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Rapid change in the germinable fraction of the weed seed bank in crop rotations

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The dynamics of soil seed banks in crop rotations of corn, soybean, and winter wheat were investigated to determine whether weed seed inputs associated with the winter wheat phases of the rotation were present in the readily germinable fraction of the seed bank in subsequent phases. Two studies were conducted, each in chisel-plowed systems. In one study, we compared seed banks in plots after 8 yr of corn grown continuously and with rotation that included winter wheat and soybean. A second study followed seed bank composition and abundance for 3 yr in plots that were planted to corn and soybean in successive years after planting to winter wheat. Seed banks were measured by direct germination in a heated greenhouse. In the first study, seed banks in plots planted to continuous corn (never planted to winter wheat) and the corn phase of the rotation (winter wheat planted 3 yr earlier) did not differ in species composition or abundance despite significant differences in seed banks in plots that had been planted to winter wheat the previous season. In the second study, seed bank abundance and composition in plots planted to winter wheat in 2001 rapidly changed after planting of corn and soybean in 2002 and 2003, respectively. Data from the two experiments suggest that seed banks in annual row crops experience rapid change in composition and abundance and can be strongly influenced by the most recent crop. This could limit our ability to infer longer term trends associated with changes in management practices from studies of soil seed banks.

Nomenclature: Corn, *Zea mays* L.; soybean, *Glycine max* (L.) Merr.; winter wheat, *Triticum aestivum* L.

Key words: Community assembly, population dynamics, multivariate, organic, seed persistence, weed communities.

Seed banks in annual row crops are assumed to contain seeds that have been shed over multiple growing seasons, reflecting the sum effects of past and present weed management on weed survival and reproduction (Cavers and Benoit 1989; Clements et al. 1996; Dorado et al. 1999). The assumption that seed banks are a memory of past management is a long-standing paradigm in weed science (Cavers and Benoit 1989; Davis et al. 2005; Murphy et al. 2006; Swanton and Booth 2004) and has often been invoked as justification for use of the seed bank to compare the long-term weed suppression potential of different management systems (Cardina et al. 2002; Moonen and Barberi 2004; Sosnoskie et al. 2006; Swanton and Booth 2004). However, if the majority of seed in the soil does not persist for more than a few growing seasons or consists primarily of relatively recent seed inputs, the usefulness of seed bank studies as a long-term indicator of management success might be limited.

The ability of seed to persist in the soil depends on a number of physiological, environmental, and evolutionary factors. In desert systems, for instance, annual plant species have evolved dormancy as a bet-hedging strategy to maintain populations in environments that are temporally variable, and a large percentage of the seed bank remains dormant even when conditions are conducive to germination (Pake and Venable 1996; Philippi 1993). In contrast, most agricultural weeds have evolved to maximize growth and reproduction during favorable conditions (Grime 1977) and therefore germinate when the appropriate microenvironmental cues are detected. Although a few examples of seeds of some arable weed species persisting for relatively long periods of time and under controlled conditions are well known (Cavers and Benoit 1989; Telewski and Zeevaart 2002), the majority of studies in cultivated systems suggest that most seed germinates or dies in the first few years after entering the soil seed bank (Cavers and Benoit 1989; Lutman et al. 2002; Teasdale et al. 2004). The discrepancy between such studies and assumptions of long-term seed bank persistence (> 1 or 2 yr) indicates that the dynamics of seed bank communities in annual row crop systems are still not well understood.

Crop rotations provide useful systems for evaluating the persistence and dynamics of weed seed banks because weed management, and therefore seed inputs to the soil, varies with each crop in rotation (Liebman and Dyck 1993). Because certain crops or management practices are often associated with distinct weed communities (Cavers and Benoit 1989; Smith 2006; Squire et al. 2000), inputs of seed during that phase of the rotation can leave a unique signature within the seed bank. The persistence of this seed input signature can be measured in successive crop phases to determine how long seed inputs remain in the readily germinable fraction of the seed bank.

