 5 were also different in that a number of seeds cards were severely damaged during the fourth and fifth observation period. It had been raining intensely already from 8 June onward, causing the sand-layer of the cards to be soaked. Frequently, we observed that the entire layer, seeds still attached, had rolled up and detached from the card. It is possible that it simply washed off the cards, as the slope of the fields was steeper than that in other fields. However, we also observed that some of these rolls had been partially dragged down the burrow system of earthworms. Usually, the density of earthworms is much higher in no-till fields than in tilled fields (EDWARDS and LOFTY, 1982). Severely damaged cards had been omitted from the analyses, causing an underestimation of the role of invertebrates in seed predation had earthworms been involved. Future research would be needed to investigate the role of tillage on the density and activity of rodents and earthworms, and how these affect seed predation.

Contrary to expectations, farming system (organic vs. conventional) had little or no effect on seed predation rates (Tab. 1). If anything, organic farming reduced seed predation. Farming system as such was therefore not the cause for the lower than usual predation rates. 'Farming system' is generic term that encompasses a set of actions and choices. The most relevant with regard to seed predators is the omission of pesticides, which should favour invertebrate predators (e.g., NAVNTOFT et al., 2006). However, it is possible that in the organic fields, a favourable effect caused by pesticide omission was counteracted by some deleterious effect caused by, for example, increased tillage intensity. This suggests that, in order to find the causes for the low predation rates in northern Germany and the most effective way to enhance seed predation, each management option will have to be tested for its merits separately.

Initially, seed predation decreased with increasing distance from the field edge but that trend reversed from the third period onward. During three observation periods, the two groups of predators behaved differently; seed predation by vertebrates decreased while seed predation by invertebrates increased with distance from the field edge. The role of field edges and other non-crop habitats on the functioning of seed predators is ambiguous. LANDIS and MARINO (1999) proposed three explanations for the observed variable responses; 1) some seed predators may not respond to non-crop habitats, 2) different seed predators may respond differently to non-crop habitats, and 3) the response to habitat differences is examined at an inappropriate spatial scale. Although the absolute contribution of vertebrates to seed predation was more or less stable, the relative contribution changed over the season; only during the first period vertebrates were responsible for most of seed predation whereas from then on invertebrates played a major role (up to 94 % during the 4^{th} period). Observed responses with regard to the presence of non-crop habitat may, therefore, be linked to predator identity, with rodents, mainly *A. agrarius*, foraging preferentially near the field edges (see also DAEDLOW, 2007), and invertebrates foraging indifferently with regard to distance from the field edge or preferentially away from the field edge. Carnivorous carabid densities were low (data not presented) and it is therefore likely that they were not responsible for the observed low density of granivorous carabids.

Biological control is affected by landscape complexity, with generally higher predation rates in complex versus simple landscapes (e.g. LANDIS and MARINO, 1999). Crop management in Mecklenburg-Vorpommern is intense and the scale of agricultural operations large. It is conceivable that instead of separate crop and soil management operations (e.g., pesticide use, tillage intensity), the impoverished landscape as a whole was responsible for the low density of seed predators and low seed predation rates observed.

Acknowledgements

We are grateful for the field assistance of Rosa Minderlen, Martina Goltermann and Ingolf Gliege. Financial support for Daniel Daedlow was provided by the Rosa Luxemburg Foundation.

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