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Effect of Simulated Tillage in Combination with Post-Shattering Temperature Conditions on *Senna obtusifolia* and *Xanthium strumarium* Seed Survival, Seedling Emergence and Seedbank Potential

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Abstract: Two of the most troublesome weeds in soybean, cotton, and corn in cropping systems of mid-south United States (US) are *Senna obtusifolia* and *Xanthium strumarium*. Understanding their population dynamics, particularly weed seedling emergence patterns, is important for the timely implementation and the success of weed management strategies. Identifying the sources of variation of emergence patterns could greatly improve our ability to predict emergence timing. A three-years field study was conducted to determine the effect of environmental conditions on *S. obtusifolia* and *X. strumarium* seedling emergence and seedbank potential. The experiment was conducted with two seed sources; *X. strumarium* burs and *S. obtusifolia* seeds from a single maternal plant source, and *X. strumarium* burs and *S. obtusifolia* seeds from multiple maternal plant sources, both being exposed either to 5 cm burial depth (buried) or left on the soil surface (soil surface) in the fallow or planted in spring after their storage under chilled (chill) or room temperature (no chill) conditions. *X. strumarium* and *S. obtusifolia* seedling emergence was lower from burs and seeds that were planted in the soil in September as compared with the chill and/or no chill seeds/burs stored for six months. *X. strumarium* seedling emergence was reduced from 37 to 1% when burs were left on the soil surface when compared to buried burs. *S. obtusifolia* seedling emergence was reduced from 47 to 13% when seeds were left on the soil surface as compared to buried. At the end of the experimental period, the soil seedbank of *X. strumarium* had been significantly depleted, whereas the remaining seeds of *S. obtusifolia* were viable.

Keywords: seed scarification; population dynamics; no-tillage; seed burial; chill temperatures

1. Introduction

Senna obtusifolia (Sicklepod) and *Xanthium strumarium* (common cocklebur) are two of the most important weeds species in row cropping systems of the mid- and southeastern United States (US) [1,2] as they have the potential to become major weeds of many crops, including soybean, cotton, and maize in short time periods [3]. In addition, these species can invade and dominate pastures, roadsides, fence lines, creek banks, and other disturbed areas [4].

Leon et al. [1] reported that integrated approaches which include multiple tactics and the incorporation of pre- with sequential post-application of herbicides are necessary to ensure *S. obtusifolia* seedbank reductions as plants that survived a single herbicide application are capable of producing

abundant viable seeds. Consequently, weed management should aim at preventing weed reproduction and reducing weed emergence after crop planting [5]. Effective weed management systems will consist of multiple control tactics, which are integrating weed biology and population dynamics [5] as a vehicle for the development of cropping systems that minimize the opportunity for weed growth, reproduction, seedling emergence, and recruitment [6–8]. Therefore, the determination of the soil seedbank is of great importance for understanding weed population dynamics and implementing effective weed management tactics since potential weed problems exist as long as weed seeds remain viable in the soil [9]. Understanding the ecophysiological processes that control weed seed dormancy and germination with the intention of explaining and eventually predicting weed seedling emergence patterns is of great interest [10,11].

In addition, research has been conducted to characterize how tillage systems affect seedling emergence patterns [12–15]. The magnitude of *X. strumarium* emergence is influenced by tillage, crop presence and various interspecific competition regimes [16,17]. Tillage increases *X. strumarium* and *S. obtusifolia* seedling emergence through soil aeration and increased temperature [18]. Under tilled conditions Bararpour and Oliver [16] reported 11% seedling emergence for both species, in relation to the initial seedbank, the first year of seed deposition. On the contrary, seedling emergence under no-tilled conditions was reduced to 0.7% and 1.6% for *X. strumarium* and *S. obtusifolia*, respectively. These authors also recorded high seed deposition for both species, even when they were grown under intra- and interspecific competitive conditions for two consecutive years. However, since weed seeds persist in the soil, understanding seedbank dynamics over multiple years is important for devising multiyear strategies to manage weeds. The purpose of this paper is to investigate how simulated tillage strategies (buried vs. unburied) in combination with chill or no chill conditions can affect the soil seedbank of both *X. strumarium* and *S. obtusifolia*. In addition, to examine the seed survival mechanisms when seeds for both *X. strumarium* and *S. obtusifolia* originated from single or multiple parental plants.

