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Cutleaf Teasel (*Dipsacus laciniatus*): Seed Development and Persistence

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Cutleaf teasel (*Dipsacus laciniatus*) is an exotic, invasive plant that infests roadsides and other minimally disturbed areas. Plants in established stands appear to be a mixture of rapidly growing rosettes and rosettes with developing reproductive structures. Research that is focused on seed characteristics and their contribution to the spread of plants may be a key to precluding spread of cutleaf teasel in the field. Field studies were conducted to determine the viability and germinability of seeds after flowering, seedling emergence patterns, and seed persistence. Flowering (60% of anthesis) was observed under natural conditions on July 24, 2004, and July 16, 2005. Seeds harvested 12 d after flowering exhibited 43% viability and 2.5% germination. Seed weight and viability were greatest 30 d after flowering, but germination was $<$ 32%. Seedling emergence was monitored over a 12-mo period with the greatest emergence in April and October with 33% of seeds germinating. Seed persistence was evaluated over a 3-yr period under field conditions. Up to 84% of the germinated seeds had germinated during the first year, with 6% of seeds remaining viable after 3 yr. Although seed persistence was relatively short, the rapid development of seeds following flowering as well as seedling emergence in both fall and spring suggests management practices are needed throughout the year to restrict reestablishment spread of cutleaf teasel.

Nomenclature: Cutleaf teasel, *Dipsacus laciniatus* L.

Key words: Capitulum, invasive, roadside, emergence, viability.

Cutleaf teasel (*Dipsacus laciniatus* L.) is an invasive plant introduced into the New England states from France in the 18th century for separating wool strands in the textile industry (Terres and Ratcliffe 1979). Following mechanization, teasel was abandoned as a crop and spread, principally in roadside habitats and physically undisturbed environments such as railroad rights-of-way, cemeteries, natural parks, and conservation areas (Solecki 1993). In these environments, teasel excludes native species, disrupts traffic visibility, and reduces water infiltration.

Plant dispersal in the United States has followed the medians of interstate highways. Solecki (1993) stated that construction of the highway system facilitated the spread of teasel. Currently, cutleaf teasel is present in 17 states, especially in the northern part of the United States (USDA 2008). Furthermore, four states have categorized cutleaf teasel as a noxious weed: Colorado, Iowa, Oregon, and Missouri. There are three species of *Dipsacus* present in the United States: *Dipsacus fullonum* L. (Fuller's teasel), *D. laciniatus*, and *Dipsacus sativus* (L.) Honck. (Indian teasel) (Ferguson 1965). Cutleaf teasel is distinguished from the others by white flowers, deeply lobed or laciniate leaves, and short involucral bracts beneath flowers (Solecki 1993).

The invasiveness of cutleaf teasel is facilitated by its lack of natural enemies, adaptivity to a wide variety of habitats, competitiveness with native species, and prolific seed production. Rector et al. (2006) described some possible biological control candidates, most of which are not available in the United States. With a deep root system teasel thrives in low-fertility soils, thereby outcompeting native species (Werner 1975). Bentivegna (2006) reported that a rapid rate of growth and a high leaf-area index are the main features that result in the highly competitive nature of this species. In addition, individual cutleaf teasel plants produce from 3 to 56 capitula (hereafter, heads) and a total 1,300 to 33,500 seeds (achenes), depending upon the density of teasel plants (Bentivegna 2006).

Cutleaf teasel is a biennial plant that grows as a rosette the first year. Rosettes can reach 117 cm (46 in) in diameter and have a compact arrangement of leaves that cover three times the area of the plant (Bentivegna 2006). This high leaf area limits light available to other plants, resulting in monoculture patches. In the second year, plants produce stems up to 2 m in height. Teasel is primarily a

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Interpretive Summary

Cutleaf teasel is an exotic biennial plant in the northeastern United States. Reproduction is only by seed. Studies of seed viability after flowering, germination, and persistence showed that cutleaf teasel produced viable seeds 12 d after flowering, and completed maturation in 30 d. Emergence was concentrated in 2 mo, April and October, and 6.1% of the seeds remained viable in the seed bank after 3 yr. Results suggest that herbicides should be applied after the two peaks of emergence and repeated for at least 3 yr. Mowing cutleaf teasel plants must be done before flowering to prevent dispersal of viable seeds. Monitoring seed production and seed bank depletion will help to prevent or reduce cutleaf teasel infestations.

cross-pollinated species, with an estimated 4% self-fertilization (Werner 1975).

