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Postharvest Tillage Reduces Downy Brome (*Bromus tectorum* L.) Infestations in Winter Wheat

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In the Pacific Northwest, downy brome continues to infest winter wheat, especially in low-rainfall areas where the winter wheat–summer fallow rotation is the dominant production system. In Washington, a study was conducted for 2 yr at two locations in the winter wheat–summer fallow region to determine the influence of four postharvest tillage treatments on vertical seed movement, seedbank depletion, and plant densities of downy brome. The four tillage implements included a disk, sweep plow, harrow, and skew treader. The study also included a no-till treatment for comparison. The sweep plow and disk led to the most vertical movement of downy brome seed compared with the no-till treatment. Approximately 75% of the fall postharvest seed in the no-till treatment was located either on the soil surface or in the 0- to 3-cm depth at both locations. In contrast, 75% of the seed in the disked treatment was located from 0 to 6 cm deep at both locations. The disk and sweep plow both decreased downy brome seed in the soil at the 0- to 3-cm depth compared with the harrow and no-till treatments. There was no difference in downy brome plant densities following postharvest tillage in the summer fallow due to any of the treatments. However, plant densities in the subsequent winter wheat crop were reduced by the disk and sweep plow compared with the no-till and skew-treader treatments. In general, seed densities as affected by the skew treader fell between the disk and the no-till treatments. The use of the sweep plow and the disk should be integrated into a weed management strategy for downy brome in the wheat–fallow region of the Pacific Northwest.

Nomenclature: Downy brome, *Bromus tectorum* L.; winter wheat, *Triticum aestivum* L.
Key words: No-till, postharvest tillage, seedbank.

En el Pacífico Noroeste, *Bromus tectorum* continúa infestando campos de trigo de invierno, especialmente en áreas con baja precipitación donde la rotación de trigo de invierno y barbecho de verano es el sistema dominante de producción. En Washington, se realizó un estudio por 2 años, en dos localidades en la región de rotación trigo de invierno y barbecho en verano, para determinar la influencia de cuatros tratamientos de labranza pos-cosecha sobre el movimiento vertical de la semilla, agotamiento del banco de semillas, y la densidad de plantas de *B. tectorum.* Los cuatro implementos de labranza fueron una rastra de discos, un cultivador de cuchilla, un cultivador de cincel, y un cultivador rotativo de dientes oblicuos. El estudio también incluyó un tratamiento de labranza cero para fines de comparación. El cultivador de cuchilla y la rastra de discos produjo el mayor movimiento vertical de semilla de *B. tectorum* al compararse con el tratamiento de labranza cero. Después de la cosecha en el otoño, aproximadamente 75% de la semilla en el tratamiento de labranza cero se localizó en la superficie del suelo o a una profundidad de 0 a 3 cm en ambas localidades. En cambio, 75% de la semilla en el tratamiento de rastra de discos se localizó de 0 a 6 cm de profundidad en ambas localidades. La rastra de discos y el cultivador de cuchillas disminuyeron la semilla de *B. tectorum* en el suelo de 0 a 3 cm de profundidad al compararse con los tratamientos de cultivador de cincel y la labranza cero. No hubo diferencia en la densidad de plantas de *B. tectorum* después de la labranza pos-cosecha en el barbecho de verano producto de los tratamientos. Sin embargo, la densidad de plantas en el siguiente cultivo de trigo de invierno se redujo con la rastra de discos y el cultivador de cuchillas al compararse con los tratamientos de labranza cero y el cultivador rotativo de dientes oblicuos. En general, la densidad de semillas producto del cultivador de dientes oblicuos estuvo entre los tratamientos de rastra de discos y la labranza cero. El uso del cultivador de cuchillas y la rastra de discos debería integrarse a estrategias de manejo de *B. tectorum* en la región de Pacífico Noroeste donde se tiene la rotación trigo-barbecho.

