Weed Science, 49:230–235. 2001

Emergence and persistence of seed of velvetleaf, common waterhemp, woolly cupgrass, and giant foxtail

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Annual emergence and seed persistence of common waterhemp, velvetleaf, woolly cupgrass, and giant foxtail were characterized in central Iowa for 4 yr following burial of seeds collected and buried in autumn 1994. First-year emergence as a percentage of the original seed bank ranged from 5 to 40%, and the relative order was common waterhemp < velvetleaf < giant foxtail < woolly cupgrass. During the second and third years, there were no differences in percent emergence among species, with emergence percentages ranging from 1 to 9% of the original seed bank. During the fourth year, seedlings continued to emerge from only the velvetleaf and common waterhemp seed banks. A greater percentage of common waterhemp seed persisted each year and 12% of the original seed was recovered after 4 yr of burial. Five percent of the velvetleaf was recovered at the end of the fourth year. No woolly cupgrass and giant foxtail seed was recovered after the third and fourth years. The proportion of the seed that was accounted for from year to year through emergence and seed recovery varied by species and year. Total recovery of velvetleaf ranged from 61 to 87%, common waterhemp from 50 to 81%, woolly cupgrass from 29 to 79%, and giant foxtail from 23 to 79%. Based on the results of this research, velvetleaf and common waterhemp form more persistent seed banks than woolly cupgrass and giant foxtail. Therefore, woolly cupgrass and giant foxtail should be more amenable to management through seed bank depletion than velvetleaf and common waterhemp.

Nomenclature: Common waterhemp, *Amaranthus rudis* Sauer AMATA; giant foxtail, *Setaria faberi* Herrm. SETFA; velvetleaf, *Abutilon theophrasti* Medik. ABUTH; woolly cupgrass, *Eriochloa villosa* (Thunb.) Kunth ERBVI.

Key words: Seed bank, seed persistence, seedling emergence, ABUTH, AMATA, ERBVI, SETFA.

The success of integrated weed management programs is dependent upon understanding weed population dynamics and matching management tactics to specific weed problems. Because annual species are the main weed problems in the U.S. corn (*Zea mays* L.) belt and many other areas of the world, an improved understanding of weed seed behavior in the soil is essential for development and implementation of integrated weed management systems (Buhler et al. 1998). Most weed seed banks in agroecosystems contain many weed species (Forcella et al. 1992). Therefore, knowledge of the differential behavior of individual species is necessary for effective control of diverse weed populations and for anticipating the effects of management practices on weed population dynamics (Buhler et al. 1997; Forcella et al. 1992).

Annual weed species are perpetuated by seeds that make up the soil seed bank. Seeds enter the soil through many sources, but the largest source is plants that escape control and produce seeds within the field (Cavers 1983). Weed seed population densities can be greatly reduced by preventing plants from producing seeds. Conversely, in soils with low seed population density, weed numbers can increase rapidly if plants are allowed to produce seeds (Buhler et al. 1998; Burnside et al. 1986).

The percentage of seeds in the seed bank that generate seedlings in a given year varies widely among species and environmental conditions. Forcella et al. (1992) reported that cumulative annual emergence percentages for several annual species ranged from 0.1 to 30%. Averaged over sites and species, mean emergence percentages tended to be higher for grass species than for broadleaf species. For most species, the greatest percentage of emergence occurs during the first growing season following introduction of seed into soil (Egley and Williams 1991).

