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Effect of Land Rolling on Weed Emergence in Field Pea, Barley, and Fallow

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In the northern Great Plains, fields are land rolled after the planting of annual pulse and forage crops to push rocks back into the soil to prevent damage to harvest equipment. Field trials were conducted in 2004 and 2005 to determine if land rolling influenced weed density or biomass associated with field pea, forage barley, and summer fallow. The experiment included two planting dates, conventional and delayed, for both barley and pea. Separate fallow plots were included with each planting date. Preplant tillage was conducted with a field cultivator for all treatments. Across years, crops, and planting dates, land rolling approximately doubled densities of tumble mustard, Russian thistle, kochia, and redroot pigweed shortly after crop emergence and at harvest compared with nonrolled. Land rolling increased density of early-emerging green foxtail but density at harvest was not affected. Wild oat densities were not influenced by rolling. Weed biomass at harvest was greater after land rolling than nonrolled. Land rolling after planting decreased subsequent pea yield by 330 kg/ha, but did not influence water use or water use efficiency. Land rolling is advantageous by hastening depletion of soil broadleaf weed seed banks in forage barley, but may increase problematic broadleaf weeds in pea.
Nomenclature: Green foxtail, *Setaria viridis* (L.) Beauv. SETVI; kochia, *Bassia scoparia* (L.) A.J. Scott KCHSC; redroot pigweed, *Amaranthus retroflexus* L. AMARE; Russian thistle, *Salsola iberica* Sennen & Pau SASKR; tumble mustard, *Sisymbrium altissimum* L. SSYAL; wild oat, *Avena fatua* L. AVEFA; barley, *Hordeum vulgare* L.; pea, *Pisum sativum* L.
Key words: Cultural control, integrated weed management, planting date, weed seed banks.

Land rollers are commonly used in the northern Great Plains to push rocks back into soil after seeding short-statured pulse crops such as pea, lentil (*Lens culinaris* Medik.), and soybean [*Glycine max* (L.) Merr.]). Land rolling protects combine harvesters and prevents crop quality losses from soil staining of seed at harvest (Gregoire 2008; Olson et al. 2004; Saskatchewan Pulse Growers 2000). Annual cereal forages and established perennial hay crops, including alfalfa (*Medicago sativa* L.), also are land rolled in this region, primarily to protect forage-harvesting and feed-processing equipment. While pushing pebbles and rocks of 1 to 25 cm diam down to the soil surface, land rollers firm soil, including interrow areas that were not firmed by packer wheels at planting.

Most cropland weed infestations are initiated from the soil weed seed bank, and decreasing the density of weed seed banks has been a long-term goal for improved weed management in crops. Prevention of weed seed production is the most effective method to decrease weed seed-bank density over time. Breaking dormancy of weed seed and increasing the germination rate is another potential method to decrease weed seed-bank density. Techniques tested for their effectiveness in stimulating weed seed germination in the field include tillage and chemical applications (Egley 1986). As reviewed by Egley (1986), ethylene, nitrates, sodium azide, and several carbamate herbicides increased weed seed germination under field conditions. Another chemical, methyl bromide, is highly lethal to live seeds when properly applied to soil, but its use has become less common because of increased regulation due to its negative, long-term environmental effects on stratospheric ozone depletion and acute toxicity to applicators. Additionally, methyl bromide was not used in lower-value crops such as annual cereal hay or field pea because of high application costs. Gallandt (2006) concluded that tillage was the most promising method to deplete the weed seed bank, other than prevention of in-field weed seed production. However, in semiarid regions, tillage depletes soil water (Hatfield et al. 2001) and can increase soil erosion from wind and water action.

The development of multitactic cultural strategies has led to improved in-crop weed management systems in semiarid regions (Anderson 1999, 2008) that concomitantly decrease weed seed production and herbicide use (Anderson 2000). However, effective system components have not been developed, other than tillage, to increase the depletion rate of existing weed seed banks in semiarid cropping systems.