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Downy brome and related annual bromes infest an estimated 20 million ha of winter wheat and fallow land in the western half of the United States (Duncan et al. 2004; Mack 1981). These winter annual grasses reproduce only by seed. Downy brome thrives in winter wheat because it germinates readily in the fall, emerges about the same time as winter wheat, matures earlier than wheat, and thus produces abundant seed for the next growing season. Downy brome is most troublesome in semiarid regions where winter wheat–fallow rotations are used. Moderate populations (24 to 65 plants m^{-2}) of downy brome can reduce winter wheat grain yields by 10 to 20% (Stahlman and Miller 1990), although yield losses with dense populations can be as high as 90% (Rydrych and Muzik 1968). Downy brome is also a prolific seed producer and can produce 5,000 to 11,000 seeds m^{-2} in winter wheat in eastern Washington (Ogg, unpublished data). Rydrych (1976) reported that downy brome seed production in northeastern Oregon varied between 9,000 and 25,000 seeds m^{-2} depending on the wheat variety being grown. Anderson (1998a) found that 6 downy brome plants m^{-2} growing in winter wheat in eastern Colorado produced an average of 4,620 seeds m^{-2}.

The longevity of downy brome seeds in agricultural soils is short, generally not more than 3 yr, although Wicks et al. (1971) reported that a few seeds could remain viable for up to 5 yr. Given ideal conditions for germination, most downy brome seeds will germinate the first fall and winter after production (Hulbert 1955; Hull and Hansen 1974; Steinbauer and Grigsby 1957). Wicks et al. (1971) reported that 98% of 8-mo-old downy brome seeds germinated when placed in soil with conditions favorable for germination. Chepil (1946) found that fewer than 2% of the downy brome seeds remained viable in the soil for 3 yr. However, if conditions are unfavorable for germination in the fall, some seeds can acquire induced dormancy and will persist for more than 1 yr (Young et al. 1969). Hull and Hansen (1974) reported that 2,940 downy brome seedlings m^{-2} emerged from the soil after the fall emergence of 7,450 seedlings m^{-2} was thought to be complete. Downy brome seeds covered by soil germinated more rapidly than the seeds left on the soil surface (Wicks et al. 1971). If downy brome seeds could be repositioned so they were in contact with the soil before fall rains, most seeds should germinate in the fall and winter after winter wheat harvest, and should provide wheat producers using a wheat–fallow rotation with an opportunity to reduce downy brome in the soil seedbank. In the past, moldboard plowing 15 cm deep was used to control infestations of downy brome (Kettler et al. 2000). Shallow tillage soon after wheat harvest (postharvest tillage) should improve soil–seed contact and enhance downy brome seed germination during the fallow year. This cultural practice has been recommended (Yenish et al. 1998), but has not been fully tested under field conditions.

The objectives of this field study were to determine: (1) if tillage soon after wheat harvest would decrease downy brome soil seedbank densities and downy brome densities in the subsequent winter wheat crop; (2) if there were differences among four types of tillage equipment in their ability to enhance downy brome seed germination in the fall and winter of the fallow year; and (3) how each type of tillage equipment affected the vertical distribution of downy brome seeds in the soil.

Materials and Methods

A 2-yr on-farm experiment was conducted at two locations in the winter wheat–fallow cropping region of central Washington. Locations were selected in fields with dense infestations of downy brome. The first experiment, initiated in August 1994, was 0.3 km northeast of Harrington, WA. Soil at this site was a Bagdad silt loam with 1.8% organic matter (OM) and pH of 5.8. Average annual rainfall was 30 cm and the previous winter wheat yield was 3,700 kg ha^{-1}. The second experiment was initiated in August 1995, and was located 9 km west of Washtucna, WA. Soil was a Ritzville silt loam with 1.5% OM and pH of 5.8. Average annual rainfall was 23 cm and the previous winter wheat yield was 2,020 kg ha^{-1}. A portable weather station, placed at each site at the beginning of the experiments, collected daily minimum and maximum air temperatures and daily rainfall.