Management of cutleaf teasel involves hand removal, herbicides, and mowing. In small areas, the removal of plants can be accomplished by digging (Glass 1991; Solecki 1993). Postemergence herbicides can be effective on established populations, but information is limited regarding the optimal time of application (Solecki 1993). Bentivegna and Smeda (2008) identified numerous growth-regulator and sulfonylurea herbicides that control teasel plants prior to bolting. Mowing is considered by some as a method of teasel management, but by others as a method to spread populations. Caylor (1998) reported that mowing teasel did not reduce infestations, but only delayed seed production. The time of mowing is critical for affecting seed production. Cheesman (1998) reported that plants mowed early in the summer later regrew and produced seeds. On the other hand, mowing reduced seed production if implemented at the onset of flowering. Mowing in the fall disperses mature seeds.

Development of timely control strategies for cutleaf teasel requires a better understanding of seed development following flowering, seed emergence, and persistence of seed in the soil. Because reproduction is only by seed, the optimal time for herbicide application or mowing plants requires knowledge of seed development. The objectives of this research were to determine the viability of cutleaf teasel seeds after flowering, the pattern of seedling emergence, and persistence of seeds in soil.

Materials and Methods

Germination and Viability of Seed after Flowering. Studies were conducted at two sites located in the state of Missouri, one at the Bradford Research and Extension Center (hereafter Bradford), the other 5 km (3.1 mi) to the north of Columbia on Highway 63 (hereafter Highway 63). The Bradford site was an abandoned pasture with a mixture of tall fescue (*Festuca arundinacea* Schreb.) and weedy species. Soil at Bradford was a Mexico silt loam (fine, montmorillonitic, mesic Udollic Ochraqualfs) with 2.9% organic matter and a pH of 5.9 (NRCS 2008). The Highway 63 site also contained tall fescue. Soil at Highway 63 was a Keswick silt loam (fine, smectitic, mesic Aquertic Chromic Hapludalfs) with 2.1% organic matter and a pH of 7.5 (NRCS 2008).

At each site, the primary head (defined as the largest and first capitulum to flower, formed on the central stem of plants), with 60% anthesis, was tagged on 120 naturally occurring plants on July 24, 2004, and July 16, 2005. One week after anthesis, each primary head was covered with a semitransparent paper bag[1] (5 by 25 by 18 cm) to prevent seeds from shattering. At each location, eight primary heads were collected every 6 d following tagging over a period of 3 mo. Air temperature was measured at the time of flowering through final seed harvest. For each head harvested, 60 seeds were sampled at random, separated into two groups of 30 seeds each, weighed, and stored at either room temperature (18 to 22 C [64 to 72 F]) or refrigerated (4 C) for 7 mo. Following storage, seeds were placed in Fisher petri dishes[2] (60 by 15 mm) inside a growth chamber at high relative humidity ($\geq$ 75%) and alternating temperatures (15 C for 8 hr and 21 C for 16 hr). Seeds were considered germinated when the radicle reached 0.5 mm in length. For seeds originating from a particular location that did not germinate following storage, a viability test was conducted by placing them in a tetrazolium salt solution of 0.2% wt/v for 2 hr at 33 C (Copeland 1976). Seeds were examined and considered live if the embryo turned red. Seed germination results were grouped into 1-mo units by averaging the results for harvest dates within a particular month after flowering. For example, the first five harvests were used to obtain the mean of the first month, and so forth. Experimental design was completely randomized, and data were transformed by arcsine of the square root of the proportion to adjust data to normal distribution (Snedecor and Cochran 1956).

Emergence Patterns. Experiments were established at Bradford on September 11, 2003, and at Bradford and the Horticulture and Agroforestry Center (hereafter New Franklin) near New Franklin, MO, on September 15, 2004. Soil at New Franklin was a Menfro silt loam (fine-silty, mixed, superactive, mesic Typic Hapludalfs) with a pH of 5.4 and 2.6% organic matter (NRCS 2008). Six 1.5-m^2 plots, located in a line at 40-cm intervals, were flagged at a site known to be free of teasel at the beginning of each experiment and maintained for 1 yr. In each plot, 1,500 seeds were planted at a depth of 1 cm and emergence of cutleaf teasel was recorded monthly by counting individual seedlings. Seedlings were considered emerged when cotyledons were fully expanded. After counting, seedlings were killed from the plot with a broadcast application of

Table 1. Mean seed weight, viability, and germination of cutleaf teasel from Bradford and Highway 63 (central Missouri) following storage under room temperature and cold conditions in 2004 and 2005.