In this study, we sought to examine weed seed bank dynamics and determine the relative persistence of seed inputs to the soil in annually tilled row crops. Specifically, we were interested in whether weed seed inputs associated with the winter wheat phase of a rotation were apparent in the readily

Table 1. Crop history of rotations at the KBS LFL sampled for seed bank abundance and composition in spring 2001.

Year	Monoculture of Continuous corn (CC)	Rotation	
		Corn phase (RC)	Wheat phase (RW)
1993	Corn	Soybean	Corn
1994	Corn	Wheat	Corn
1995	Corn	Corn	Soybean
1996	Corn	Corn	Wheat
1997	Corn	Soybean	Corn
1998	Corn	Wheat	Corn
1999	Corn	Corn	Soybean
2000	Corn	Corn	Wheat

germinable fraction of the seed bank in successive phases of a corn–soybean–winter wheat rotation. Fall-sown crops such as winter wheat have been shown to be associated with a weed flora that is distinct from spring-sown crops (Hald 1999; Hallgren et al. 1999; Squire et al. 2000) such as corn and soybean, in part because of differences in the timing of major management practices, such as primary tillage, that favor certain subsets of species over others (Crawley 2004; Smith 2006). Data from two studies were used to investigate seed bank dynamics and relative persistence of seed inputs attributable to the winter wheat phase of the rotation. The first study compared weed seed banks in corn grown continuously and in a long-term crop rotation with winter wheat and soybean under conventional and organic management. The two management systems were compared to determine whether the system of weed control and nutrient inputs affected seed bank persistence. The second study followed seed bank abundance and composition for 3 yr in replicate plots that were planted to winter wheat in 2001, corn in 2002, and soybean in 2003 in a rotation experiment managed without external chemical inputs. Seed banks were sampled each year in spring, and the composition and abundance of seed in the readily germinable fraction of the soil seed bank was assessed by direct germination in a heated greenhouse.

Materials and Methods

Study Sites

Studies were carried out at two locations at the W. K. Kellogg Biological Station Long Term Ecological Research (KBS LTER) site in southwest Michigan. Soils at both study locations were a mixture of Kalamazoo (fine-loamy, mixed, mesic Typic Hapludalfs) and Oshtemo (coarse-loamy, mixed, mesic Typic Hapludalfs) sandy loams (Crum and Collins 1995). Annual precipitation at the LTER site is 90 cm, and mean annual temperature is 9.7 C. Detailed soil and management descriptions of the site are available at http://lter.kbs.msu.edu.

The first study was conducted in 2001 at the Living Field Lab (LFL) experimental plots. The LFL was established in 1993 to examine the effects of extended rotations and different management systems on nutrient cycling and agroecosystem function. The site was planted to alfalfa (*Medicago sativa* L.) in 1992 and rotation treatments consisting of continuous corn and each phase of a 4-yr corn–corn–soybean–winter wheat rotation were initiated in 1993. Rotation treatments were randomly assigned to plots within blocks that received one of four management system treatments in a split plot design. All phases of the rotation were present each year. For this study, we focused only on continuous corn (CC) and the second-year corn (rotation corn, RC) and winter wheat (rotation wheat, RW) phases of the rotation in two management systems: a conventional system that received full inputs of fertilizer and herbicides (broadcast applications) at rates recommended for the region (Sanchez et al. 2004) and an organic system that received composted dairy manure but no synthetic chemical inputs. Weed management in the organic system was via periodic (2–4 times/yr) interrow cultivation (row cultivation and rotary hoeing). Each phase of the rotation represented different times since the last appearance of winter wheat in the rotation. Plots planted to continuous corn (CC) had never been planted to winter wheat; second-year corn plots (RC) had been planted to corn the previous year and to winter wheat 3 and 7 yr before sampling; winter wheat plots (RW) had been planted to wheat the previous season and 5 yr earlier (Table 1). Plots in both management systems were chisel plowed each year before planting. All treatments (management system by rotation) were replicated four times. Plot sizes differed between the two management systems and measured 15 by 9 m (conventional) and 15 by 4.5 m (organic).