At both locations, experiments were initiated immediately after winter wheat harvest in late July to early August. Combines were equipped with chaff and straw spreaders. Treatments at each location were tillage implements including tandem disc, skew treader, sweep plow, and spike-tooth harrow. A skew treader is an implement with four gangs of rolling curved spikes arranged in a pattern similar to a tandem disc and is normally used as a secondary tillage operation (Gollaney et al. 2005). All implements used in the study were commercial field-sized models. A no-till treatment was included at each site. All treatments were replicated four

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times in a randomized block design. Replications were situated so that plots within a replication had similar downy brome densities. Plots were 46 m long and from 9 to 15 m wide depending on the width of the tillage implement used. Downy brome seed in each plot was sampled pretillage, posttillage, and in the spring for densities and soil position by collecting soil and seeds from nine predetermined sites (subsamples) in each plot. Sampling dates were: (1) pretillage August 8 and 9, 1994; August 10, 1995; (2) posttillage August 15 and 16, 1994; August 14 to 17, 1995; and (3) spring April 18, 1995; March 25 and 26, 1996. Soil was subsampled at the ends and mid-point lines of a "W"-shaped pattern in each plot based on procedures recommended by Roberts (1981). Subsamples were collected from a total of nine points in each plot. The W was inverted and offset 1 to 2 m for the posttillage and spring sampling to eliminate the chance of sampling in the same location as the pretillage sampling. A 10-cm square metal tube with a reinforced upper edge was driven into the soil and used to collect seeds and soil at incremental depths of 0 to 3 cm, 3 to 6 cm, and 6 to 12 cm. Surface subsamples were collected by vacuuming all debris and seeds from the soil surface inside the square metal frame. Subsurface subsamples were collected at the indicated depths after the metal frame was driven into the soil 3, 6, and 12 cm. Twelve centimeters was chosen as the maximum sampling depth because downy brome seedlings seldom emerge from seeds deeper than 10 to 12 cm (Wicks et al. 1971). Subsamples within a plot were bulked by depth, placed in plastic bags, transported to the laboratory in coolers, and placed in a freezer (−18 C) for later analyses for number of viable seeds.

After the initial sampling for downy brome seeds, tillage treatments were conducted as follows: tandem disc with 61-cm-diameter blades set at maximum working angle and 8- to 10-cm working depth; sweep plow equipped with 51-cm-wide sweeps on 48-cm centers and set 10- to 13-cm working depth; skew treader set at three-fourths maximum angle and tilled the soil 2.5 to 4 cm deep; spike-tooth harrow with teeth set vertical to till soil about 2.5 cm deep. A no-till plot was included as a control treatment with which tillage treatments could be compared. All implements were pulled at 6.4 to 8.0 km h^{-1}. At Harrington, the spike-tooth harrow had a rigid frame, whereas at Washtucna the spike-tooth harrow had a flexible frame. Within 1 wk after tillage treatments and before any significant rainfall, the plots were again sampled for downy brome seed as described above. Plots were sampled a third time in the spring, as described above, for downy brome seed in the soil.

Densities of downy brome in each plot were counted in five 0.25 m^{-2} quadrats in February 1995 at Harrington and in October 1995 at Washtucna before any additional tillage was performed. Growers followed their usual practices for mechanical summer fallowing and planted winter wheat in September. Typical summer fallow operations generally consist of spring fertilizing with an undercutter followed by several rod weedings (Thorne et al. 2003). After significant fall rains and emergence of downy brome, weed densities were again counted in ten 0.25 m^{-2} quadrats in each plot. Spring-applied glyphosate controlled weeds in the no-till plots. Counts were recorded in the wheat crop November 20, 1995 at Harrington and on March 7, 1997 at Washtucna.

