Depletion of an Artificial Weed Seed Bank during the Dormant Period via Heating and Subsequent Chilling of Soil

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Additional index words. nonchemical weed control, johnsongrass, *Sorghum halepense*, hemp sesbane, *Sesbania exaltata*, barnyardgrass, *Echinochloa crus-galli*

Abstract. Depletion of the weed seed bank by stimulating germination during winter months and subsequently exposing the seedlings to adverse air temperatures is a possible means of controlling weeds in small-scale horticultural operations. Johnsongrass [*Sorghum halepense* (L.) Pers.], hemp sesbania [*Sesbania exaltata* (Raf.) Rydb. ex A.W. Hill], and barnyardgrass [*Echinochloa crus-galli* (L.) Beauv.] were seeded in soil trays and maintained for 4 days at 4 or –12 °C, then heated to 32 °C for 4 days using electric heating pads. Germination percentages, after heating soils, were: 55% and 70% for hemp sesbania, 82% and 72% for barnyardgrass, and 45% and 55% for johnsongrass, respectively; for seeds kept at –12 and 4 °C, respectively. Subsequent exposure of seedlings to –12 °C for 7 days killed all seedlings, while exposure to 4 °C killed only 18% to 28%. The temperature regimes of –12 °C for 4 days, and 32 °C for 4 days followed by –12 °C killed 95%, 78%, and 68% of the johnsongrass, hemp sesbania, and barnyardgrass, respectively.

Preventive measures to control weeds before crop seeding or emergence are of particular interest to growers. Although weed life cycles have been exploited historically in weed management strategies, Bhowmik (1997) and Norris (1997) have recently stressed the importance of seed biology in weed management. Bhowmik emphasized the development of environmentally safe weed management systems, while Norris, based on a survey, predicted an increase in importance of weed seed dynamics in the future.

The top 10–15 cm of soil contains viable seeds, which germinate under suitable conditions, or after breaking dormancy. Seed bank sizes have been estimated at ≈1 million seeds/m² under dense infestations (Fenner, 1985). Of the 2 million seeds produced by a single horseweed [*Conyza canadensis* (L.) Cronq.] plant in a no-till site, ≈80% of the total germinable seeds were found within the top 2 cm of soil (Bhowmik and Bekech, 1993).

The soil seed bank is the primary source of new infestations of annual weeds (Cavers, 1983; Hume and Archibald, 1986). The vegetative growth phase of weeds often coincides with that of annual crops. Primary and secondary tillage are used to deplete the weed seed bank prior to crop planting (Ross and Lembi, 1999). Other nonchemical techniques to deplete the weed seed bank have yet to be thoroughly investigated. King and Oliver (1994) increased the germination percentage of large crabgrass [*Digitaria sanguinalis* (L.) Scop.] seed by elevating the soil temperature from 15 to 25 °C, and johnsongrass seed germination increased by 20% to 30% when the temperature was raised from 10 to 28 °C (Huang and Hsiao, 1987).

We propose a novel method of weed control by artificially heating a seedbed during winter months to stimulate weed seed germination and then allowing the temperature to fall to its original level. If this technique is effective, it may be applicable for weed management in small-scale commercial operations or home gardens.

The objectives of this study were to determine: 1) the effect of heating an artificial seed bank maintained at cold temperatures on seed germination; and 2) the effect of subsequent chilling on seedling survival.

Materials and Methods

All weed seeds used in the study were obtained from a commercial seed company (Valley Seeds, Fresno, Calif.), and were stored in a refrigerator at 4 °C prior to initiation of the study. Minimum germination of weed

species was ≥90% based on petri-dish germination tests. Galvanized trays (55 × 40 cm, 12 cm deep) were filled with moist soil from the upper 30 cm of a Candler fine sand (hyperthermic, uncoated Typic Quartzipsamment; organic matter content 1.2%, pH 6.3). Soil moisture was brought to 22% (dry weight basis) by adding known volumes of water per unit volume of sand. Fifty seeds each of johnsongrass, hemp sesbania, and barnyardgrass were placed in six rows on either the soil surface or at 2.5 cm depth in each tray.

Expt. 1. The effect of seed exposure to low temperatures on subsequent germination was determined in a preliminary study. Seeded trays were transferred either to 4 or –12 °C, respectively, or to a greenhouse (32 °C day/25 °C night). Cold room-treated trays were transferred to the greenhouse 7 d later and seedling counts were recorded upon germination.