Year	Storage conditions	Sample date	Days after flowering	Bradford			Highway		
				Weight[a]	Viability	Germination	Weight[a]	Viability	Germination
				g	%		g	%	
2004	Room	07/30	6	1.12 d[b]	0 d	0 b[b]	1.17 d[b]	0 d	0 c[b]
		08/05	12	1.88 c	44.8 c	2.5 b	1.70 c	27.9 c	1.7 bc
		08/11	18	2.34 b	70.7 b	26.7 a	2.49 b	71 b	3.4 b
		08/17	24	3.16 a	88.6 a	14.2 a	3.04 a	85.5 a	12.9 a
	Cold	07/30	6	1.15 d	0 c	0 b	1.20 d	0 c	0 b
		08/05	12	2.23 c	0 c	0 b	2.01 c	0.42 c	0 b
		08/11	18	2.78 b	67.5 b	18.6 a	3.03 b	71.7 b	19.2 a
		08/17	24	3.67 a	94.9 a	22.9 a	3.61 a	94.4 a	15.4 a
2005	Room	07/22	6	1.59 d	0 d	0 b	1.67 d	0 c	0 c
		07/28	12	2.29 c	11.9 c	2.1 b	2.05 c	11.5 b	1.7 bc
		08/03	18	3.04 b	90 b	0.4 b	2.85 b	80.4 a	2.1 b
		08/09	24	3.36 a	93.1 a	30.8 a	3.23 a	77.9 a	17.1 a
	Cold	07/22	6	1.57 d	0 d	0 b	1.71 c	0 c	0 a
		07/28	12	2.82 c	33.6 c	0.4 b	2.35 b	0 c	0 a
		08/03	18	3.57 b	82.7 b	1.3 a	3.13 a	76.8 b	0.4 a
		08/09	24	3.99 a	86.7 a	0.4 b	3.50 a	80.1 a	0.4 a

[a] Weight of 1,000 seeds.

[b] Means within storage condition for a given location and year with the same letter were not different according to Fisher's Protected LSD test at $P \leq 0.05$.

paraquat at 1.17 kg ai ha^{-1} (1.04 lb ai ac^{-1}) plus 0.125% v/v nonionic surfactant. Soil temperature data were recorded with a StowAway® TidbiT® temperature logger[3] at a depth of 2 cm. Precipitation was measured for the duration of study from a weather station within 0.5 km of the site.

Seed Persistence. One hundred and fifty seeds, with a mean viability of 99.5%, were placed in buried polypropylene pots (10 by 18 cm) under field conditions at two locations (Bradford and New Franklin) on November 10, 2004. In each pot, polyethylene mesh was buried at 1 cm depth to prevent the seeds from falling any deeper. The seeds were them mixed with soil from each location and the mixture was placed on the mesh to simulate the conditions of the seeds fallen under natural field conditions. In the middle of spring, summer, and fall (May 5, August 5, and November 5) from 2005 to 2007, five pots at each location were collected at random. Seeds were washed and stored at 4 C. Seed viability was estimated using the tetrazolium test as described above. During the course of the study, seedling emergence (described above) was monitored. Final data for seeds were divided into three categories: germinated, viable, and lost or dead. The latter category took into consideration all seeds that could not be recovered and those with a negative tetrazolium test.

Data from the three studies conducted were subjected to analysis of variance using SAS statistical software.[4] The test of normality for Shapiro-Wilk and analysis of residuals for equal variance were determined using PROC UNIVARIATE in SAS with a probability of $P \leq 0.05$. Means were separated using Fisher's Protected LSD test at $P \leq 0.05$ (Steel and Torrie 1980).