Packer wheels have long been used to improve soil–seed contact for more uniform crop emergence and subsequent maturity in semiarid regions (Djokoto et al. 1971; Widtsoe 1913). Packer wheels are positioned on seeding equipment to firm soil only over the seed row, leaving interrow soils unpacked. Utilization of a land roller may be viewed analogously to using a very large packer wheel that firms both seed row and interrow areas. Soil firming with land rollers may improve soil–weed seed contact and increase weed seed emergence. This study was conducted to determine if land rolling can influence weed seed germination and emergence, as measured by seasonal weed density and biomass at crop harvest.

Materials and Methods

The experimental site was located at the Roosevelt and Sheridan County Conservation District Farm, 11 km south of Froid, MT. Soil at the location was a Dooley sandy loam (fine-loamy, mixed, superactive, frigid Typic Argiustolls). Mean annual precipitation at the site is 340 mm, with about 75% occurring from April through September. The experimental area followed forage barley each year.

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The experiment was conducted in 2004 and 2005 and was designed as a split-plot randomized complete block. The whole-plot treatment was planting date. Subplots were a factorial of three cropping treatments with and without rolling. Cropping treatments were: (1) awnless 'Haybet' barley for hay production, (2) 'Majoret' field pea, and (3) summer fallow. Individual subplot size was 3.1 m by 9.1 m. There were four replicates of each subplot treatment combination within each of two planting dates, conventional and delayed.

Before preplant tillage and after crop harvest, samples were collected by hydraulic probe for gravimetric soil water determinations at five soil depths, 0–15, 15–30, 30–60, 60–90, and 90–105 cm. Samples were weighed, oven-dried, and reweighed. Water use efficiency as kg/ha per millimeter was calculated by dividing crop yield by water use, where water use was calculated as preplant water plus rainfall minus postharvest soil water.

Preplant conventional tillage was conducted with a field cultivator equipped with C-shanks and attached 45-cm-wide sweeps and coil-tooth spring harrows with 60-cm bars. Tillage depth, 7–8 cm, was controlled by stabilizer wheels on the field cultivator frame. Barley and pea were planted with a 3.1-m-wide drill with row spacing of 20.3 cm. The drill was equipped with double-shoot Barton[1] openers for low-disturbance planting and single-pass seeding and fertilization. Barley was planted at 78 kg seed/ha, with nitrogen supplied at 67 kg/ha as banded urea. Fertilizer was placed about 2.5 cm below and to the side of the seed row. Phosphorus (11-52-0) and potash (0-0-60) were applied on all barley and pea plots at 56 and 48 kg/ha, respectively, at planting. Phosphorus and potash placement was with the urea fertilizer band. Field pea was planted to establish 60 pea plants/m^2. Immediately after planting, land was rolled on appropriate barley, pea, and summer fallow plots. The roller consisted of a metal cylinder, 1.1-m diam by 3.1-m width (identical to individual plot width), attached to a carriage frame. Total weight of the roller was 2,415 kg. After tillage, rolling was observed to compress soil from 2 to 5 cm. Ballast, typically water, was not added to the roller for this study.

Early-emerging weeds from barley and summer fallow plots were counted when barley was at the two-leaf stage, and with pea at the three- to four-leaf stage. Weeds were identified by species and counted within five 0.1-m^2 circles per plot. After counts of early-emerging weeds, weeds were controlled in field pea with a POST application of bentazon[2] (0.5 kg ai/ha), sethoxydim[2] (0.1 kg ai/ha), ammonium sulfate (1.7 kg/ha), and crop oil[3] (1 L/ha). Herbicide treatments were applied with 8001 flat fan nozzles[4] at 241 kPa and the application volume was 38 L/ha. Barley planted for forage rarely is treated with herbicides in Montana, so this crop did not receive a herbicide application.

Barley and weeds were harvested when crop development was 5.5 to 5.7 on Zadoks scale (Zadoks et al. 1974) by hand-clipping two 0.5-m^2 quadrats per plot. Barley was separated from weeds. Weeds were identified, counted by species, and composited into paper bags. Weed and crop samples were transported to a laboratory, placed into a forced-air oven at 55 C until dry, and then weighed. Counting and harvest of weeds from summer fallow was done with identical methods on the same dates as barley harvest.