Expt. 2. For the main experiment, seeded trays were held in the greenhouse (control, 32 °C day/25 °C night), or at 4 or –12 °C. In each cold room, the trays were subjected to three successive temperature regimes. In the first regime, the soil temperature at a depth of 2.5 cm was allowed to equilibrate to the ambient temperature (4 or –12 °C), and the trays were monitored for germination for an additional 4 d. After recording germination counts, if any, electric heating pads (Low Watt Propagation Heating Mat; Olson Products, Medina, Ohio) were placed directly on top of the trays, after ensuring proper contact with the soil surface. The heating pad thermocouple sensor was placed at a depth of 2.5 cm, and was calibrated to maintain a soil temperature of 32 °C at this depth. A 1-cm-thick insulating material, made of polyisocyanurate foam with aluminum foil on both sides (Tuff-R insulating sheathing; The Celotex Corp., Fremont, Calif.), was placed over the heating pad to minimize convective heat loss. The heating pads were removed after a period of 4 d and germination counts were recorded for each seeding depth, in situ. Following heating, the trays remained in the cold rooms for an additional 7 d.

At the end of the 7-d period, trays were transferred to the greenhouse, irrigated, and seedling survival was quantified by counting actively growing seedlings 1 week later. Trays were irrigated to field capacity on a daily basis, and counted seedlings were removed by hand. Trays were maintained in the greenhouse for an additional 2-week period to allow germination of additional seeds. Weed counts in control trays were taken at the same time intervals as temperature treatments. The two counts (1 and 3 weeks) were added and the sum was divided by the total that had germinated in trays maintained continuously in the greenhouse. Germination data were expressed as a percentage of the control.

All treatments were replicated four times in a randomized complete-block design. Data were subjected to analysis of variance (ANOVA) and treatment means separated by least significant difference (LSD) at $P \leq 0.05$. The study was repeated and data from the two

Received for publication 17 May 1999. Accepted for publication 16 Feb. 2000. Florida Agricultural Experiment Station Journal Series No. R-06213. The cost of publishing this paper was defrayed in part by the payment of page charges. Under postal regulations, this paper therefore must be hereby marked *advertisement* solely to indicate this fact.

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studies were pooled after performing a test of homogeneity of variance.

Results and Discussion

Expt. 1. Exposure of weed seeds to 4 or -12°C for 7 d, followed by transfer to greenhouse ($32/25^{\circ}\text{C}$) reduced subsequent germination percentage of hemp sesbania and johnsongrass, relative to that of control seeds maintained in the greenhouse (Table 1). However, germination percentage of barnyardgrass was not reduced. This may indicate that cold treatment of hemp sesbania and johnsongrass seed induced them into secondary dormancy. Also, some seeds may have been killed as a result of the cold treatment. We did not further investigate these possibilities since they were beyond the scope of experimental objectives. The effects of high and low temperatures on secondary dormancy induction in weed seeds are discussed by other researchers (Dubey and Mall, 1972; Fischer et al., 1982; Twentyman, 1974).

Expt. 2. Seeds of all species exposed to 4 or -12°C for 96 h failed to germinate under cold room conditions (data not shown). Although some seeds on the soil surface showed signs of germination under greenhouse conditions, $>90\%$ of the seedlings failed to become established (data not shown). This may be attributed to lack of sufficient uptake of water from the surface layer because of the absence of a well-developed root system.

Heating soils to 32°C for 96 h in the cold room resulted in germination of the buried seeds (Table 2). No statistical differences were observed in seedling emergence at 4 vs. -12°C . Emergence following heat treatment for seeds held at 4 and -12°C was 70% and 55% of the control for hemp sesbania, 72% and 82% for barnyardgrass, and 55% and 45% for johnsongrass, respectively. The effects of temperature on germination are well-established (Devlin and Witham, 1983; King and Oliver, 1994; Probert and Black, 1994).

Heating also caused the seeds on the soil surface to germinate, but further growth was retarded. When the heating pads were removed, all seedlings appeared to be etiolated, because of the presence of the opaque heating pad and the insulating material.

After an additional 96 h of cold treatment, all seedlings exposed to -12°C were killed (Table 2). Although the seedlings exposed to 4°C were still alive, growth was minimal. Thus 4°C was too low for rapid growth, but

not lethal. These results were more distinct after the seedlings were transferred to the greenhouse, where seedlings placed in the cold room at -12°C failed to grow, while those kept at 4°C developed some green pigmentation after 2–3 d.

Exposure to 4°C resulted in 21% control of hemp sesbania, 18% control of barnyardgrass, and 28% control of johnsongrass from a depth of 2.5 cm. Greenhouse conditions provided adequate sunlight for the etiolated seedlings to develop pigmentation. Death of some seedlings from this treatment was perhaps due to their poor adaptability to cold stress.

Some seeds of all three species subjected to -12°C were viable after the two successive cold treatments (Table 3). About 20%, 30%, and 5% of hemp sesbania, barnyardgrass, and johnsongrass seeds, respectively, failed to germinate following artificial heating. Thus, either the duration of artificial heating was inadequate or physiological or environmental thresholds necessary for seed germination were

not attained. Total germination percentages for trays kept in the greenhouse throughout the study were 82%, 102%, and 88%, for hemp sesbania, barnyardgrass, and johnsongrass, respectively (Table 3). We speculate that total germination percentage of barnyardgrass seeds exceeding 100% was a result of counting regenerated seedlings, which may have been partially hand-weeded after initial counts.