In a preliminary test, downy brome seeds were collected in April from the top 12 cm of soil in a winter wheat stubble field. Twenty-five seeds were placed on moistened blotter paper in petri dishes and then placed in an incubator at 20 C for 4 wk. None of the seeds germinated. Three other 25-seed lots were placed in paper bags and held at 30 C for 4 wk. After 4 wk, seeds were removed from the bags, placed on moistened paper in petri dishes, and incubated at 20 C. Seeds germinated within a few days. This procedure was effective in breaking the induced dormancy of downy brome seeds and a modification of this procedure was used to assess viable seeds in the study.

Subsamples containing seeds were removed from frozen storage, thawed rapidly, and washed through a seed elutriator equipped with a 500-μm mesh screen that separated the seed and plant debris from the soil (Kovach et al. 1988). Contents of the screen were washed onto ordinary coffee filters and transferred that same day to a greenhouse held at constant 20 C ± 5 C. The seed and accompanying debris were spread evenly on the surface of 35- by 46-cm flats containing commercial greenhouse potting mix. Seeds and debris were covered evenly with fine vermiculite to retain moisture and aid seedling emergence. Flats were moistened thoroughly and covered with the subsample plastic bag.

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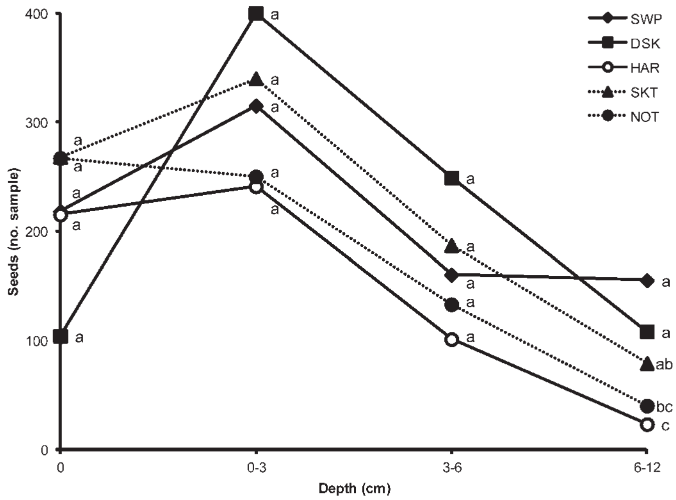

Figure 1. Effect of postharvest tillage on downy brome seed collected from the soil surface and at three depths at Harrington in the fall of 1994. Means within a depth with different letters are significantly different at $P \leq 0.05$. Means are back transformed. Abbreviations: SWP = sweep plow; DSK = disk; HAR = harrow; SKT = skew treader; NOT = no-till. Seed densities are presented per sample with sample sizes being: soil surface, 10 cm^2; 0 to 3 cm, 300 cm^3; 3 to 6 cm, 300 cm^3; and 6 to 12 cm, 600 cm^3.