The second study was conducted from 2002 to 2004 at the Biodiversity Experimental Plots (BEP) ~ 1 km south of the LFL site. The BEP was established in 2000 to investigate the effects of manipulating row crop diversity on ecosystem functioning. Treatments in the BEP included continuous monocultures and two- and three-crop rotations of corn, soybean, and winter wheat grown with and without cover crops. The BEP was managed without external chemical inputs, and plots were chisel plowed and soil was finished each year before planting. All phases of the rotation treatments were present each year. Plots were 9 by 27 m, and treatments were arranged in a randomized complete block with four replications. For this study, we followed seed bank abundance and composition for 3 yr in four replicate plots that were planted to winter wheat in 2001, corn in 2002, and soybean in 2003 and compared these to the seed banks in plots planted to continuous monocultures of the same crops (Table 2).

Seed Bank Sampling

Soil seed banks were sampled in a similar manner in both the LFL and BEP studies. In 2001 (LFL study) and 2002

Table 2. Crop history of rotations at the Kellogg Biological Station Biodiversity Experimental Plots sampled for seed bank abundance and composition. Treatments were sampled in the spring after each crop was harvested (i.e. seed banks for wheat grown in 2001 were sampled spring 2002).

Treatment	Rotation			
	2000	2001	2002	2003
Monoculture				
Wheat	Wheat	Wheat	Wheat	Wheat
Corn	Corn	Corn	Corn	Corn
Soybean	Soybean	Soybean	Soybean	Soybean
Rotation	Soybean	Wheat	Corn	Soybean

to 2004 (BEP study) soil seed banks were sampled by taking 10 soil cores (2-cm diameter) to a depth of 5 cm from an area 25 by 25 cm in three central locations in each plot according to the method employed by Davis et al. (2005) and Menalled et al. (2001). Sampling occurred in mid-May after the plots had been tilled and crops planted, but before crop emergence. Sampling in the spring has been shown to provide reliable estimates of the viable seed bank (Forcella 1992) because it allows natural dormancy-breaking mechanisms to operate over the winter. Sampling immediately after tillage and planting also ensured that seed banks were thoroughly mixed. Each 10-core soil sample was composited and spread on sterile growing medium[1] in half-flats (25 by 25 cm) in a greenhouse. Flats were watered daily from above with a mist sprayer to keep the soil surface moist. Flats were monitored for germination approximately twice a week from May to October. Seedlings that emerged from the flats were identified and removed. Seedlings that could not be identified immediately were transplanted and grown in separate pots until identification was possible.

Statistical Analysis

For each soil sample collected from the LFL, we calculated the density (total seedlings emerged) and species richness (number of species). Data for each of the three samples taken from each plot were averaged, and plot means were used as the unit of replication. The effects of management system and rotation on seed bank density and species richness were analyzed with a split plot design, with management system (conventional, organic) as the whole plot factor and rotation phase (continuous corn, rotation corn, rotation wheat) as the subplot factor. ANOVAs were performed with the MIXED procedure in SAS.[2] Treatment means were separated with errors appropriate for a split plot design with the Tukey–Kramer test at the P = 0.05 level. Seedling density and species richness data were square root transformed before analysis to satisfy the assumptions of ANOVA. Seedling density data are expressed as number of emerged weed seedlings per square meter. Data were back transformed for presentation in tables and figures.