Pea yield and yield components were determined at crop maturity by hand-clipping two 0.5-m^2 subsamples per plot. Pod numbers were counted from each subsample, seed shelled, cleaned, oven-dried, counted, and weighed. Seeds per pod was determined by dividing total number of seed by the number of pods, and seed weight was determined by dividing total seed weight by the number of seeds.

Data were analyzed with SAS[5] using the mixed procedure with appropriate error terms for a split-plot analysis with planting date, land rolling, crop, and year factors considered fixed effects. Weed density data were $\log_{10}(n + 1)$ transformed before analyses. Weed data taken at harvest of field pea were analyzed separately from summer fallow and barley because field pea received POST herbicide treatment. Differences among treatments are reported as significant at the 0.05% level unless otherwise noted.

Results and Discussion

The conventional planting date was April 20 for both years. The delayed planting date was June 1 and May 23 for 2004 and 2005, respectively. Barley harvest dates were July 6 and 26, 2004, and July 1 and 15, 2005, for conventional and delayed planting dates. Pea harvest dates were August 2 and 31, 2004, and July 28 and August 5, 2005, for conventional and delayed planting dates. The 2004 and 2005 growing season rainfall was 9 and 43% above the long-term average of 249 mm.

The weed community was composed of 22 species. Green foxtail and wild oat were the two most numerous species observed. Redroot pigweed, Russian thistle, kochia, ribseed sandmat [*Chamaesyce glyptosperma* (Englm.) Small], and tumble mustard were the most numerous broadleaf weeds, comprising 27% of the total community. Together, these two grass and five broadleaf weeds comprised 98% of the observed individuals over the course of the study.

The main effects of land rolling, planting date, and year varied for numerous parameters, as did several two-way interactions between planting date and year. Interactions between land rolling and other treatment factors, however, were rarely significant. The primary focus of this research was on the influence of land rolling on weed density and biomass, so results for two-way interactions between planting date and year are not shown.

Weed Response to Land Rolling. At the early-season evaluation, land rolling had increased the density of 6 [green foxtail, kochia, prickly lettuce (*Lactuca serriola* L.), redroot pigweed, Russian thistle, and tumble mustard] of the 10 weed species evaluated (Table 1); the other four species, Canada cocklebur [*Xanthium strumarium* var. canadense (P. Mill.) Torr. & Gray], horseweed [*Conyza canadensis* (L.) Cronq.], ribseed sandmat, and wild oat, were not affected. Land rolling did not decrease the density of any of the weed species evaluated. The planting date by land rolling interaction varied for prickly lettuce and tumble mustard because these species

Table 1. Effect of land rolling on weed density as averaged over year, planting date, and crop.

Weed species/category	Early season[a]		Harvest[b]	
	Rolled	Nonrolled	Rolled	Nonrolled
	No./m^2			
Species				
Canada cocklebur	0.7	0.4	1.2	1.3
Green foxtail	24.1	15.8*	104.1	122.5
Horseweed	0.7	0.4	2.4	0.8*
Kochia	2.9	1.7*	17.4	6.4*
Prickly lettuce	1.1	0.2*	0.7	0.3
Redroot pigweed	2.6	0.8*	25.5	11.5*
Ribseed sandmat	0.1	0.1	18.6	8.8*
Russian thistle	4.9	2.7*	11.4	6.4*
Tumble mustard	9.5	3.3*	7.6	4.3
Wild oat	24.3	23.8	26.2	40.5
Categories				
Broadleaves	22.1	9.6*	87.5	42.8*
C_3 grasses	22.1	24.3	26.2	42.2
C_4 grasses	24.1	15.8*	105.2	127.2
Total weeds	71.4	49.8*	218.9	211.3

[a] Data pooled over planting date and year and barley, pea, and summer fallow.

[b] Data pooled over planting date and year and barley and summer fallow.

* Indicates significant difference between rolled and nonrolled treatments within early-season or harvest sample times according to *F* test (P = 0.05).