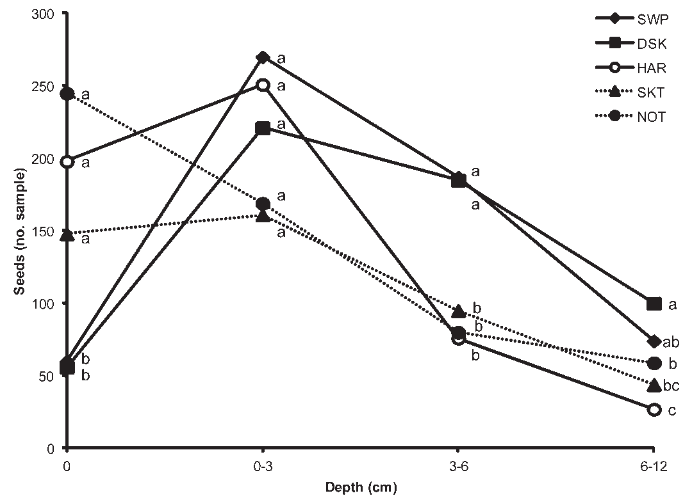

Figure 2. Effect of postharvest tillage on downy brome seed collected from the soil surface and at three depths at Washtucna in the fall of 1995. Means within a depth with different letters are significantly different at $P \leq 0.05$. Means are back transformed. Abbreviations: SWP = sweep plow; DSK = disk; HAR = harrow; SKT = skew treader; NOT = no-till. Seed densities are presented per sample with sample sizes being: soil surface, 10 cm^2; 0 to 3 cm, 300 cm^3; 3 to 6 cm, 300 cm^3; and 6 to 12 cm, 600 cm^3.

The plastic bag was removed as soon as downy brome began to emerge, usually 5 d. Emerged downy brome seedlings were recorded 18 d after planting. Each flat was then sprayed with 0.63 kg ae ha^{-1} glyphosate plus 0.25% nonionic surfactant, thoroughly moistened 2 d later and re-examined 18 d later for any subsequent emergence of downy brome. The process of spraying glyphosate and counting emerged downy brome was repeated two more times. Usually, 99% of the downy brome seedlings emerged in the first three cycles.

The experimental design was a randomized complete block with four tillage treatments and no-till and four depths present in each replication in each location. Viable seed counts were analyzed with a two-way ANOVA using SAS PROC MIXED version 9.2 (SAS Institute Inc., Cary, NC). The analysis examined treatment and depth effects on plant counts within depth analyzed as a repeated-measure factor. Downy brome seed densities varied among replications, plots with replications, and within depth so pretillage seed count was used as a covariate. This allowed more valid comparisons among tillage treatments and depths. Viable seed counts were averaged over subsamples and the averages were log transformed when necessary to improve validity of normality and homogeneity of variance assumptions. Tillage effects were compared for each depth using Fisher's Protected LSD test to identify how the influence of tillage changed with depth.

Results and Discussion

There was a significant location-by-tillage treatment interaction for the data, therefore the data are presented separately by location. Sample sizes for downy brome seeds are: 10 cm^{-2} for soil surface; 300 cm^{-3} for the first two depths; and 600 cm^{-3} for the third depth.

Postharvest Tillage Effects on Fall Soil Seedbank. As stated earlier, pretillage seed count was used as a covariate for tillage and depth comparison. As an indication of pretillage downy brome seeds that emerged from the subsamples in the greenhouse, there were an average of 870 seeds per total sample areas (surface plus three depths) at Harrington and an average of 570 seeds per total sample areas at Washtucna. There was a significant tillage-by-depth interaction for fall posttillage seeds at both locations (Figures 1 and 2).

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At Harrington, in the fall of 1994 all five treatments had similar posttillage downy brome seed densities on the soil surface, in the 0- to 3-cm depth, and in the 3- to 6-cm depth (Figure 1). Although not significant, the trend was apparent that disking moved much of the seed into the 0- to 3- and 3- to 6-cm depths, compared with the no-till treatment. The sweep plow and the disk had significantly higher seed densities at the 6- to 12-cm depth, with 155 and 110 seeds respectively, compared with the no-till and harrow treatments, which had $<$ 40 seeds. These totals reflect seed movement down to the tillage depth for these implements, which was $\geq$ 10 cm. Seed densities for the skew treader at the 6- to 12-cm depth were similar to the seed densities found in the sweep plow and disk treatment, but higher than the harrow treatment (Figure 1).

In the fall of 1995 at Washtucna, downy brome seeds in the sweep plow and disk treatments on the soil surface were $<$ 60 seeds and significantly lower than the other three treatments where seed densities ranged from 150 to 250 (Figure 2). As in the case of the Harrington location, the density of seeds located at the 0- to 3-cm depth was similar regardless of tillage, although seeds in the sweep plow and disk treatments increased from $<$ 60 seeds on the soil surface to 270 and 220 seeds, respectively. Seed densities were greatest in the sweep plow and disk treatment (185) compared with seed densities in the other three treatments (75 to 95) at the 3- to 6-cm depth (Figure 2). The number of downy brome seeds in the 6- to 12-cm depth was significantly greater in the disk treatment compared with the number of seeds in the harrow, skew-treader, and no-till treatments, indicating very little seed distribution in those three treatments. The lowest seed density was with the harrow.