2. Materials and Methods

2.1. Seed Material and Experimental Set up

Hundred *S. obtusifolia* seeds and *X. strumarium* burs from a single maternal source (one plant), three days after their collection in September, were planted at a 5-cm depth within a circle of 7-cm in diameter. Another hundred *S. obtusifolia* seeds and *X. strumarium* burs were left on the soil surface of an experimental plot, which was enclosed by a 0.5- by 0.5-m wood frame 15 cm in height to prevent seeds/burs from being washed or blown out of the plot area. The planting area had no previous history of the weed species under investigation.

Some of the harvested *S. obtusifolia* seeds and *X. strumarium* burs were stored at room temperature (no chill) 18 to 24 °C, and some of the seeds and burs were exposed under chilling conditions at 0 to 2 °C and relative humidity between 25–30%. In May, one-hundred no chill *S. obtusifolia* seeds and *X. strumarium* burs and one-hundred chill seeds from both of the species were planted at a 5-cm depth in the middle of 0.5 × 0.5-m plots. Experimental plots, the middle of which was marked with a flag, were arranged in a completely randomized design with four replications. The soil was a Taloka silt loam (fine, mixed, thermic Mollic albaqualfs), with 25% sand, 62% silt, 13% clay, 1% organic matter, and pH of 6.7. The second year of the study, another experiment was conducted using the same procedure as above, except that the seed source was originating from a multiple maternal seed sources of the initial cocklebur and *S. obtusifolia* populations, had already established in previous year, and left to grow under intense intraspecific interference. The first germination experiment was run over three years, while the second was an independent treatment that was run over two years. Seedling emergence was recorded every two weeks until the end of the growing season.

2.2. Monitoring Soil Seed Reserves

After three years, soil samples were taken from the middle of each plot (buried treatment) with an 11-cm-diameter soil core at a 15-cm depth to retrieve the remaining *S. obtusifolia* seeds and *X. strumarium* burs. Each soil sample was passed through a series of four sieves containing screens of the following sizes: 4.75 mm to collect *X. strumarium*, 2.00 mm to collect *S. obtusifolia*, 1.00 mm security sieves for escaped *S. obtusifolia* seeds, and 0.25 mm to collect soil so that most of the soil would not go down the sink drain. Prior to screening, soil cores were soaked until a slurry was obtained. Water was run through the sieves with the sample slurry to enhance the movement through the screens. Seeds and burs were separated and were counted according to species. The seeds that were left on the soil surface of the 0.5 m × 0.5 m framed plots were collected by hand. To secure that the entire seed sample was collected, the soil surface of the sampling area was swapped and the debris was moved to the lab for further processing.

2.3. Germination Tests

Visual examination of the *X. strumarium* burs by bur dissection indicated whether enclosed seeds were desiccated, therefore not suitable for germination test. Germination tests were conducted to assess the viability of collected seeds that were retrieved from the sampling areas. *S. obtusifolia* seeds before expose to germination test were scarified with H_2S0_4 (98%) for 10 min. For the germination evaluations, the remaining *S. obtusifolia* seeds were placed in a 9-cm diameter plastic petri dish (Fisher Scientific, Suwanee, GA, USA) lined with two layers of Whatman filter paper (Whatman's No. 1, Fisher Scientific, Suwanee, GA, USA) and moistened with 10 mL of distilled water containing 100 ppm of captan [*N*-(trichloromethyl-thio)-*r*-cyclohexene-1,2-dicarboximide] (Drexel Chemical Company, Memphis, TN, USA) to control pathogens. These were incubated for seven days at 25 °C. Distilled water was added as needed to remoisten Whatman filter papers. Germinated seeds were counted and removed at seven days after seeds were placed in the incubator. Then, non-germinated *S. obtusifolia* seeds were scarified for a second time for 12 min and were placed back to the petri dishes and incubator. After five days, the remaining non-germinated seeds were scarified for a third time for 15 min.

2.4. Data Analysis

The expected number of remaining seeds after seedling emergence was estimated based on Equation (1).

$$E = I - SE \quad (1)$$

The number of seeds loss was estimated based on Equation (2).

$$SL = I - (SE + R) \quad (2)$$

E = Expected No. of seeds; I = Initial seed deposition; SE = Seedling emergence; SL = Seed loss; R = Retrieved seeds.

Data were subjected to analysis of variance and means were separated with least significant difference (LSD) at the 5% level of probability using SAS 9.3 software (SAS Institute Inc., Cary, NC, USA).