Results and Discussion

Germination and Viability after Flowering. Cutleaf teasel flowering began on July 24, 2004, and July 16, 2005. More than 90% of flowering occurred in the first 45 d after initial flowering of the primary head. The primary head completed flowering within 4 d after initial flowering. Seed weight increased on average 253% from 6 to 24 d after flowering (Table 1). Seed weight reached a maximum 30 d after flowering in 2004 and 24 days after flowering in 2005 (Figure 1). In both years, germinable seed were initially detected 12 d after flowering (Table 1). Seed viability reached 71% in 2004 and 90% in 2005, 18 d after flowering. Collected seeds resulted in 75% viable by 30 d after flowering (Figure 2), and maximum viability changed little thereafter. Storage conditions following seed harvest did not influence seed viability (Figure 2).

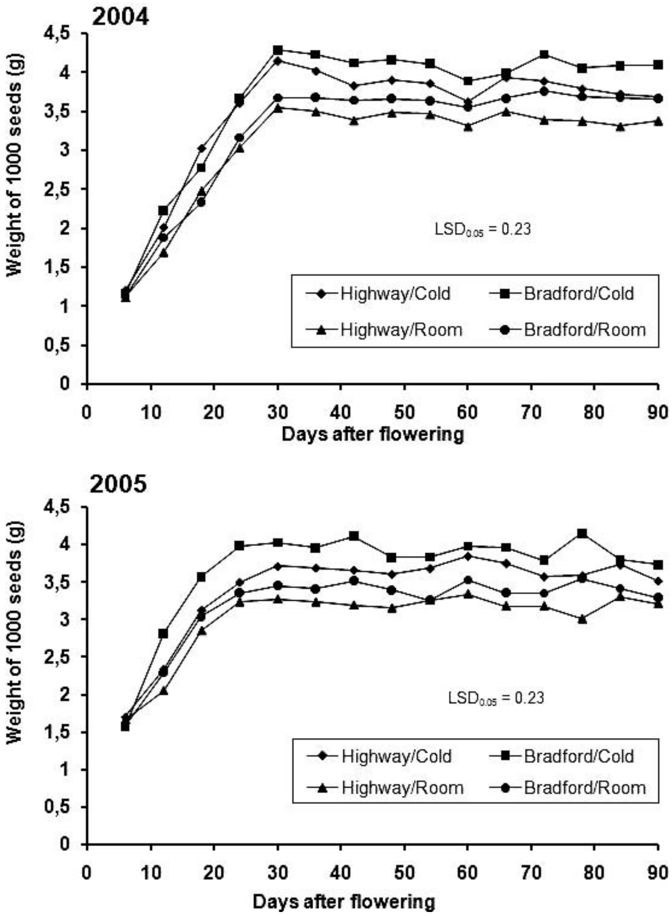

Figure 1. Cutleaf teasel seed weight following flowering. Seeds stored at room temperature and in cold conditions following harvest in 2004 and 2005 for two locations in central Missouri: Bradford and Highway 63. Means separated by Fisher's Protected LSD test at $P \leq 0.05$.