To visualize plot-level patterns in species abundance and composition among the rotation and management system treatments, we performed nonmetric multidimensional scaling (NMDS; Mather 1976; McCune and Grace 2002) with the PC-ORD package (McCune and Mefford 1999).[3] NMDS is an ordination method that maximizes rank order correlation between distances derived from the original data set and those in ordination space, and it is often the most appropriate ordination method for community data sets (McCune and Grace 2002). Before ordination, seedling abundance values were $\log(x + 1)$ transformed, and a distance matrix was calculated by the Bray–Curtis distance metric. Forty runs of the ordination (at random starting configurations and with a maximum of 400 iterations per run) were performed with an instability criterion of 0.00001. These runs were compared with 50 randomized runs to assess the significance of the reduction in stress from six dimensions to one (Monte Carlo test).

In addition to the ordination, we used a nonparametric distance-based multivariate analysis[4] (Anderson 2001, 2004) to test for significant differences in seed bank community composition and abundance among the treatments. Main effects of management system, rotation phase, and their interactions on species abundance were tested by permutation (9,999 permutations) with error terms appropriate for a split plot design. The test statistic (pseudo F) is analogous to Fisher's F ratio and was calculated from a distance matrix of Bray–Curtis dissimilarity coefficients. Species abundance values were $\log(x + 1)$ transformed before analysis.

Seed bank data from the BEP were analyzed with NMDS ordination to determine how seed bank composition and abundance changed when plots planted to winter wheat in 2001 were subsequently planted to corn in 2002 and soybean in 2003. NMDS was performed on the species abundance values measured for the four replicate plots of the rotation treatment each year from 2002 to 2004 and the four replicates of the continuous monoculture that corresponded to the crop planted in the rotation replicates (i.e., continuous monoculture of winter wheat in 2001, corn in 2002, and soybean in 2003). Seedling abundance data were $\log(x + 1)$ transformed before calculating Bray–Curtis distances and performing ordination.

Results and Discussion

LFL Seed Bank Density and Species Richness

In the LFL plots, there was no effect of management system (organic vs. conventional) on seed bank density or species richness (density P = 0.76; richness P = 0.14); however, there was a significant effect of rotation phase (density $F_{2,12} = 4.89$, P = 0.03; richness $F_{2,12} = 7.70$, P = 0.007). In both management systems, seed bank density and species richness were significantly greater after the winter wheat phase (RW, last planted to winter wheat in 2000) than the rotation corn phase (RC, last planted to winter wheat in 1998) or continuous corn monoculture (CC; Figure 1). Seed bank density and richness did not differ between RC and CC, and there was no interaction between management system and rotation phase (density P = 0.99; richness P = 0.26).

LFL Species Composition and Abundance

Thirty-seven species were identified from the soil samples collected in the LFL (Table 3). Of these, six were unique to the wheat phase of the rotation (RW). These species tended to be present at relatively low densities within the seed bank (< 1%).

The NMDS ordination reduced the dimensionality of the LFL seed bank data set to three main axes (minimum stress = 11.58, P = 0.02), which accounted for 52.2, 23.5, and 11.2% (cumulative $r^2 = 86.9\%$) of the information in the analytical data set, respectively. Ordination showed a clear distinction in seed bank abundance and composition between the winter wheat phase of the rotation and the continuous and rotation corn (Figure 2). The nonparametric multivariate analysis confirmed that compositional differences among seed banks were due to the effect of rotation phase (rotation phase pseudo $F_{2,12} = 8.82$, P = 0.0001) and that effects of management system and the interaction were not significant (management P = 0.055; interaction P = 0.084).