3. Results

3.1. Single Maternal Seed Source

There were no significant differences between the buried seed treatments (i.e., buried in September or May after having exposed to chill or no chill conditions) for *X. strumarium* or *S. obtusifolia* seedling emergence (Figures 1 and 2). Seedling emergence of *X. strumarium* and *S. obtusifolia* was 54% and 46% (an average of September and May planting dates), respectively, when seeds and burs were buried.

When the seeds and burs remained on the soil surface, only 1% and 5% of *X. strumarium* burs and *S. obtusifolia* seeds emerged, respectively. The second year the *X. strumarium* seedbank was depleted (Figure 1). After three years, an average of 58% of *X. strumarium* burs had emerged regardless of whether burs were planted in September or exposed to chill or no-chill conditions. Soil sampling indicated that an average of 28 and 19% of the burs were lost when they were buried or left on the soil surface, respectively (Figure 3). None of the *X. strumarium* burs that were collected by soil sampling contained viable achenes. Three years after, the *S. obtusifolia* seedbank was not completely depleted (Figure 2). The total percent seedling emergence by that time was recorded at 62% and 54%, respectively, for seeds under chill conditions or seeds that were exposed under room temperature (no chill). Buried seeds or seeds that were left on the soil surface in September resulted in 40% and 18% seedling emergence, respectively. Soil sampling indicated that an average of 36% of the seeds were lost when seeds were planted (Figure 4) versus 34% when seeds were left on the soil surface. Germination test indicated that 100% of remaining *S. obtusifolia* seeds were viable and would germinate (Table 1).

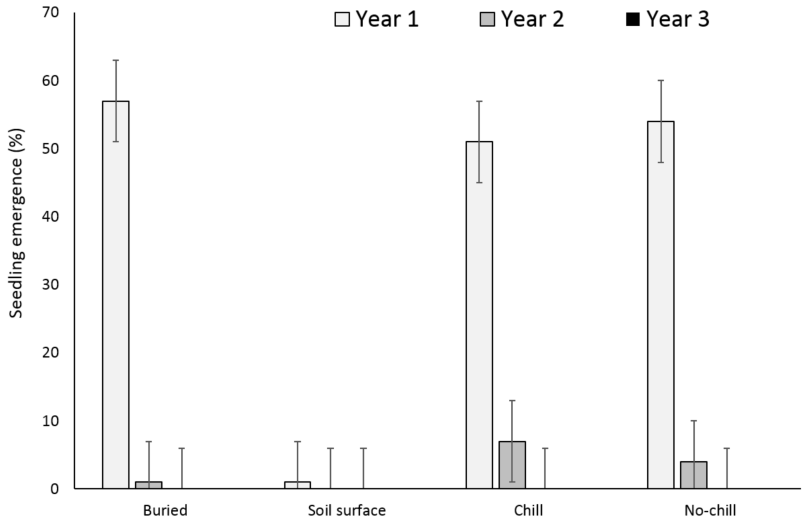

Figure 1. Effect of environmental conditions on *X. strumarium* emergence originating from a single maternal source. Vertical bars represent least significant difference (LSD) at 5% significance level.

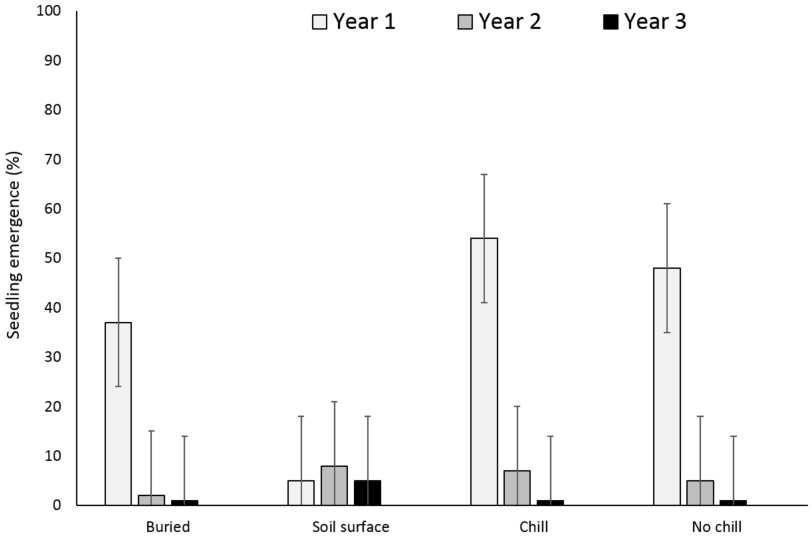

Figure 2. Effect of environmental conditions on *S. obtusifolia* emergence originating from a single maternal source. Vertical bars represent LSD at 5% significance level.