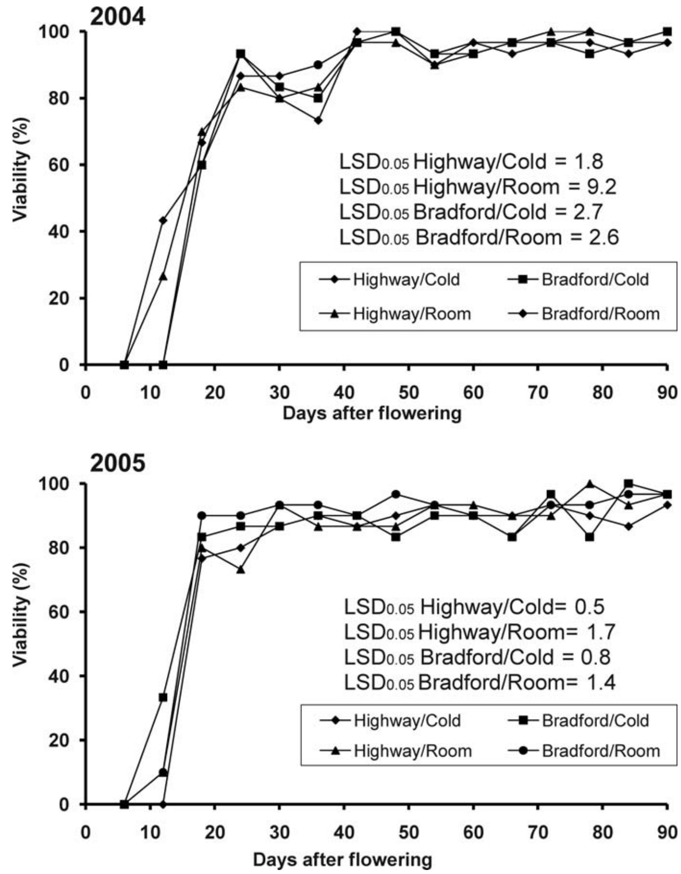

Figure 2. Cutleaf teasel seed viability at different periods after flowering. Seeds stored at room and in cold conditions from Missouri samples harvested in 2004 and 2005 for Bradford and Highway 63 locations. Means separated by Fisher's Protected LSD test at $P \leq 0.05$.

Seed germination was monitored for up to 90 d after flowering (Figure 3). Germination of seeds stored at room temperature was higher than seeds stored at cooler temperatures, which suggests that cutleaf teasel did not require a stratification period (Werner 1975). Maximum germination occurred for Bradford seeds that were stored at room temperature 2 mo after flowering in 2004 (24%); maximum germination was 20% 3 mo after flowering in 2005 for the same location and storage conditions (Figure 3). During flowering, air temperatures were higher in 2005 than in 2004 with maximum daily mean temperature of 31 and 29 C, respectively. This daily mean temperature difference (up to 11.5 C) was greatest at the time of flowering, which may have delayed seed maturation and germination of teasel (Figure 3B). In 2004, germination increased during the 3 mo after flowering for seeds stored at room conditions compared with cold conditions at Bradford, but not for Highway 63 seeds (Figure 3 2004). In contrast, germination was higher in seeds stored at room conditions compared with cold conditions in 2005 (Figure 3 2005). Overall seed germination was lower than expected, given seed viability rates exceeding 80% (Figure 2).

Viable cutleaf teasel seeds were detected in as few as 12 d after flowering, and increased rapidly for seeds harvested up to 30 d after initial flowering. This is important as it relates to the use of mowing following the onset of teasel flowering. Due to the short period between flowering and production of viable seeds, mowing of teasels must be done prior to flowering to avoid seed production in stands of cutleaf teasel plants. Solecki (1989) reported that viable seeds were produced from teasel heads that had been cut before flowering was complete.

Emergence Patterns. Cutleaf teasel emergence was concentrated during two periods of the year (Figures 4A and 4B). Emergence in April and October accounted for > 95% of all seeds that germinated. Maximum emergence of cutleaf teasel was 21% in October of 2004 (Figure 4B). After 1 yr of monitoring emergence, cumulative emergence