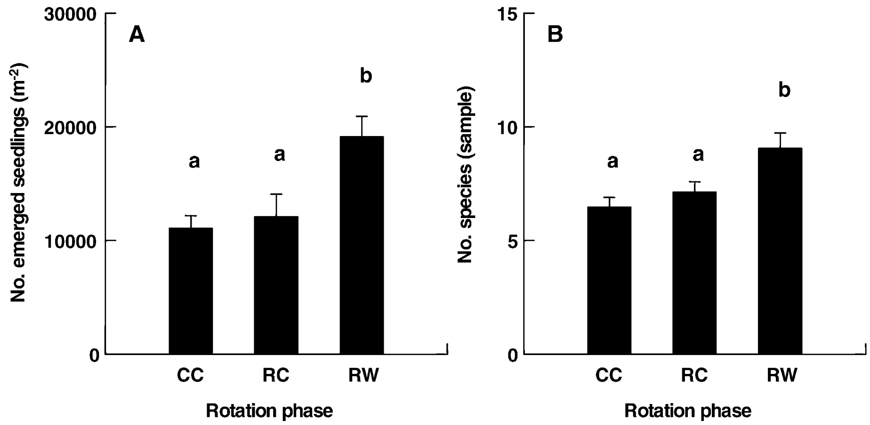

FIGURE 1. Density (A) and species richness (B) of seedlings emerged from soil seed bank samples collected in May 2001 in continuous corn (CC, never planted to winter wheat), the rotation phase of corn (RC, planted to winter wheat in 1998), and winter wheat (RW, planted to winter wheat in 2000) of a 4-yr corn–corn–soybean–winter wheat rotation. Values are mean ± 1 SE averaged across management system, n = 8. Bars sharing the same lowercase letter are not significantly different at P = 0.05 (Tukey–Kramer test).

BEP Seed Bank Dynamics

In the BEP site, seed banks in four replicate rotation plots were measured each year as they cycled through a 3-yr rotation and were compared with those in continuous monoculture plots. Eight weed species were unique to both the continuous wheat and rotation plots planted to wheat in 2001 (Table 4). After 2 yr, after planting to corn (2002) and soybean (2003), only three of these species were still detectable in the seed bank of the rotation plots in 2004.

Ordination of the BEP seed bank data allowed us to visualize yearly changes in composition and abundance. The NMDS ordination reduced dimensionality to three main axes (minimum stress = 11.30, P = 0.020), which explained 49.6, 28.3, and 8.7% (cumulative r^2 = 86.6%) of the information in the analytical data set, respectively. The ordination showed that seed banks in the continuous monocultures of wheat, corn, and soybean were distinct from one another and abundance and composition changes from year to year in the crop rotation plots (Figure 3). After planting to wheat in 2001, seed bank abundance and composition in three of the four rotation plots was similar to that of continuous wheat in 2002. In 2003, after a year of corn, seed bank abundance and composition in the rotation plots had shifted toward that of continuous corn. In 2004, the abundance and composition of the seed bank had again shifted, this time in the direction of continuous soybean. The seed bank in the fourth rotation plot was less similar to that of continuous wheat in 2002 but still showed a similar pattern of change after planting to corn and soybean.

Results of both the LFL and BEP studies show that in crop rotation, the germinable fraction of the weed seed bank experiences relatively rapid change in composition and abundance. Given the limited extent of the data collected (1 and 3 yr in the LFL and BEP studies, respectively) and because both studies were conducted under the same tillage system, inferences from these results might be somewhat limited to chisel-plow systems. However, other studies performed under differing tillage systems have found similar rapid changes in the composition and abundance of the seed bank from year to year (Buhler et al. 2001; Leck and Leck 1998; Teasdale et al. 2004). For example, Buhler et al. (2001) found that in a system in which tillage practices varied with each crop, the seed bank changed with each crop over a 5-yr rotation that included hay, corn, soybean, and oat and that abundances of seeds of common waterhemp (*Amaranthus rudis* Sauer) and foxtail (*Setaria* spp.) changed 2- to 33-fold from crop to crop. In an old field, seed bank density increased 14-fold in just 2 yr after abandonment from agriculture, and elimination of seed rain for a period of 1 yr caused a significant decrease in both seed bank density and species richness (Leck and Leck 1998).