Although the literature on weed emergence is expanding, the majority of research has looked at emergence from a seed bank in a single year. However, since weed seeds persist in the soil, understanding seed bank dynamics over multiple years is important for devising multiyear strategies to manage weeds. For example, velvetleaf (*Abutilon theophrasti*) has been reported to have similar levels of emergence (Egley and Williams 1991) or greater emergence (Hartzler 1996) from 2-yr-old seed than from first-year seed. Hartzler (1996) found that 25% of the velvetleaf seed introduced into the soil produced seedlings over the following four growing seasons with maximum emergence of 11% occurring during the second year. Emergence in the fourth year declined to 2% of the original seed bank. Webster et al. (1998) observed that cumulative emergence of velvetleaf ranged from 6 to 25% over four growing seasons, depending on tillage system and planting depth. The maximum emergence occurred during the first 2 yr, and emergence declined to 1% or less of the original seed bank by the fourth year. Hartzler et al. (1999) found that 3-yr cumulative emergence of woolly cupgrass (*Eriochloa villosa*) and giant foxtail (*Setaria faberi*) was greater than of velvetleaf and common waterhemp (*Amaranthus rudis*). Emergence of woolly cupgrass and giant foxtail was greatest during the first year and declined rapidly in subsequent years. Emergence of velvetleaf and common waterhemp did not decline as rapidly after the first year, and emergence was generally greater than woolly cupgrass and giant foxtail in years 2 and 3. The fate of seeds that did not produce seedlings was not evaluated in these studies.

There are numerous reports of extreme seed longevities when seeds were placed in an artificial environment and not exposed to tillage and other management practices (Burnside et al. 1996 and references therein). The goal of these studies was to determine the maximum potential life of seeds. However, these studies may not be good indicators the longevity of seed banks subjected to agricultural practices. For example, tillage increased the depletion rate of itchgrass [*Rottboellia cochinchinensis* (Lour.) W. Clayton] seeds in soil by 32% per year (Bridgemohan et al. 1991). Lueschen et al. (1993) found that after 17 yr with no seed return, soil that had not been tilled still contained 15 to 25% of the original velvetleaf seed. When the soil was moldboard plowed at least once each year, 0.8 to 2.5% of the initial seed remained viable after the same time period.

Weed seed persistence plays a key role in weed population behavior over time. For example, Burnside et al. (1986) found that seed density in the soil declined by 95% after a 5-yr weed-free period. During the sixth year, herbicides were not used and seed density increased to 90% of the original level at two of five locations. Buhler (1999) reported that maintaining weed-free conditions through canopy closure for 4 yr greatly reduced weed densities; however, enough weeds remained to reduce soybean [*Glycine max* (L.) Merr.] yields by 22 to 51% when no herbicide was applied during the fifth year.

Common waterhemp and woolly cupgrass are two species of increasing importance in the north-central United States. Common waterhemp is native to the region and reported to emerge later into the summer than most annual weeds (Hager et al. 1997; Hartzler et al. 1999). Common waterhemp biotypes resistant to acetolactate synthase (ALS)-inhibiting herbicides have been identified (Hinz and Owen 1997). Woolly cupgrass is native to China and has been recognized as a serious weed problem in the north-central United States (Strand and Miller 1980). The increase in problems associated with woolly cupgrass has been attributed to the relatively low efficacy of many herbicides used to control this species in corn (Owen et al. 1993; Schuh and Harvey 1991), less crop rotation, tillering and seed production following cultivation or herbicide treatment (Pullins 1995), and multiple emergence events within a growing season (Owen 1990).

Better understanding of the persistence of the seed of important annual weed species is essential to determine the multiyear response of weed populations to management practices, such as crop rotation or no-seed thresholds, that eliminate seed production. The objective of this research was to characterize emergence and seed persistence of velvetleaf, common waterhemp, woolly cupgrass, and giant foxtail for 4 yr following seed deposition under field conditions.

Materials and Methods

A field experiment was conducted from October 1994 until October 1998 at the Iowa State University Horticulture Research Farm near Ames, IA. A site maintained in a Kentucky bluegrass (*Poa pratensis* L.) sod for at least 10 yr prior to initiation of the study was selected to minimize the presence of seeds of the target species within the seed bank. The soil was a Clarion silt loam (fine-loamy, mixed, mesic typic Hapludoll) with 60% silt, 23% clay, and 17% sand; pH 6.5; and 4.5% organic matter. In July 1994, the sod was removed with a sod cutter to a depth of 2 cm, then the soil was tilled 15 cm deep with a rototiller. Frames (45 by 61 cm) were constructed of pressure-treated lumber (5 by 15 cm) with an unfinished surface and were placed horizontally in the soil, so that 2.5 cm of the frame remained above the soil surface, and positioned such that row crops could be seeded between the rows of frames.