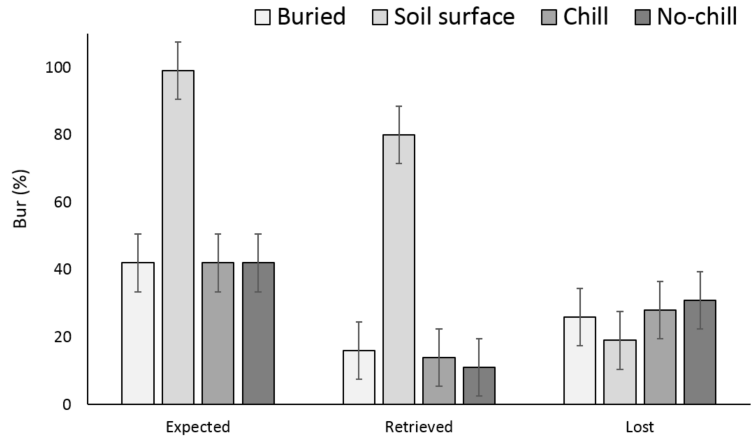

Figure 3. Effect of environmental conditions on *X. strumarium* bur loss originating from a single maternal source after three years. Vertical bars represent LSD at 5% significance level. Expected is the sum of non-germinated seeds.

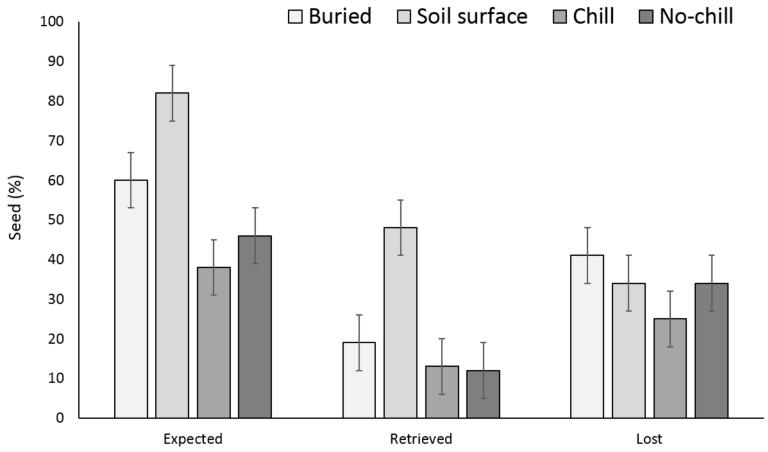

Figure 4. Effect of environmental conditions on *S. obtusifolia* seed loss originating from a single maternal source after three years. Vertical bars represent LSD at 5% significance level. Expected is the sum of non-germinated seeds.

Table 1. Percentage germination of *S. obtusifolia* seeds from single maternal source under various environmental conditions.

	Scarification *		
	1	**2**	**3**
	% germination		
Buried	78	93	100
Soil surface	30	61	100
Chill	72	91	100
No-chill	76	82	100
LSD	20	NS	NS

* 1 = first time of scarification (10 min), 2 = ungerminated seed from 1, scarified again for 12 min, and 3 = ungerminated seed from 2, scarified third time for 15 min.

3.2. Multiple Maternal Seed Source

Two years after, *X. strumarium* and *S. obtusifolia* seedling emergence was highest when the seeds or burs were exposed to chill conditions for six months and were planted in the field in May (Figures 5