Two main factors likely contributed to the rapid changes in seed bank composition and abundance observed in these two studies. First, relatively little longer term persistence (i.e., > 2 yr) of germinable weed seed appeared to be associated with past crops in the rotation—that is, weed seed associated with the winter wheat phase of the rotation were present in plots that had been planted to winter wheat the previous season but were often not present in measurable densities in the same plots after successive planting of corn and soybean (and vice versa). Other researchers have found a similar lack of longer term persistence of seed banks in agricultural field studies. A summary of crop management studies found that most viable seed was lost from the seed bank after 1 to 4 yr of reduced or eliminated weed seed inputs (Cavers and Benoit 1989). Buhler (1999) found that giant foxtail (*Setaria faberi* Herrm.) seed densities in the soil decreased rapidly when seed inputs were eliminated. In a controlled field study, Lutman et al. (2002) reported annual seed loss rates of from 20 to 99% for 15 weed species.

The observation from the LFL study that a few weed species were present in both the winter wheat and corn rotation phases, but not continuous corn (Table 3), suggests that some species are capable of limited short-term persistence in the seed bank. Studies reporting higher species richness in crop rotations compared with continuous monocultures (Cardina et al. 2002; Dorado et al. 1999; Liebman and Dyck 1993) also support the notion of limited short-term persistence in some weed species. The relatively small percentage of seed in the soil that does persist for more than one or two seasons likely plays a large role in maintaining populations across rotation cycles (Buhler and Hartzler 2001; Liebman and Dyck 1993). However, because these persistent seeds are present at such low densities, their de-

TABLE 3. Relative density of weed species that emerged from the soil seed bank in 2001 in continuous corn (CC, never planted to winter wheat) and in the corn (RC, last planted to wheat in 1998) and winter wheat (RW, last planted to wheat in 2000) phases of a corn–corn–soybean–winter wheat rotation.

Weed species	Relative density		
	CC	RC	RW
	%		
Amaranthus retroflexus L.	0.00	0.59	1.03
Ambrosia artemisiifolia L.	0.00	0.24	1.03
Arabidopsis thaliana (L.) Heynh.	9.97	8.83	3.59
Aster sp.	0.00	0.12	0.00
Capsella bursa-pastoris (L.) Medicus	0.00	1.18	0.00
Cardamine hirsuta L.	0.26	0.00	0.00
Chenopodium album L.	7.93	11.43	1.76
Conyza canadensis (L.) Cronq.	0.00	0.12	0.59
Digitaria ischaemum (Schreb. *ex* Schweig.) Shreb	0.13	0.71	1.54
Digitaria sanguinalis (L.) Scop.	0.90	0.47	3.45
Echinochloa crus-galli (L.) Beauv.	0.26	0.00	0.00
Eleusine indica (L.) Gertn.	0.38	0.12	0.00
Epilobium sp.	0.00	0.00	0.07
Eragrostis cilianensis (All.) E.Mosher	0.00	0.00	0.07
Erigeron strigosus Muhl. *ex* Willd.	0.64	0.00	0.07
Juncus tenuis Willd.	0.13	0.00	0.07
Lepidium virginicum L.	0.13	0.12	0.00
Mollugo verticillata L.	0.26	14.72	0.07
Oxalis stricta L.	1.15	2.36	4.91
Panicum capillare L.	0.00	0.00	0.07
Panicum dichotomiflorum Michx.	0.00	0.24	5.94
Panicum sp.	0.00	0.00	0.15
Plantago major L.	0.00	0.35	3.96
Poa sp.	11.89	3.06	0.51
Polygonum aviculare L.	0.00	0.00	0.29
Polygonum convolvulus L.	0.26	0.24	0.00
Polygonum persicaria L.	0.13	1.53	1.91
Portulaca oleracea L.	0.64	1.18	0.51
Setaria faberi Herrm.	0.00	0.00	0.07
Setaria glauca (L.) Beauv.	0.00	0.12	0.07
Setaria viridis (L.) Beauv.	0.00	0.12	0.07
Solanum ptycanthum Dun.	0.00	0.12	0.15
Stellaria media (L.) Vill.	22.63	23.79	2.49
Taraxacum officinale Weber *in* Wiggers	11.51	5.18	54.62
Trifolium repens L.	0.13	0.00	0.07
Veronica peregrina L.	29.80	22.03	10.56
Veronica persica Poir.	0.90	1.06	0.29

tection within the seed bank could be difficult and might not provide useful information regarding past weed management.