Seeds of four weed species were collected from agricultural fields in central Iowa in late September 1994. Mature seeds of woolly cupgrass and giant foxtail were harvested by tapping inflorescences inside paper bags, whereas mature velvetleaf and common waterhemp floral structures were stripped from plants and placed in paper bags. Seeds were cleaned, counted, and stored at room temperature until burial.

Germination percentage and viability of seed were determined just prior to burial. Germination was determined by placing four replicate samples of 100 velvetleaf seeds, or 200 seeds of the other species, in petri dishes between germination paper that was moistened with water then incubating in a growth chamber at 24 C for 14 d in light at 30 μmol m^{-2} s^{-1}. Seeds with emerged radicals were defined as germinated. After 14 d, the remaining seeds were removed and tested for viability using tetrazolium. The number of viable seeds was determined by adding the number of seeds that germinated and the number of seeds that tested positive in the tetrazolium test.

Seeds were buried on October 21, 1994, by removing the upper 5 cm of soil from each frame individually and placing it in a 19-L bucket. Two thousand viable seeds of an individual species were added and thoroughly mixed with the soil, and the soil was returned to the frame. A randomized complete block split plot design with four replications was used. Weed species were whole plots and years were subplots.

Soil within frames was not disturbed the first spring after seed burial, but in subsequent years, soil was mixed by hand using a garden trowel to a depth of 5 cm during early April prior to weed emergence. Soybean was planted (96-cm-wide rows) between rows of frames on May 26, 1995, and May 16, 1997, whereas corn was planted on May 10, 1996, and May 25, 1998. On May 1, 1996, 810 kg ha^{-1} of a 20-4-5 fertilizer was broadcast over the experimental area. Urea was applied at a rate of 242 kg ha^{-1} on June 5, 1998. Crops were harvested by hand, and crop residue was spread over the experimental area.

Seedling population density was determined weekly during the first 2 mo after initial emergence, after which counts were taken every other week in all frames in all years. All seedlings of target species were counted and subsequently removed by hand. All other weeds were removed periodically from the experimental area. Seedlings of the species included

TABLE 1. Total annual emergence of four weed species as a percentage of 2,000 seeds buried in the upper 5 cm of a 0.27-m^2 quadrat of soil in October 1994 near Ames, IA.

Species[a]	Emergence 1995	1996	1997	1998	LSD (0.05)
	% of original seed bank				
Velvetleaf	23	6	1	1	6
Common waterhemp	5	7	1	2	2
Woolly cupgrass	40	9	2	0	8
Giant foxtail	30	9	3	0	5
LSD (0.05)	7	NS	NS	0.7	

[a] Velvetleaf, *Abutilon theophrasti;* common waterhemp, *Amaranthus rudis;* woolly cupgrass, *Eriochloa villosa*; giant foxtail, *Setaria faberi.*

in the study were found only in frames where we seeded them.

In autumn 1995, each frame was divided into four equal 22.5- by 30.5-cm sections containing 500 seeds. Sections within each frame were randomly assigned to the years 1995 through 1998. At the time of sampling, steel plates were inserted into the soil to delineate the sections. Each autumn, the soil from the designated section of each frame was completely excavated to a depth of 7.5 cm and replaced with soil from the adjacent area that was not amended with weed seeds. Samples were bagged and stored at 0 C until the seeds were extracted. Seeds were extracted using a flotation/centrifugation method (Buhler and Maxwell 1993). Seeds were enumerated by species, assessed using a pressure test, and placed on moistened filter paper in petri dishes. Dishes were placed in a germinator for 14 d for germination testing followed by tetrazolium testing of the remaining seeds, as described for the initial determination of viability. Seeds that germinated or tested positive to the tetrazolium test were summed to equal viable seeds. To determine seed bank dynamics on a year-to-year basis, the number of seeds remaining each autumn was used as the basis for calculating germination, persistence, and recovery as a percentage of the available seed pool for the year.

Analyses of variance were conducted on all emergence, seed recovery, and viability data prior to converting to percentages. Analyses were conducted on both raw and arcsine-transformed data. Results of the two analyses were similar, so transformation was not necessary. Fisher's protected LSD test ($\alpha = 0.05$) was used for mean separation among species within a year and parameter. Fisher's protected LSD test ($\alpha = 0.05$) was also used for mean separation among years within a species and parameter.