and 6). *X. strumarium* and *S. obtusifolia* seedling emergence was the lowest when seeds and burs were left on the soil surface; only 0.4% and 4% emerged, respectively. An average of 12% and 34% of *X. strumarium* burs and *S. obtusifolia* seeds emerged, respectively, when seeds/burs were planted in the soil. Upon the completion of the experiment (two years after the establishment of the study), there were differences in *X. strumarium* seedling emergence at different planting dates or when burs were left on the soil surface (Figure 5). *S. obtusifolia* seedling emergence was the lowest when seeds were left on the soil surface when compared to seeds planted in soil (Figure 6). Total seedling counts indicate that when *X. strumarium* burs and *S. obtusifolia* seeds were exposed under chill or no-chill conditions (for 6 months), seedling emergence was the highest (Figures 5 and 6). Soil sampling indicated that an average of 53 and 36% of *X. strumarium* burs and *S. obtusifolia* seeds were lost when burs and seeds were buried (Figures 7 and 8). *X. strumarium* burs and *S. obtusifolia* seed lost were 23% and 25% when burs and seeds were left on the soil surface (Figures 7 and 8). Seed or bur loss probably was due to decay, disease, and predation. Germination of remaining *X. strumarium* burs was 0% due to decomposition. The germination test indicated that 100% of the remaining *S. obtusifolia* seeds were viable and would germinate.

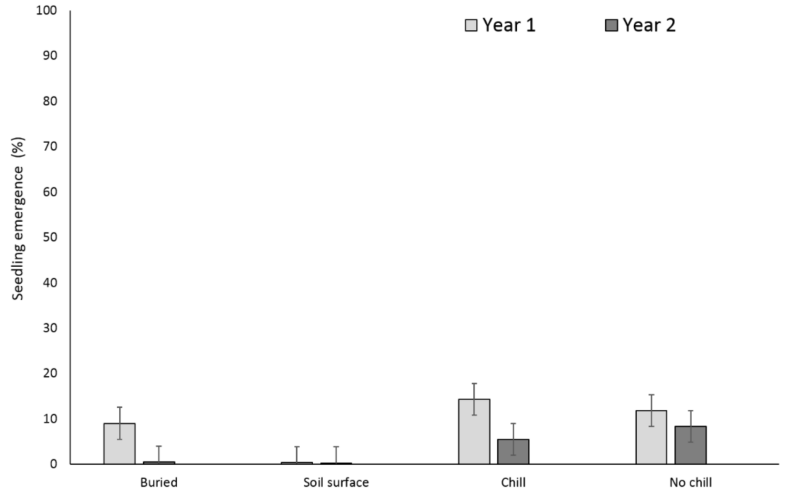

Figure 5. Effect of environmental conditions on *X. strumarium* emergence originating from a multiple maternal source. Vertical bars represent LSD at 5% significance level.

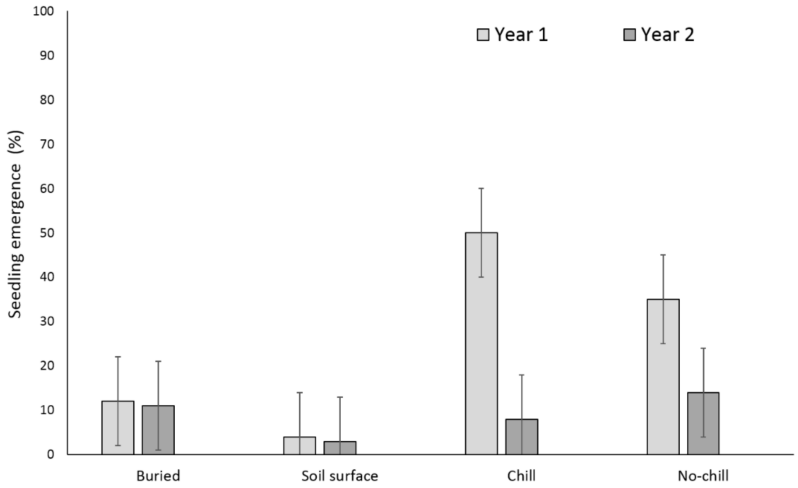

Figure 6. Effect of environmental conditions on *S. obtusifolia* emergence originating from a multiple maternal source. Vertical bars represent LSD at 5% significance level.