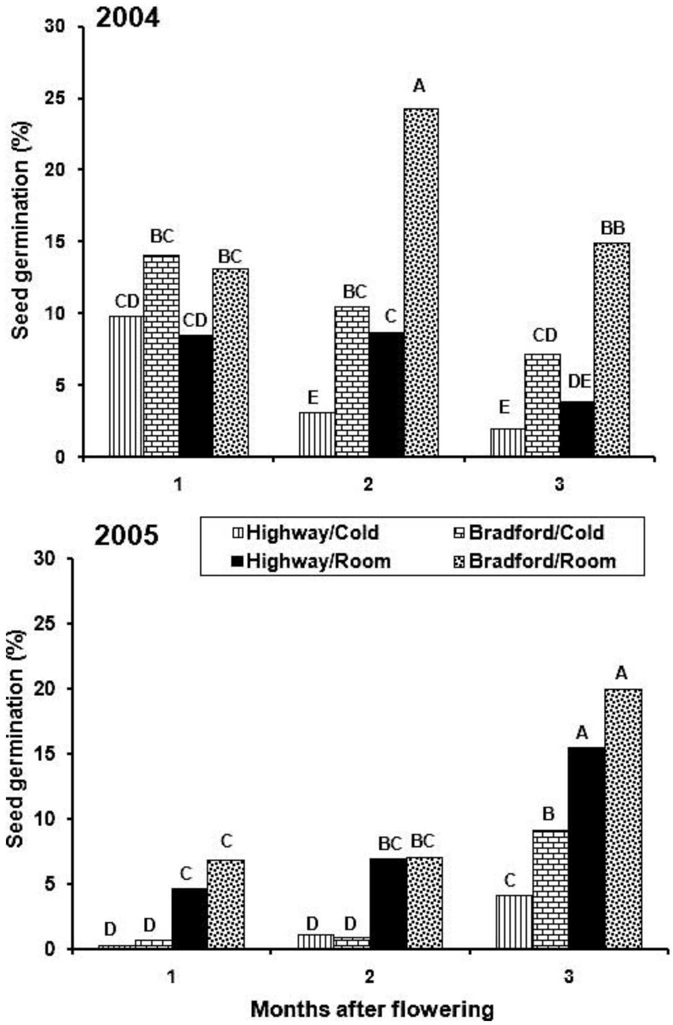

Figure 3. Mean cumulative germination of cutleaf teasel harvested at various times following flowering. Seeds were harvested in 2004 and 2005 from two locations (Bradford and Highway 63) in central Missouri, and stored under cold (4 C) and room temperature (18 to 22 C) conditions. Means with the same letter were not different according to Fisher's Protected LSD test at P ≤ 0.05.

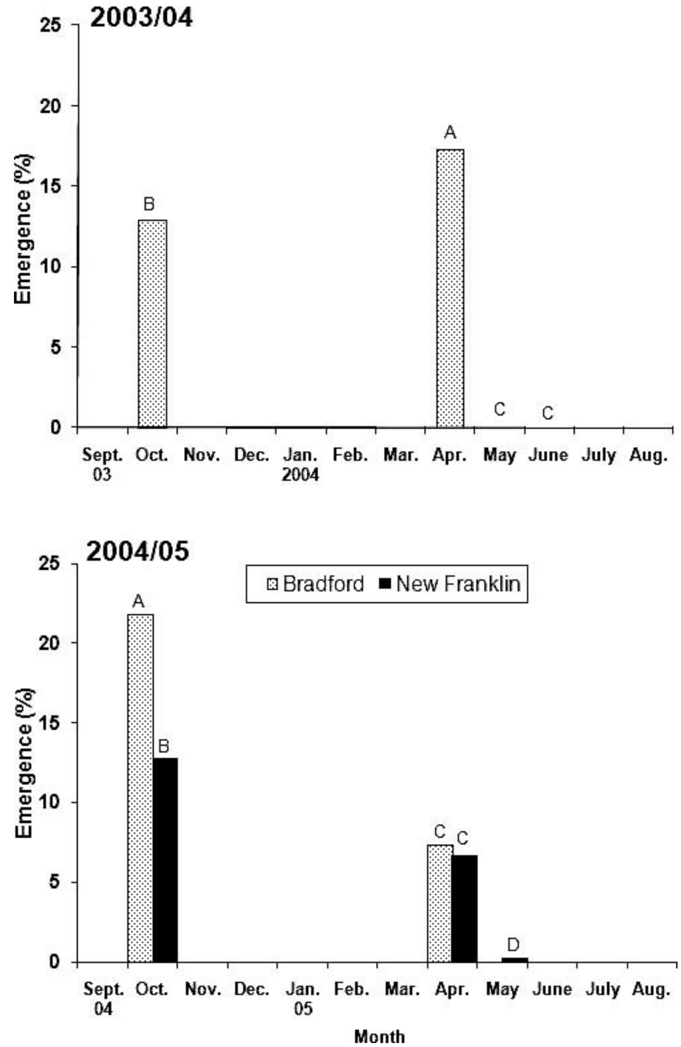

Figure 4. Cutleaf teasel emergence in central Missouri from 2003 to 2004 at Bradford and 2004 to 2005 at Bradford and New Franklin. Letters within years were not statistically different according to Fisher Protected LSD test at P ≤ 0.05.

was less than 0.1% of the remaining seed. Soil temperatures during October and April ranged from 5 to 20 C and 4 to 20 C, respectively. Average precipitation throughout locations was 89 and 73 mm for October and April, respectively. The lack of emergence in November to March and July to September suggests cutleaf teasel needs a defined temperature and available water for emergence.

Similar to this study, Roberts (1986) in the United Kingdom reported two periods of emergence for *D. sylvestris* (Huds.): April (48%) and September (17%). Werner (1975) showed that *D. sylvestris* had high emergence rates in April and September in Michigan. According to Hubbell and Werner (1979), most of *D. sylvestris* emergence occurs late in the spring following seed production, and a small percentage remains dormant. In addition, Caswell and Werner (1978) showed that only a few seedlings emerged in the second year.