Results and Discussion

Annual Emergence

During the first growing season following seed burial, seedling emergence as a percentage of the original seed bank was 5% for common waterhemp, 23% for velvetleaf, 30% for giant foxtail, and 40% for woolly cupgrass (Table 1). During the second and third years after burial, there were no differences in percent emergence among the four species. By the fourth year, there was no emergence of woolly cupgrass or giant foxtail, whereas emergence of common waterhemp was 2% and velvetleaf 1% of the original seed bank.

In this research, velvetleaf emergence was greatest in the first year after burial and declined to 1% of the original seed bank by the fourth year with cumulative emergence of 31% of the original seed bank. In two experiments using similar methodology as the research reported in this paper, Hartzler et al. (1999) measured 17 to 35% cumulative emergence of velvetleaf over 3 yr. In one experiment, 8% emerged during each of the first 2 yr and 1% emerged during the third year. In a second experiment, total emergence was 35% of the original seed bank and emergence was similar, approximately 12%, during each year of the 3-yr experiment. Webster et al. (1998) measured only 6 to 7.4% cumulative emergence of velvetleaf over the first four growing seasons following seed burial in soil subjected to annual moldboard plowing. Greatest emergence occurred during the second year after burial. Under no-tillage conditions, cumulative emergence ranged from 12.5 to 25%, with the greatest emergence occurring in the first year after burial.

Annual emergence of common waterhemp never exceeded 7% of the original seed bank but continued at significant levels over the 4 yr of the experiment with cumulative emergence of 15%. Hartzler et al. (1999) observed cumulative emergence of 15% over 3 yr with almost all of the emergence occurring during the first 2 yr. In another experiment at the same location in different years, cumulative emergence was 25%, with 3% occurring during the third year. First-year emergence of pigweeds (*Amaranthus* spp.) ranged from 0.2 to 13% and averaged 3.3% over 19 site-years in the north-central United States (Forcella et al. 1997).

Emergence of woolly cupgrass was greater than the other three species during the first year after burial. High emergence for 1 to 2 yr, followed by a rapid decline, was similar to that observed by Hartzler et al. (1999), where up to 69% emergence occurred during the first year after seed burial.

First-year emergence of giant foxtail was less than woolly cupgrass, but the general pattern over years was similar for both species. The temporal pattern of giant foxtail emergence in this study was similar to one of the two experiments of Hartzler et al. (1999), where cumulative emergence over 3 yr was 43% and only 1% emerged during the third year. However, in a second experiment conducted at the same location in different years, there was 9% emergence in the third year. First-year emergence of giant foxtail in the present study was similar to mean first-year emergence in the multiyear, multilocation research of Forcella et al. (1992, 1997).

Long-term emergence studies typically express emergence over years as a percentage of the initial seed bank. Calculating annual seedling emergence based on the pool of seeds that remained in the soil at the beginning of the annual cycle will provide a more realistic assessment of the behavior of those seeds. By determining the residual seed bank at the end of each growing season, we compared the annual fate of seeds as they aged. Percent emergence of velvetleaf was similar (23 to 35%) over the course of the experiment when calculated as a percentage of the seed bank that remained the previous autumn (Figure 1). These values were similar to those previously reported for first-year emergence (Forcella et al. 1997; Hartzler et al. 1999; Webster et al. 1998). Emergence of common waterhemp as a proportion of the previous autumn's seed bank was more variable over years, but fourth-year emergence as a percentage of the seed pre-