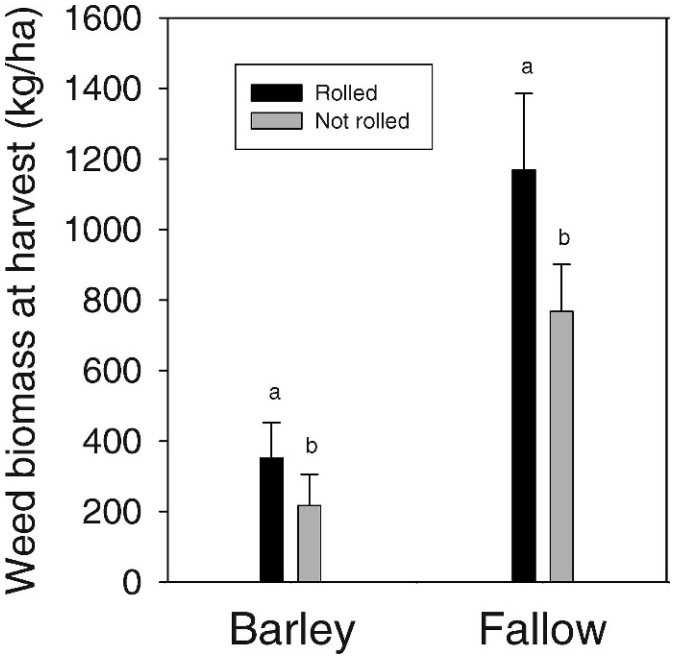

Figure 1. Effect of land rolling on weed biomass at harvest in barley and summer fallow averaged over conventional and delayed planting dates. Bars within a crop treatment with different letters are significantly different on the basis of the LSD (0.05) test.

predominantly were present after rolling from the conventional planting date (results not shown). Across the three crop treatments, densities of early-emerging broadleaf weeds, C_4 grasses (warm-season species), and total weeds were greater after land rolling compared with nonrolled. Density of C_3 grasses (cool-season species), predominantly wild oat, was not influenced by land rolling. Additionally, the treatment factor ''crop'', comprised of barley, pea, and summer fallow, did not vary for early-emerging weeds, indicating that land rolling after tillage likely will increase broadleaf emergence across a wide range of crop species, including other legumes that are rolled such as alfalfa, lentil, and soybean.

Weed density and timing of weed emergence relative to crop emergence influence crop–weed competition (Sanyal et al. 2008). Earlier-emerging weeds typically are more competitive with associated crops than later-emerging weeds. Land rolling increased early emergence and density of a wide range of weeds, providing both positive and negative management opportunities. Grass weeds such as green foxtail usually are not difficult to control with POST herbicide applications in pea and other pulse crops, and land rolling pulses may lead to improved control of green foxtail across time. However, increased density of broadleaf weeds is problematic in pea, lentil, and other pulse crops because of limited POST herbicide options. Several commonly used dinitroaniline herbicides are labeled for pea, lentil, and other pulse crops, but cruciferous weeds and prickly lettuce are poorly controlled by this herbicide class, indicating that land rolling may increase density of these weeds.

At the time of barley harvest, land rolling had increased densities of Russian thistle, kochia, redroot pigweed, ribseed sandmat, horseweed, and tumble mustard (P = 0.057) (Table 1) across barley and summer fallow. Total broadleaf weed density was greater with rolling, but grass and total weed density did not differ between rolled and nonrolled. Rolling increased weed biomass at harvest from barley forage and summer fallow (Figure 1). Barley is highly competitive with weeds, even though cultivars may differ in their competitiveness (Watson et al. 2006). Previous research has documented that forage harvest of barley as silage decreased wild oat seed production (Harker et al. 2003). In another study, barley harvested for hay prevented seed production of various weeds when planted early, even if herbicides were not applied (Lenssen 2008).

Targeting the weed seed bank to decrease crop yield losses due to weed competition has been difficult (Davis 2006; Egley 1986), especially in dryland farming systems with limited financial resources. Developing a multitactic cultural system, such as combining land rolling and planting barley specifically for forage harvest, may provide opportunities for dryland producers to concomitantly increase broadleaf weed emergence from the seed bank while preventing weed seed production, thus decreasing the seed bank. An additional benefit of a multitactic cultural system with forage barley is reduced herbicide use and costs by not utilizing preplant nonselective or PRE and POST in-crop herbicides.

