



Effects of resource distribution on overwinter foraging by mice in agricultural fields and the implications for maize volunteer control



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ABSTRACT

Seed predation may be an important ecosystem service for controlling glyphosate-resistant crop volunteers, which are a growing management concern in conventional cropping systems that rely heavily on pesticide based management. In the Midwest USA, prairie deer mice (*Peromyscus maniculatus*) are important seed predators, removing unwanted weed seeds and waste grain from the soil surface all year round. In this study, we examined how the spatial distribution of experimental maize (*Zea mays*) seed patches influenced overwinter foraging, mouse populations and waste grain removal in conventional crop fields. We predicted that (1) individual mice will increase foraging on maize waste grain in fields with many small maize seed patches compared to fields with a few large maize seed patches (functional response) and (2) more mice will forage in fields with many small seed patches than in fields with a few large seed patches (numerical response). We found mouse functional responses were not influenced by the spatial distribution of maize seed patches nor did mice respond numerically to seed addition in general. Mice did, however, remove 59–66% (94–106 kg ha⁻¹) of the maize seeds, providing a valuable ecosystem service. Our work shows that prairie deer mice are able to remove large amounts of waste grain from the soil surface over winter, supporting the hypothesis that overwinter seed predation by mice can drastically reduce volunteer maize densities in conventional crop fields. Future research should further examine what management practices (such as practicing no-till) increase mouse abundance and foraging efficacy, so that management strategies that maximize seed predation can be developed.

1. Introduction

Glyphosate-resistant crop volunteers are a growing management concern in conventional cropping systems (Stewart, 2011). In the USA, about 180–298 kg ha⁻¹ of maize seed (*Zea mays*) can be lost during harvest (Foster et al., 2010), resulting in volunteer maize the following spring. As with other weeds, volunteer maize can reduce farm profit by increasing the costs associated with chemical or mechanical removal (Cerdeira and Duke, 2006). Additionally, volunteer maize is highly competitive and can decrease crop yield by competing with the target crops for sunlight, nutrients, and water (Becket and Stoller, 1988; Cerdeira and Duke, 2006; Gressel, 2005). Moreover, glyphosate is an ineffective means of control for glyphosate resistant volunteer maize, necessitating alternative solutions. Seed predation has been shown to significantly reduce overwinter weed-seed populations in conventional cropping systems (Westerman et al., 2005, 2008) and could be an important ecosystem service for controlling glyphosate-resistant maize volunteers as well.

In his elegant and classic study, Holling (1959) showed the two

mechanisms by which predators exert direct influence on the abundance of their prey. The first was the concept of the functional response where by predators alter their own behavior to consume greater proportions of the prey population as prey availability increased. The second was the numerical response, in which predators abundances increased through increases in births, survival, migration, or any combination of these. In conventional cropping systems, weed patches with higher seed density have greater predation rates by small mammals (Westerman et al., 2008), but whether this was via a functional or numerical response or both was unclear. Furthermore, laboratory trials strongly suggest that maize seeds are more desirable to deer mice than the foxtail seeds (genus *Setaria*) used in Westerman et al., 2008 (B. Danielson and J. Doudna, unpublished data).

Prairie deer mice (*Peromyscus maniculatus bairdii*) are a common seed predator found in conventional crop fields and are widely distributed across the USA (Getz and Brighty, 1986; IUCN, 2016). Deer mice are the only seed predator in the Midwest that are abundant and active year round, allowing them to remove seeds from the soil surface through the fall and winter months following postharvest seed dispersal

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Fig. 1. Example of a pair of wooden mouse burrows used by a prairie deer mouse *Peromyscus maniculatus* for both caching maize seeds (left burrow) and nesting (right burrow) in one of the experimental plots during the winter. Burrows were buried in the soil after the fields were harvested and tilled. This image shows burrows with their lids removed. (For a color version of this figure the reader is referred to the web version of this article.)

(Diaz 1994; Delinger and Lee, 1998). Previous work has focused on their role in reducing weed-seed densities in crop fields (Harrison et al., 2003; Heggenstaller et al., 2006; Westerman et al., 2005), and although Gets and Brighty (1986) and Stewart (2011) have hypothesized that “granivorous rodents” may effectively reduce volunteer maize, this has yet to be explicitly tested. Therefore, our first objective is to test this hypothesis using a controlled seed addition experiment in conventional crop fields overwinter.