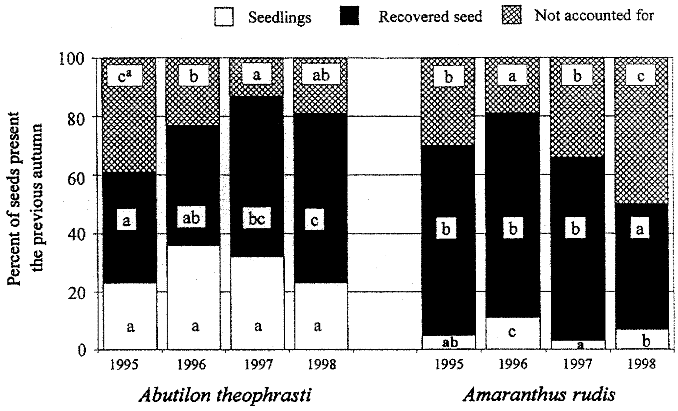

FIGURE 1. Annual fates of velvetleaf (*Abutilon theophrasti*) and common waterhemp (*Amaranthus rudis*) seeds as a percentage of the seed bank the previous autumn. The seed bank was sampled in October each year. Velvetleaf percentages were based on 2,000, 760, 300, and 160 seeds in 1995, 1996, 1997, and 1998, respectively. Common waterhemp percentages were based on 2,000, 1,300, 900, and 560 seeds in 1995, 1996, 1997, and 1998, respectively. [a] Bars within a seed classification and species with the same letter are not significantly different according to Fisher's LSD test ($\alpha = 0.05$).

sent the previous autumn was similar to first-year emergence (Figure 1). Again, all values (3 to 10%) were similar to previous reports of first-year emergence (Forcella et al. 1997; Hartzler et al. 1999). Emergence of woolly cupgrass and giant foxtail as a percentage of the previous autumn's seed bank declined by about 50% the second year compared with first-year emergence (Figure 2). Third-year emergence as a percentage of the remaining seed bank was near 100%, but this is difficult to interpret because of the small quantity of seeds that were present in the soil at that time. However, it is interesting to note the shorter persistence of the residual seed bank of the grass species compared with the broadleaf species. These differences may indicate that the grass species are not as capable of maintaining a small, recalcitrant seed bank as species with hard seed coats such as velvetleaf and common waterhemp (Murdock and Ellis 1992).

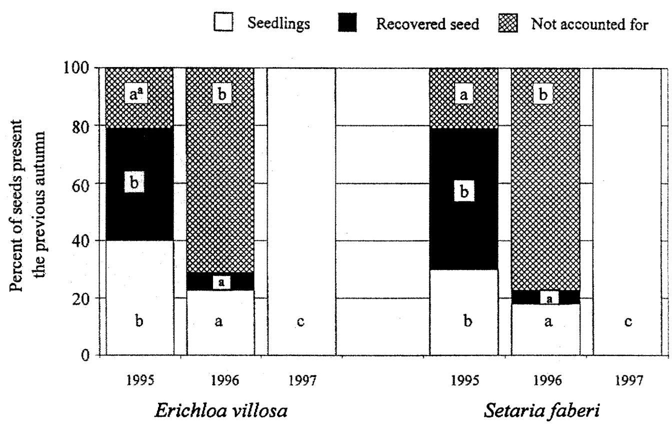

FIGURE 2. Annual fates of woolly cupgrass (*Eriochloa villosa*) and giant foxtail (*Setaria faberi*) seeds as a percentage of the seed bank the previous autumn. The seed bank was sampled in October each year. Woolly cupgrass percentages were based on 2,000, 780, 40, and 0 seeds in 1995, 1996, 1997, and 1998, respectively. Giant foxtail percentages were based on 2,000, 980, 60, and 0 seeds in 1995, 1996, 1997, and 1998, respectively. [a] Bars within a seed classification and species with the same letter are not significantly different according to Fisher's LSD test ($\alpha = 0.05$).

TABLE 2. Recovery of four annual weed species in autumn of each year as a percentage of 2,000 seeds buried in the upper 5 cm of a 0.27-m^2 quadrat of soil in October 1994 near Ames, IA.

	Recovery				
Species[a]	1995	1996	1997	1998	LSD (0.05)
	% of original seed bank				
Velvetleaf	38	15	8	5	3
Common waterhemp	65	45	28	12	7
Woolly cupgrass	39	2	0	0	6
Giant foxtail	49	3	0	0	5
LSD (0.05)	9	4	6	3	

[a] Velvetleaf, *Abutilon theophrasti*; common waterhemp, *Amaranthus rudis*; woolly cupgrass, *Eriochloa villosa*; giant foxtail, *Setaria faberi*.