Control of germinated seedlings as a result of heating, followed by chilling to -12°C , was greatest with johnsongrass (95%) followed by hemp sesbania (78%), and barnyardgrass (68%) (Table 3). Depending upon location and the severity of winter climatic conditions, the topsoil or potting media containing weed seeds experiences temperatures unfavorable for seed germination. Elevating the temperature, as simulated in this laboratory study, promoted seed germination (Table 2). The heterogeneous population of the soil seed bank, differences in seed dormancy, and differences in early-season weather make weed control difficult for single-

Table 1. Effect of a 7-d temperature treatment on subsequent weed seed germination within 3 weeks after transfer to a greenhouse (32°C day/ 25°C night). Expt. 1.

Temperature regime	Species		
	Hemp sesbania	Barnyardgrass	Johnsongrass
	Emergence (%)		
$4^{\circ}\text{C} \rightarrow 32/25^{\circ}\text{C}$	76	92	64
$-12^{\circ}\text{C} \rightarrow 32/25^{\circ}\text{C}$	70	90	58
$32/25^{\circ}\text{C}$ (Control)	94	96	80
LSD ($P \leq 0.05$)	8	NS	14

NS=Nonsignificant.

Table 2. Seedlings emerged under cold room conditions after concomitant heat treatment (32°C for 96 h) or in a greenhouse, of a soil seeded at 2.5 cm depth, and seedlings killed after subsequent chilling for 7 d.

Temperature regime ^a	Species		
	Hemp sesbania	Barnyardgrass	Johnsongrass
	Emergence (%)		
$4^{\circ}\text{C} \rightarrow 32^{\circ}\text{C}$	56	68	44
$-12^{\circ}\text{C} \rightarrow 32^{\circ}\text{C}$	44	78	36
$32/25^{\circ}\text{C}$ (Control)	78	94	80
LSD ($P \leq 0.05$)	16	16	16
	Mortality (%) ^b		
$4^{\circ}\text{C} \rightarrow 32^{\circ}\text{C} \rightarrow 4^{\circ}\text{C}$	21	18	28
$-12^{\circ}\text{C} \rightarrow 32^{\circ}\text{C} \rightarrow -12^{\circ}\text{C}$	100	100	100
$32/25^{\circ}\text{C}$ (Control)	---	---	---
LSD ($P \leq 0.05$)	10	18	10

^aCold room temperatures (where seeded soils were chilled), concomitant heat treatment temperatures, and reversal to cold room temperatures. Control represents ambient greenhouse temperature (32°C day/ 25°C night).

^bPercentages of emerged seedlings that died after a second cold treatment. Control treatments were not subjected to cold treatment.

Table 3. Effects of exposing an artificial seed bank to greenhouse temperatures ($32/25^{\circ}\text{C}$) after subjecting the seed bank to three temperature regimes, on residual germination and total germination.

Temperature treatment	Species					
	Hemp sesbania	Barnyardgrass	Johnsongrass	Hemp sesbania	Barnyardgrass	Johnsongrass
	Residual germination (%)			Total germination and control (%) ^z		
4 °C	12	8	8	68 (32)	76 (37)	52 (54)
−12 °C	18	32	4	62 (78)	110 (68)	40 (95)
32/25 °C (Control)	4	8	8	82	102	88
LSD (<i>P</i> ≤ 0.05)	8	10	6	---	---	---

^aTotal percentage of germination was calculated as: [(seedlings surviving after second cold treatment + residual germination)/Total number of seedlings germinated in untreated soils] *100%. Percentage of control given in parenthesis were calculated as, $\{1 - [(\text{Seedlings surviving after second cold treatment} + \text{Residual germination}) / \text{Total number of seedlings germinated in control soils}]\} *100\%$.

tactic management approaches. Heating of the soil may help management efforts by triggering weed emergence and by simulating a homogeneous environment for uniform germination. Soil solarization is another heat-mediated technique used to deplete the seed bank; the soil is heated during summer months by using plastic sheets placed on a moist soil to trap the solar radiation (Horowitz et al., 1983), and weed propagules or seedlings are killed as a result of heating them. Soil solarization would be less useful for temperate regions, where duration and intensities of sunlight are inadequate to heat the soils to temperatures required to kill seeds or seedlings.

Based upon electric energy costs of \$0.047 U.S. per kilowatt hour (Tampa Electric Co., Tampa, Fla.), heating 1 m² of soil from -12 to 32 °C for 96 h would cost ≈\$ 0.65, assuming that the heating pads operated continuously. The cost-effectiveness of heating soils artificially during winter months could be a limiting factor for large-scale use. If proven useful for a natural weed seed bank, this method may be suitable only for small-scale, commercial, organic gardening operations or home gardens. This method may also be utilized to deplete weed seeds in potting soils during the winter

months. Further research is required to determine the effect on a natural population of weed seeds of artificial heating of topsoil. Studies under controlled conditions are required to further determine the duration of heating and optimum temperature required to maximize peak germination.

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