A second factor that appeared to contribute to the rapid change in the readily germinable fraction of weed seed bank was the degree to which the rotation phase influenced the composition and abundance of seed inputs to the soil each season. Annual inputs of weed seed to the soil can be thought of as the consequence of multiple filters that operate within the context of the cropping system (Booth and Swanton 2002; Cavers and Benoit 1989). These filters, which include the crop and associated management practices, exclude some weed species and allow others to establish and reproduce (Booth and Swanton 2002; Smith 2006). If these annual filters are strong enough, they can obscure residual variation in communities. For example, a comparison of the emergent weed communities under three different 6-yr crop

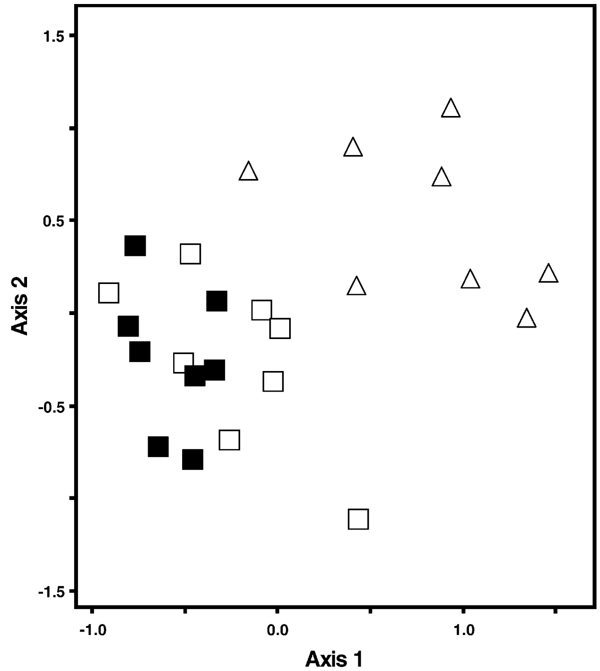

FIGURE 2. NMDS ordination of weed seed banks sampled in May 2001 in continuous corn (CC, never planted to winter wheat, filled squares), the rotation phase of corn (RC, last planted to winter wheat in 1998, open squares), and winter wheat (RW, last planted to winter wheat in 2000, open triangles) of a 4-yr corn–corn–soybean–winter wheat rotation under conventional and organic management. Values plotted are replicate scores. Only the two most explanatory axes (r^2 = 0.757) are displayed.

rotations in Sweden found the species of crop was a much more important factor influencing the weed flora than crop rotation (Andersson and Milberg 1998). Similarly, Doucet et al. (1999) found that when continuous monocultures and three-crop rotations containing corn, soybean, and winter wheat that had been in place for 9 yr were planted to corn in the 10th year, residual effects of the rotation on the emergent weed community were few. The identity of the crop is often assumed to be an important filter because it determines which herbicides are applied (Thomas et al. 2004). However, in our study, crop type appeared to be the most significant filter on seed bank abundance and composition regardless of management system, suggesting that factors

TABLE 4. Relative densities in the soil seed bank of the eight weed species common to both the continuous winter wheat monoculture and the wheat phase of rotation in 2001 and after planting of corn (2002) and soybean (2003).