Seed distribution from the disk in our two experiments were similar to those by Mohler et al. (2006) where 70% of tracer beads placed on the soil surface moved down vertically to 10 cm during a disking operation. However, our results differ from Anderson (1998b), who found that downy brome emergence was unaffected by the sweep plow even though his tillage depth (8 to 10 cm) was only 3 cm shallower than the sweep-plow depth in our study. He speculated that one explanation for his results was lack of sufficient vertical downy brome seed movement. In our study, the sweep-plow tillage deposited the greatest number of seeds at the 6- to 12-cm depth at Harrington and the second greatest number of seeds at Washtucna compared with other treatments. In addition, along with the disk treatment the sweep-plow treatment had the greatest seed density in the 3- to 6-cm depth at Washtucna compared with the other treatments.

Table 1. Influence of postharvest tillage on downy brome densities during fallow at Harrington and Washtucna WA.[a]

Treatment	Harrington	Washtucna
	no. m^{-2}	
Disk	730 a	665 a
Harrow	1,055 a	875 a
No-till	1,090 a	695 a
Skew treader	780 a	870 a
Sweep plow	690 a	680 a

[a] Means within a column with a same letter are not significantly different at $P \leq 0.05$.

Postharvest Tillage Effects on Downy Brome Plant Densities. For in-field downy brome densities, the treatment-by-location interaction was significant so the data were analyzed separately. Precipitation was not sufficient to germinate downy brome in the fall of 1994 at Harrington so counts were recorded the following spring. At Washtucna, $>$ 2.5 cm of precipitation was received on September 7, 1995, seeds germinated, and counts were recorded in October. Tillage did not affect downy brome plant densities at either location, although the range at Harrington (690 to 1,090 plants m^{-2}) was greater than at Washtucna (665 to 870 plants m^{-2}) (Table 1).

Postharvest Tillage Effects on Spring Soil Seedbank. There was a significant tillage-by-depth interaction for the spring 1995 data at Harrington. Vertical seed distribution varied greatly in the no-till and harrow treatments. These treatments had the highest seed number at both the soil surface and the 0- to 3-cm depth (Figure 3) and decreased greatly at the 3- to 6-cm and 6- to 12-cm depths. The sweep plow and disk treatments had significantly lower seed densities on the soil surface and the 0- to 3-cm depth compared with the no-till and harrow treatments (Figure 3). Downy brome seed distribution with the skew treader was similar to and in between the harrow treatment and the sweep plow and the disk. Downy brome seed densities were $<$ 50 for four depths with the sweep plow and

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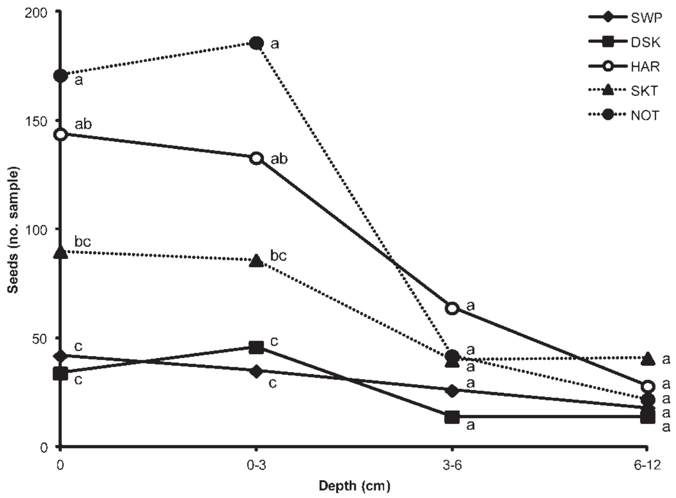