Seed Persistence. The dynamics of cutleaf teasel in the seed bank are shown in Figure 5. There was no interaction between location and harvest time; therefore, data were pooled over locations. Seedling emergence was 13.3% in 2005, with no statistical difference thereafter (Figure 5). Maximum seed germination was 15.9%. Seed viability decreased in the first year from 98 to 20%. In spring 2006, seed viability decreased to 11% with no statistical change thereafter. After 3 yr, only 6.1% of seeds remained viable (Figure 5). The death or loss of teasel accounted for approximately 70% after 1 yr. There was no significant change in the death or loss of seeds after the first year.

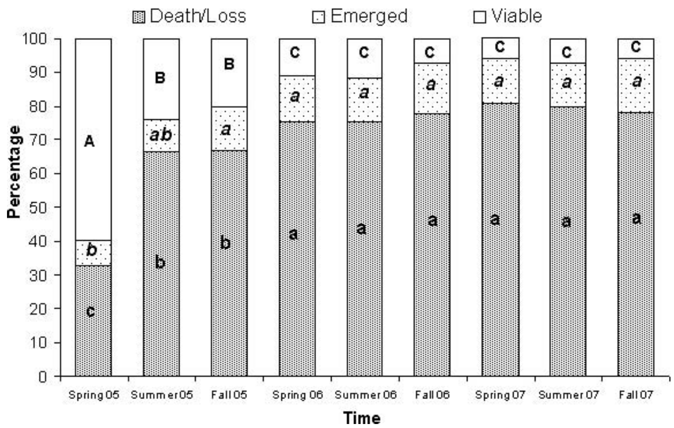

Figure 5. Cumulative seed germination, viability, and death or loss of cutleaf teasel collected over a period of 3 yr. Data were combined over two locations in central Missouri: New Franklin and Bradford. Means with the same letter inside each variable were not different according to Fisher's Protected LSD test at $P \leq 0.05$.

Cutleaf teasel seedling emergence was greatest in the first year following production; other authors reported 4.8 and 2.2% of seed emergence of *D. sylvestris* in the third and fourth years after sowing, respectively. Roberts (1986) concluded that *D. sylvestris* was relatively persistent at Warwick, UK. Conversely, Werner (1977) reported that teasel seeds were considered dead 2 yr after sowing under natural conditions in Michigan.

The dynamics of teasel seed viability after flowering, emergence patterns, and seed persistence indicate that management practices for infested areas must be continuous for up to 3 yr after initial seed production. Seedling emergence in the fall and spring indicate that postemergence herbicide applications at the beginning of May (spring) and November (fall) should prevent cutleaf teasel seedling establishment. Because teasel actively grows late into the fall, application of nonselective herbicides at that time may result in reduced damage to dormant grasses (Missouri Vegetation Management Manual 1997).

With viable seeds produced just 12 d after flowering, there is a brief period when mowing could be effective. Indeed, the lack of natural techniques for seed dispersal suggests that mowing is likely the cause for new infestation sites. Solecki (1993) claimed that residual plant resources allowed the formation of viable teasel seeds following cutting with a sickle-bar mower after the flowering period. If plants were mowed 24 d after flowering, little or no regrowth of plants was observed, but many mature seeds were spread.

We conclude that mowing teasel has to be done prior to flowering and herbicides should be applied after the two peaks of emergence. Short durations of intensive management (mechanical or chemical control) can greatly reduce cutleaf teasel infestation; however, prolonged management must be done over at least 3 yr to deplete the cutleaf teasel seed bank. One survivor plant per square meter after control measures have been applied can produce more than 33,500 seeds (Bentivegna 2006), which ensures a large number of seedlings to sustain a monoculture population.

Sources of Materials

[1] Lawson Bags, 480 Central Ave., P.O. Box 577, Northfield, IL 60093.

[2] Fisher Scientific, 200 Park Lane Dr., Pittburgh, PA 15275-9943.

[3] Onset Computer Corporation, 470 MacArthur Blvd., Boure, MA 02532.

[4] SAS version 9.1, SAS Institute Inc., Cary, NC 27513.

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