Weed species	Relative density		
	2001 wheat	2002 corn	2003 soybean
	%		
Chenopodium album L.	4.8	37.1	25.5
Digitaria ischaemum (Schreb. *ex* Schweig.) Schreb	1.6	0	0
Digitaria sanguinalis (L.) Scop.	8.0	2.9	0
Erigeron spp.	1.6	0	0
Mollugo verticillata L.	34.9	2.9	9.6
Panicum dichotomiflorum Michx.	3.2	0	0
Potentilla norvegica L.	3.2	0	0
Stellaria media (L.) Vill.	25.4	51.4	46.8

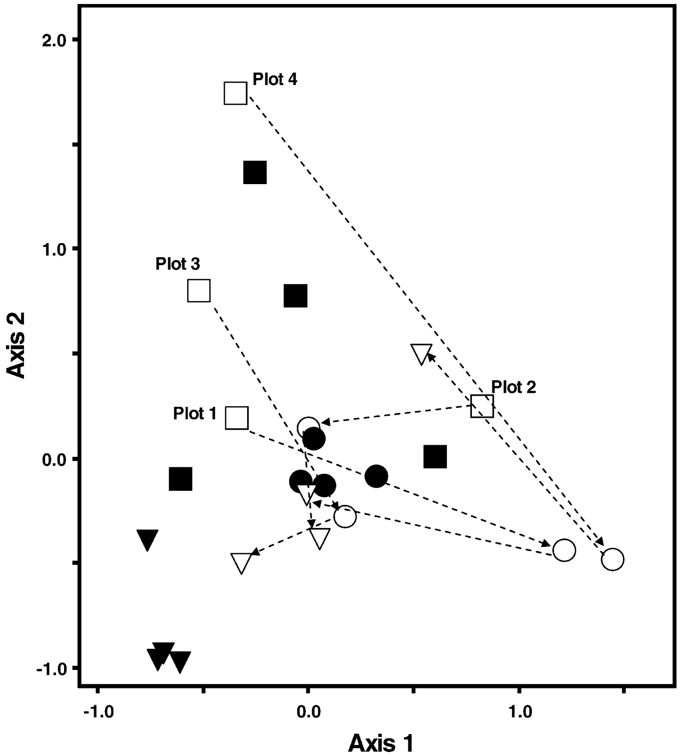

FIGURE 3. NMDS ordination of weed seed banks in four replicate plots (open symbols) in 2001, 2002, and 2003 after planting to winter wheat (squares), corn (circles), and soybean (triangles), respectively, and the corresponding continuous monoculture in that year (filled symbols). Replicate plots are labeled 1 through 4, and dashed arrows indicate each plot's trajectory through time. Only the two most explanatory axes (r^2 = 0.780) are displayed.

other than herbicides are also important filters on weed communities (Smith 2006). Thus, strong filtering effects of the crop and associated management practices coupled with a lack of longer term persistence of the germinable fraction of the seeds that escaped filtering likely contributed to the observed similarities in seed banks between crops in rotation and monocultures of the same crop.

The relatively rapid change in seed bank composition and abundance observed in this study is likely not specific to crop rotations. Crop rotations only make this process more apparent. Given the rapid dynamics and short persistence times of many arable weed species' seeds in the soil (Lutman et al. 2002), we suggest caution be exercised when using the seed bank to infer past trends in weed control or weed seed production or to evaluate the weed management efficacy of a given cropping system. Seed banks, particularly in high-disturbance tillage systems and composed of seeds that do not persist for more than one or two seasons, should likely be viewed more as a reflection of the weed management success or failures that occurred the previous season rather than the cumulative effects of management occurring over longer time scales. Given this constraint, it might be unwise to use the seed bank to infer the long-term weed suppression potential of a given management system or to relate the size and composition of the seed bank to weed management practices occurring over time scales longer than one or two cropping seasons.

Sources of Materials

[1] Sunshine Germinating Mix #3, Sun Gro Horticulture, 15831 NE 8th Street, Suite 100, Bellevue, WA 98008.

[2] SAS Version 8.02, SAS Institute, 100 SAS Campus Drive, Cary, NC 27513.

[3] Version 4.25, MjM Software Design, P.O. Box 129, Gleneden Beach, OR 97388.

[4] DISTLM v.5, Department of Statistics, University of Aukland, Private Bag 92019, Auckland, New Zealand.

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