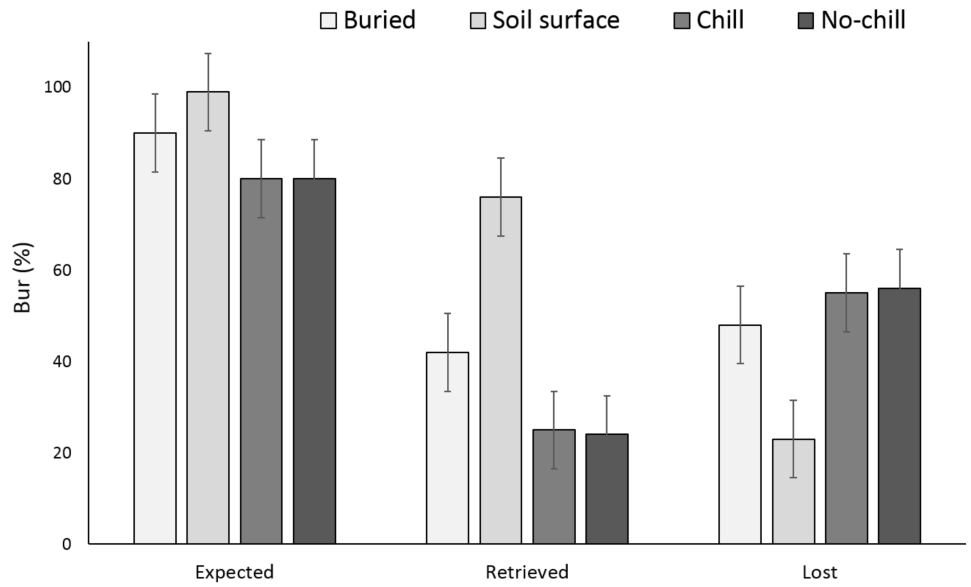

Figure 7. Effect of environmental conditions on *X. strumarium* bur loss originating from a multiple maternal source after two years. Vertical bars represent LSD at 5% significance level. Expected" is the sum of non-germinated seeds.

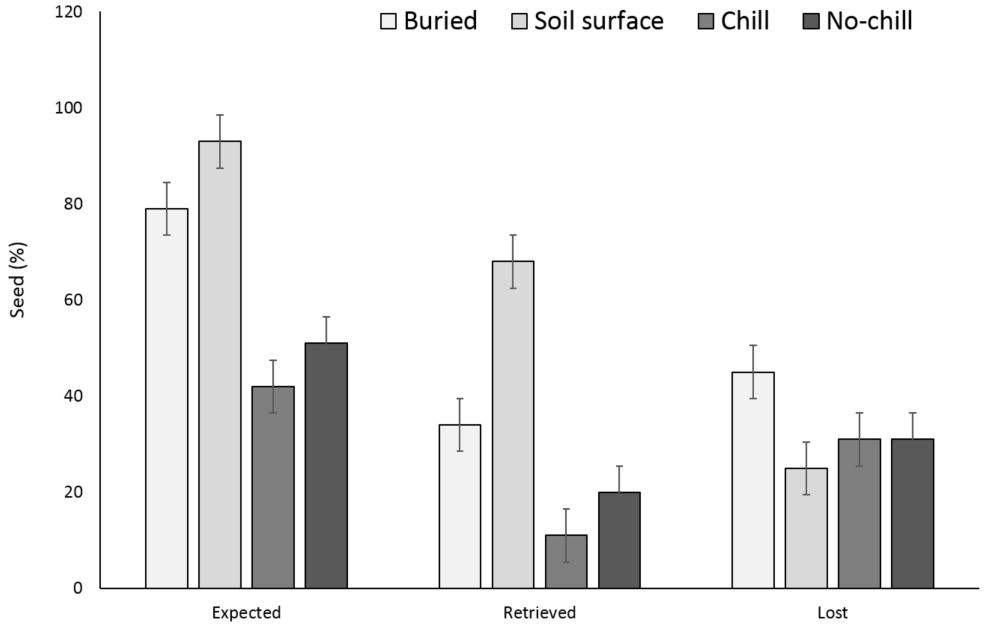

Figure 8. Effect of environmental conditions on *S. obtusifolia* seed loss originating from a multiple maternal source after two years. Vertical bars represent LSD at 5% significance level. Expected" is the sum of non-germinated seeds.

Single maternal seed source buried in the soil had approximately 75% germination after the first scarification (Table 1); however, seeds on the surface had more resistant seed coats with only 30% germination (Table 1). A second scarification doubled germination of the seeds remained on the soil surface.

On the contrary, the multiple maternal seed source exhibited a greater variation in seed germination after one scarification (Table 2). Results from both experiments indicated that seedling emergence was lower when *S. obtusifolia* seeds and *X. strumarium* burs were buried at 5-cm depth than

when seeds/burs were stored at 18 to 24 °C (no-chill) or at 0 to 2 °C (chill) for six months (Figure 1, Figure 2, Figure 5, and Figure 6), which was possibly due to differing planting days of September and May for both of the treatments. The lower emergence was due to loss of seed viability and seed decay when seed material was buried hence exposed to seed predators and microorganism attack. *X. strumarium* seedling emergence was reduced from 58 to 1% from single maternal seed source (Figure 1) and from 16 to 0.7% from multiple maternal seed source (Figure 5) when burs were left on the soil surface as compared to burs that were buried in the soil. *S. obtusifolia* seedling emergence was reduced from 52 to 18% from single maternal seed source (Figure 2) and from 43 to 7% from multiple maternal seed source when seeds were left on the soil surface compared with seeds buried in the soil.