Figure 3. Effect of postharvest tillage on downy brome seed collected the following spring from the soil surface and at three depths at Harrington in 1995. Means within a depth with different letters are significantly different at $P \leq 0.05$. Means are back transformed. Abbreviations: SWP = sweep plow; DSK = disk; HAR = harrow; SKT = skew treader; NOT = no-till. Seed densities are presented per sample with sample sizes being: soil surface, 10 cm^2; 0 to 3 cm, 300 cm^3; 3 to 6 cm, 300 cm^3; and 6 to 12 cm, 600 cm^3.

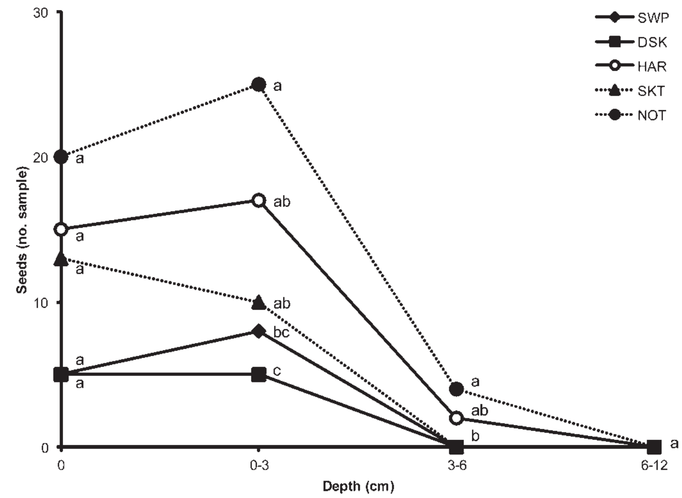

Figure 4. Effect of postharvest tillage on downy brome seed collected the following spring from the soil surface and at three depths at Washtucna in the spring of 1996. Means within a depth with different letters are significantly different at $P \leq 0.05$. Means are back transformed. Abbreviations: SWP = sweep plow; DSK = disk; HAR = harrow; SKT = skew treader; NOT = no-till. Seed densities are presented per sample with sample sizes being: soil surface, 10 cm^2; 0 to 3 cm, 300 cm^3; 3 to 6 cm, 300 cm^3; and 6 to 12 cm, 600 cm^3.

disk treatments. Seed densities were similar for all five treatments at the 3- to 6- and 6- to 12-cm depths.

Springtime seedbank densities (Figure 4) at Washtucna in 1996 were much less than seed densities at Harrington the previous year. There was no tillage-by-depth interaction for the Washtucna spring seedbank densities. Seed densities on the soil surface were similar for all treatments and ranged from 5 (sweep plow and disk) to 20 seeds (no-till). Seed densities were significantly less for the sweep plow and disking compared with no-till at the 0- to 3-cm depth and 3- to 6-cm depth. Seed densities for all treatments were $\leq$ 4 at the 3- to 6-cm depth and $<$ 1 at the 6- to 12-cm depth.

The great decrease in downy brome seeds at both locations from fall sampling to spring sampling at the 0- to 3- and 3- to 6-cm depths would indicate that disking and sweep plowing prevented induced dormancy (Young et al. 1969), promoted fall/winter seed germination by increased seed/soil contact, and increased seed death in the soil. These data agree with previous research conducted with ripgut brome (*Bromus rigidus* L.) where shallow tillage increased seedling emergence and subsequent seedbank decline (Gleichsner and Appleby 1989).