Pea Response to Land Rolling. Land rolling resulted in decreased pea biomass, number of seed/m^2, and seed yield (Table 2). The decrease in pea yield could not be partitioned to the effect on a single component, as pea stand, pod number/m^2, seed/pod, seed weight, and harvest index were not influenced by land rolling. Likewise, neither water use of pea or summer fallow nor water use efficiency of pea was influenced by land rolling (Table 2), indicating that precip-

Table 2. Effect of land rolling on yield components, aboveground biomass, and water use of field pea averaged across two planting dates and 2 yr.[a]

Treatment	Yield components					Yield	Crop biomass	Weed biomass[b]	HI[c]	WU	WUE
	Plants	Pods	Seed	Seed	Seed						
	No./m^2		No./pod	mg/seed	No./m^2	kg/ha				mm	kg/ha per mm
Nonrolled	63	239	4.5	222	1,074 a	2,393 a	5,160 a	573 b	0.46	300	8.5
Rolled	59	219	4.2	218	933 b	2,062 b	4,435 b	850 a	0.46	292	8.0

[a] Means within columns followed by different letters differ at P = 0.05.

[b] Means within this column followed by different letters differ at P = 0.057.

[c] Abbreviations: HI, harvest index; WU, water use; WUE, water use efficiency.

itation was able to satisfactorily move into soil for subsequent plant use regardless of rolling treatment.

Land rolling pea increased weed biomass at harvest compared with biomass with pea that was not rolled (Table 2). Mean weed biomass of land-rolled plots was 48% greater than that associated with peas that were not land rolled. Overall, weed biomass associated with pea was greater than that associated with the more competitive barley and less than that associated with summer fallow due to the absence of any crop competition.

Management Implications. Commercial pea fields in the northern Great Plains are land rolled to protect expensive harvest equipment, improve ease of harvest, and protect crop quality. Although lentil was not included in this trial, the lack of differences among barley, pea, and summer fallow for density of early-emerging weeds would indicate that, in the absence of PRE herbicide application, pea and lentil likely would have similar early-season weed communities within a given site and environment. Pulse producers and researchers in Montana have observed that peas often are weedier crops than wheat. Part of the reason for that perception could be that wheat crops are almost never land rolled because cutting height at harvest typically is above exposed rocks. Land rolling increased early-season emergence of green foxtail and a suite of broadleaf weeds, including prickly lettuce, horseweed, and several crucifers, that are not well controlled by preplant herbicide applications in field pea. Therefore, pea production is recommended for sites that have lower weed pressure. One potential avenue to decrease early-emerging weed competition with pea may be to delay land rolling until the crop has reached the three- to four-leaf stage of the crop instead of rolling shortly after planting, as was done in this study. However, crop injury can occur if rolling is delayed beyond the three-to-four leaf stage. At this time, research has not been conducted to evaluate this potential management change.

Land rolling will continue to be part of the production practices in short-statured pulse crops such as pea and lentil to prevent damage to harvest equipment and crop quality, despite causing an increase in broadleaf weed recruitment. Consequently, development of improved multitactic management strategies remains an important goal for pulse production systems.

Land rolling an annual cereal forage crop such as barley may be an effective practice to decrease the broadleaf weed seed bank. Improved weed management opportunities exist for northern Great Plains producers through the deployment of land rolling and barley hay or silage production.

Sources of Materials

[1] Barton openers, CNH Flexicoil, Minot, ND 58702.

[2] Rezult®, BASF Corp., Research Triangle Park, NC 27709.

[3] Crop oil concentrate® nonionic adjuvant, Helena Chemical Co., Collerville, TN 38017.

[4] Flat-fan nozzles, TeeJet Spraying Systems Co., Wheaton, IL 60189.

[5] Statistical Analysis Systems. The SAS System for Windows, Release 9.1, SAS Institute Inc., P.O. Box 8000, Cary, NC 27512.

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