Table 2. Percentage germination of *S. obtusifolia* seeds from multiple maternal sources under various environmental conditions.

	Scarification *		
	1	**2**	**3**
	% germination		
Buried	75	100	100
Soil surface	60	91	100
Chill	56	91	100
No-chill	43	88	100
LSD	19	NS	NS

* 1 = first time of scarification (10 min), 2 = ungerminated seed from 1, scarified again for 12 min, and 3 = ungerminated seed from 2, scarified third time for 15 min.

4. Discussion

These results indicate that a no-till production system that does not favor seed burial may effectively reduce *X. strumarium* seedling emergence [16,19], and, to a lesser extent, *S. obtusifolia* emergence. The germination test indicated that 100% of the remaining *X. strumarium* burs were decayed, but 100% of *S. obtusifolia* seeds were viable. These results also indicate that the *X. strumarium* seedbank was depleted after three years, but the *S. obtusifolia* seedbank was not depleted and the remaining seeds were viable. Thus, *S. obtusifolia* seed remain viable in or on the soil longer than those of *X. strumarium*. An average of 36 and 33% of *X. strumarium* burs and *S. obtusifolia* seeds were lost after three years. The large number of seeds or burs that were lost during the experiment was probably due to decay and/or predation [20,21]. Scarification of *S. obtusifolia* seed indicates that there are different levels of seed coat hardness (Bararpour and Oliver 1997) [22]; the hardness may be due to a thin impermeable waxy gel covering the *S. obtusifolia* seed. The hard seed coat of *S. obtusifolia* seed (i.e., survival mechanism) [22] accounts for the long-term survival of *S. obtusifolia* seed in the soil seedbank.

The soil seedbank of *X. strumarium*, as shown in Figures 3 and 7, can be declined dramatically within three years after the deposition of seed on the soil. This indicates the relatively short life span of *X. strumarium* burs, hence the seedbank persistence of *X. strumarium*, therefore timing for management implementation tactics against this species, especially these that have developed herbicide resistance.

X. strumarium achenes, as revealed by germination and viability tests, are very sensitive to decay, particularly these that are left on the soil surface (a simulated no-tillage cropping system) as their emergence was recorded at 1% in the first year and 0% for the second and third year (Figure 1). Therefore, no-tillage can be an effective management practice to disturb X. strumarium seedbank dynamics and reduce the population of this species. Similar results were observed by Korres et al. (2018) [23] when the seeds of *Amaranthus palmeri* and *A. tuberculatus* were placed at two depths (0 and 15 cm for three years.

On the contrary, the seedbank of *S. obtusifolia*, as shown in Figure 4, was not depleted. Germination and viability tests revealed the resistance of *S. obtusifolia* seed against decay, which was most probably

due to the characteristic hard seed coat. Therefore, in the case of this species, no tillage is less effective management practice for the reduction of *S. obtusifolia* population. These results are indicative of changes cropping system might exert on weed composition. In support of these results, Sosnoskie et al. (2006) [24] stated the effects of no-tillage systems as opposed to conventional or minimum tillage on the composition and diversity of weed communities.

5. Conclusions-Practical Applications

No tillage cropping systems that are suitable for conservational agriculture practices can contribute significantly in *X. strumarium* control tactics through seedbank reductions. *X. strumarium* bur prickles prevented good soil contact under no-till and many burs remained on the soil surface therefore fail to germinate and progressively were exposed to decay. In contrast, the smooth waxy surface of the smaller *S. obtusifolia* seeds allowed for good soil contact, even in no-till systems. *S. obtusifolia* can be a more problematic species to control in comparison with *X. strumarium*, especially under no-tillage conditions.

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Author Contributions: Taghi Bararpour conducted the experiments, collected and analyzed the data and wrote the manuscript. Nicholas E. Korres analyzed the data and wrote the paper.

Conflicts of Interest: No conflicts of interest are declared.

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