Postharvest Tillage Effects on Downy Brome Seedling Density in Winter Wheat. There was a significant amount of downy brome seed that persisted for more than 1 yr as indicated by plants growing in the subsequent winter wheat crops (Table 2). When averaged over locations (no significant difference between locations), the disk and sweep plow reduced downy brome density 43% compared with the density in the no-till treatment. However, if left unmanaged, even the densities that remained from those tillage operations can significantly reduce wheat yield (Rydrych and Muzik 1968; Stahlman and Miller 1990) and replenish the seedbank in the soil (Anderson 1998a).

Although our study was short term, a 5-yr study that overlapped the second experiment at Washtucna utilized postharvest disking to promote germination of downy brome seeds, reduce plant densities, and decrease seed in the soil in a winter wheat–summer fallow rotation (Thorne et al. 2006; Young and Thorne 2004). This study consisted of adjacent fields with a winter wheat–summer fallow rotation alternating in each field so that winter wheat was grown in one field one year and summer fallow in the adjacent field the same year. The rotation was switched in the fields the following

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Table 2. Downy brome densities in winter wheat following four tillage treatments and a no-till treatment.[ab]

Treatment	Plants
	no. m^{-2}
Sweep plow	105 a
Disc	105 a
Harrow	145 ab
Skew treader	155 b
No-till	185 b

[a] Means within a column with different letters are significantly different at $P \leq 0.05$.

[b] Means are averaged over locations.

year. The east field was disked postharvest four times and the west field was disked postharvest once (Young and Thorne 2004). In the intensely managed east field, downy brome densities decreased from 600 plants m^{-2} initially to 8 plants m^{-2} at the conclusion of the study. In contrast, the initial downy brome density in the west field was 475 plants m^{-2} and concluded with 380 plants m^{-2}. In addition, downy brome seed in the top 15 cm of soil in the east field decreased from an initial density of 5,540 seeds m^{-2} to 0 seeds m^{-2} 5 yr later (Thorne et al. 2006). Downy brome seed density in the west field was 100 seeds m^{-2} initially and concluded the study with 6,015 seeds m^{-2}.

In general, the sweep plow and especially the disk influenced vertical seed distribution in the soil compared with no-till and harrowing, moving the seed throughout the soil profile to the 6- to 12-cm depth. Greatest seed densities were in the 0- to 3- and 3- to 6-cm depths with the disk and the sweep plow. In the spring, these depths and tillage had the lowest seed densities, which would indicate enhanced seed germination. This may be due to the sweep plow and the disk having more uniform seed age for a given depth (Yenish et al. 1992). At Harrington, a total of 1,110 seeds germinated in the no-till treatment and 970 seeds germinated in the disked treatment. The difference, however, was that 62% of the total seed germinated in the first fall in the no-till, whereas 89% of the seed germinated in the first fall in the disked treatment. In the subsequent winter wheat crop, the sweep plow and disk treatments reduced downy brome densities significantly compared with the no-till treatment. This study would indicate that postharvest tillage with the sweep plow and the disk would distribute downy brome seed throughout the soil profile, enhance weed seed germination, and decrease plant densities in the subsequent crop. The disadvantage of disking is the amount of residue left on the soil surface. In the long-term study, depending on depth of disking, wheat residue from the previous crop, and number of summer-fallow operations, the wheat–fallow system was out of compliance with the Food Security Act (Thorne et al. 2003) 2 of 4 yr.

A review of the literature did not find any research on the effect of the harrow and skew treader on weed seed distribution and weed densities. We are unsure as to why downy brome densities with the harrow were significantly less than in the no-till treatment in the subsequent wheat crop (Table 2), especially when data for the harrow treatment mimicked the data for the no-till treatment for seed densities. Although reductions in downy brome densities in winter wheat following postharvest tillage with a skew treader were not significant in this study, its use should be investigated further as it does appear to increase seed–soil contact and it retains residue on the soil surface for erosion control. Postharvest tillage should be integrated into an intense weed management effort for several rotation cycles to control downy brome in a winter wheat–fallow rotation, especially in the Pacific Northwest where fall and winter precipitation is plentiful to germinate downy brome seed.

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