Waste grain is often patchily distributed across post-harvest maize fields (personal observation). At small scales, maize seeds can be clustered on lost cobs or left in piles of varying sizes in addition to being scattered as individual grains. A central concept in ecology is that spatial heterogeneity influences many ecological phenomena (Weins, 2002), including foraging, which suggests that the heterogeneity in seed distribution could influence seed predation. Seed predation by small mammals is often density dependent, with more seeds being removed from patches with higher seed density (Baraibar et al., 2012; Davidson and Morris 2001; Westerman et al., 2008). While the effects of seed density on seed predation by small mammals are relatively well studied, there are few studies that have looked at the effects of seed patch arrangement (but see Marino et al., 2005). For example, a large number of more evenly distributed small seed patches may elevate resources for many individuals, whereas the same amount of resources in just a few patches may be monopolized by comparatively few individuals (Berger-Tal et al., 2015). Therefore, our second objective is to test how the spatial distribution of seed patches influences how effectively mice can remove seeds overwinter. To empirically test how the spatial arrangement of patches influences foraging we compare mouse foraging in experimental crop fields where a fixed amount of grain was added in many small patches (MS) or a few large patches (FL) while controlling for within-patch seed density and total patch area. Fields with many small seed patches will have lower average inter-patch distances (Wosniack et al., 2014), therefore we predict that mice within these fields will remove more seeds (indicating a greater functional response) due to decreased average travel costs between a patch and any point in the field. Davidson and Morris (2001) have shown that deer mice are able to remove more seeds per individual (greater functional response) at lower mouse population densities, suggesting that mice will also be able to remove more seeds if they are distributed more evenly in fields with many small patches. Following this, we predict that mice in fields with many small patches are less likely to be limited by other density-dependent factors (ex. space, burrow availability, intraspecific interactions, etc) than in fields with a few large patches resulting in more mice (greater numerical response) as well as a greater

functional response (as in Davidson and Morris (2001)).

To test our predictions, we experimentally manipulated the spatial distribution of maize seed patches in conventionally managed crop fields. In each experimental plot, we measured and compared with controls 1) the total number of mice (numerical response), 2) the densities to which they lowered added waste grain (functional response), and 3) total number of maize seeds remaining overwinter (volunteer maize control). To explicitly test the effects of the spatial arrangement of seed patches on foraging at the field scale, we controlled for the total patch area within an experimental plot and within patch seed density.

2. Methods

2.1. Experimental set-up

Our study was conducted from November 2012 to April 2013 in four maize fields (*Zea mays*) owned by Iowa State University near Ames, Iowa, USA (Bennett Farm, Woodruff Farm, Main Kelley Farm and East Kelley Farm). Bennett Farm was dropped from the study due to extensive flooding at various points throughout the study as well as the presence of wintering geese towards the end of the study. All fields were harvested and cultivated immediately prior to establishing our experimental treatment plots. Additionally, maize biomass was removed from all fields except for the Main Kelley Farm, where it was tilled into the soil.

Within each field, three 100 × 100 m treatment plots were delineated at least 10 m from the nearest edge of the field and at least 50 m from each other. Each of these plots was a 25 × 25 m grid with burrows placed at the center of each grid cell. Wooden burrows were used to monitor the mice living within the boundaries of the plots. Previous work has shown that deer mice living in these fields preferentially occupied burrows when they were provided (B. Danielson, unpublished data), using them for both nesting and caching throughout the fall and winter (Fig. 1). Burrows were buried in the soil in pairs (mice often use one burrow for nesting and the other for caching seeds) so that the entrances of the two burrows were pointing away from each other and the lids of the burrows were flush with the soil surface for easy access. Since the majority of natural biomass had been removed from the crop fields, cotton bedding was placed in each burrow to encourage nesting. Live trapping on experimental plots has shown that this experimental set-up ‘captures’ the majority of mice living in these areas indicating that there are few if any mice left living in natural burrows within the boundaries of the experimental plots (B. Danielson, unpublished data).

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