Seed Recovery and Viability

A greater percentage of the original seed of common waterhemp was recovered than of the other three species in all 4 yr (Table 2). Four years after burial, 12% of the original common waterhemp seed was recovered from the soil compared with 5% of the velvetleaf. Recovery of giant foxtail seed was greater than velvetleaf and woolly cupgrass after 1 yr, but velvetleaf recovery was greater than the two grass species in the three subsequent years. No seed of woolly cupgrass or giant foxtail was recovered after the second year.

Viability of the seeds at the time of burial was 83% for common waterhemp and 93% or more for the other species (Table 3). The viability percentages of the velvetleaf and common waterhemp seed that were recovered were over 70% each year. Viability percentage of recovered velvetleaf seeds was lower after 1 yr of burial than in subsequent years. Viability of recovered common waterhemp seeds after each of the first 3 yr was 71 to 80%, but it increased to 95% after the fourth year. Viability of recovered woolly cupgrass and giant foxtail seeds was less than 20% after 1 yr of burial. Viability of woolly cupgrass increased to 33% after 2 yr, but viability of giant foxtail was similar to the first year at 20%. Although an increase over time in the percentage of the recovered seeds that were viable may seem counterintuitive, the response may have been caused by decay of nonviable seed (Murdock and Ellis 1992). Viable seeds were more resistant to decay than nonviable seeds. Therefore, nonviable seeds disappeared from the seed bank more rapidly than

TABLE 3. Viability of the recovered seeds of four annual weed species after burial in the upper 5 cm of a 0.27-m^2 quadrat of soil in October 1994 near Ames, IA. Samples were collected during October each year.

	Viability					
Species[a]	1994[b]	1995	1996	1997	1998	LSD (0.05)
	% of recovered seed					
Velvetleaf	100	73	95	95	97	18
Common waterhemp	83	80	71	75	95	12
Woolly cupgrass	97	18	33	—[c]	—	8
Giant foxtail	93	15	20	—	—	9
LSD (0.05)	8	4	14	12	NS	

[a] Velvetleaf, *Abutilon theophrasti*; common waterhemp, *Amaranthus rudis*; woolly cupgrass, *Eriochloa villosa*; giant foxtail, *Setaria faberi*.
[b] Seed tested prior to burial.
[c] No seed present.

TABLE 4. Percentage of the original seed bank of four annual weed species that remained viable each autumn (2,000 seeds buried in the upper 5 cm of a 0.27-m^2 quadrat of soil in October 1994 near Ames, IA).

Species[a]	Viability 1995	1996	1997	1998	LSD (0.05)
	% of original seed bank				
Velvetleaf	28	13	6	4	2
Common waterhemp	52	32	21	11	8
Woolly cupgrass	7	1	0	0	3
Giant foxtail	7	0.5	0	0	1
LSD (0.05)	4	7	5	3	

[a] Velvetleaf, *Abutilon theophrasti*; common waterhemp, *Amaranthus rudis*; woolly cupgrass, *Eriochloa villosa*; giant foxtail, *Setaria faberi*.

viable seed, increasing the percentage of the remaining seeds that were viable.

A higher percentage of the original seed bank of common waterhemp remained viable in years 2 through 4 than in any other species, and 11% remained viable after 4 yr of burial (Table 4). A significant portion of the velvetleaf seed bank also remained viable after 4 yr. The percentage of the original seed bank of woolly cupgrass and giant foxtail that remained declined to 7% after 1 yr, to 1% or less after 2 yr, and to 0% after 3 yr of burial.

One of the objectives of this study was to expose seeds to conditions approximating the field while maximizing seed recovery. Annual recovery (annual emergence plus recovered seed as a percentage of the seed bank the previous autumn) varied by species and year. After 1 yr, we accounted for 61% of the velvetleaf (Figure 1), 70% of the common waterhemp, and 79% of both woolly cupgrass and giant foxtail (Figure 2). Annual recovery of velvetleaf increased to 77 to 87% in years 2 through 4 (Figure 1). Annual recovery of common waterhemp between years 1 and 2 was 81%, but declined to 50% by year 4. Annual recovery of woolly cupgrass and giant foxtail declined to 29 and 23%, respectively, between years 1 and 2 (Figure 2). These results indicate that we still were not accounting for a significant portion of the seed added to the soil. Possible fates of these seeds include predation, fatal germination, or decomposition (Kennedy 1999). Other investigators have found that predation (Brust and House 1988) and microbial activity (Kremer 1993) were important mechanisms of seed loss.

Seeds of velvetleaf and common waterhemp were much more persistent than woolly cupgrass and giant foxtail. The persistence of velvetleaf and common waterhemp was expected based on the results of buried seed studies (Burnside et al. 1996), where seed of velvetleaf and tall waterhemp [*Amaranthus tuberculatus* (Moq.) J.D. Sauer] germinated after 17 yr of burial. The rapid disappearance of giant foxtail was somewhat surprising. Burnside et al. (1996) found that green foxtail [*Setaria viridis* (L.) Beauv] and yellow foxtail [*S. lutescens* now *S. pumila* (Poir.) Roem et Schult] persisted up to 17 and 12 yr, respectively, when buried 20 cm deep in sealed capsules. We were unable to find similar information on woolly cupgrass.

Although studies of seeds buried in various types of containers are useful in understanding the potential longevity of weed seeds, they may have limited value in understanding seed fate in agricultural fields. Under typical agricultural conditions, many seeds will remain near the soil surface where they are subjected to conditions more conducive to germination, predation, and degradation than the experimental systems used in most studies of buried seed (Murdock and Ellis 1992). Soil disturbance by tillage and soil-inhabiting organisms may increase soil aeration, scarify seeds, expose seeds to light, or otherwise promote germination. This is supported by Lueschen et al. (1993), who found that after 17 yr with no seed return, soil that had not been tilled still contained 15 to 25% of the original velvetleaf seed, but when moldboard plowing was conducted each year, only 0.8 to 2.5% of the initial seed remained after the same period of time.

The seed bank dynamics of woolly cupgrass and common waterhemp, two weed species of increasing importance in the north-central United States, were distinctly different from each other. However, the behavior of woolly cupgrass was similar to giant foxtail, and common waterhemp was similar to velvetleaf. Emergence of common waterhemp was less than the other species during the first year, but was greatest by the fourth year. Delayed and prolonged emergence of common waterhemp has been attributed to its survival under current weed management systems that include fewer herbicides with soil residual and less postplanting cultivation (Hager et al. 1997; Hartzler et al. 1999). Results of this research indicate that a long-lived seed bank also contributes to the success of common waterhemp as it has for velvetleaf.

Woolly cupgrass had been characterized as having continuous germination throughout the growing season and a persistent seed bank (Owen 1990). In this study, woolly cupgrass had the greatest cumulative emergence during the first 3 yr, but the seed bank declined rapidly and no seed was recovered 3 yr after burial. The rapid and high percentage of emergence of woolly cupgrass seed may contribute to the poor control provided by soil-applied herbicides (Owen et al. 1993; Schuh and Harvey 1991), because high weed densities have been shown to decrease herbicide effectiveness (Doub et al. 1988; Hartzler and Roth 1993). However, the rapid decline of the seed bank may make management practices that eliminate seed production, such as rotation to perennial forage crops, grazing, or timely tillage, effective in depleting the seed bank. Similar practices should also be effective for giant foxtail. In addition, the persistence of these two species is highly dependent on regular seed deposition to the soil.

Based on the results of this research, it should be easier to manage woolly cupgrass and giant foxtail through seed bank depletion than velvetleaf or common waterhemp. Although velvetleaf is often considered one of the longest lived seeds under agricultural conditions (Lueschen et al. 1993), common waterhemp was slightly more persistent in this research. These results demonstrate that once common waterhemp and velvetleaf become established, they will be difficult to eliminate, regardless of the level of weed control.

Acknowledgments

We thank Keith Kohler, Lowell Sandell, and several undergraduate students for assistance. This manuscript is a joint contribution of the U.S. Department of Agriculture, Agricultural Research Service, National Soil Tilth Laboratory, and Iowa State University and was partially supported by a grant from the Leopold Center for Sustainable Agriculture.

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Received April 6, 2000, and approved November 28, 2000.