Ecology and Control of Russian Thistle (*Salsola iberica*) After Spring Wheat Harvest

William F. Schillinger*

Russian thistle is the most problematic broadleaf weed for spring-sown crops in the low-precipitation (< 340 mm yr^{-1}) region of the inland Pacific Northwest of the United States. A 6-yr field experiment was conducted at Lind, WA, to evaluate three postharvest control strategies for Russian thistle in continuous annual spring wheat. Postharvest treatments were (1) tillage with low-disturbance overlapping undercutter V-blade sweeps; (2) paraquat + diuron at the labeled rate, which is widely used by farmers; and (3) an untreated check (letting Russian thistle grow unhindered). The undercutter V-sweep consistently killed all Russian thistle with essentially no residue burial, and no seed was produced. In contrast, the paraquat + diuron treatment halted Russian thistle dry biomass production, but plants continued to extract soil water and produce an average of 310 seeds m^{-2} on the lower branches. In the check, Russian thistle produced an average of 700 kg ha^{-1} postharvest dry biomass and 5,670 seeds m^{-2}. The undercutter V-sweep treatment had significantly more water in the 180-cm soil profile at time of wheat harvest, after a killing frost in October, and in mid March as well as greater spring wheat grain yield compared with the herbicide and check treatments. Results show that postharvest tillage with an undercutter V-sweep consistently achieved 100% control, retained ample wheat residue on the surface to control erosion, and was by far the most effective treatment in this experiment.

Nomenclature: Diuron; paraquat; Russian thistle, *Salsola iberica* Sennen & Pau SASKA; wheat, *Triticum aestivum* L.

Key words: Annual cropping, drought, dryland spring wheat, soil water depletion.

Russian thistle is a C_4 summer annual broadleaf weed with a deep and aggressive root system and prolific seed production that presents a formidable obstacle to successful dryland spring cropping in the western United States and Canada. Winter wheat–summer fallow (one crop every other year) is the dominant crop rotation in the < 340 mm yr^{-1} region of east-central Washington and north-central Oregon. This region covers 1.8 million ha of dryland crops and is by far the largest contiguous dryland cropping zone in the western United States (Schillinger et al. 2006). Farmers are interested in substituting a spring crop (mostly spring wheat) for summer fallow in some years. Russian thistle infestation is most severe in spring wheat (Young 1986) and other spring-sown crops that have slow early growth and canopy closure compared with winter wheat that grows vigorously in early spring. Infestation is most acute if crop competition is reduced by poor stands, drought, inadequate fertility, and late growth.

Russian thistle seedlings first emerge in March or April, flower in June, and produce seed beginning in August. Russian thistle infestation in spring wheat is generally greatest during drought years and can reduce grain yield by 50% (Young 1988). After wheat is harvested in late July or early August, Russian thistle reinitiates root elongation (Pan et al. 2001) and rapidly produces aboveground biomass. The root system of Russian thistle can extend 5 m in diameter and at least 2 m deep (Holm et al. 1997) and can extract soil water down to 2% by volume, well beyond the available range for wheat that rarely extracts water below 4% by volume. Schillinger and Young (2000) reported that individual Russian thistle plants allowed to grow in a grid pattern without competition from other weeds used 70 L of soil water growing within a spring wheat crop and an additional 100 L of soil water between wheat grain harvest and killing frost in late October. At maturity, Russian thistle plants often break off at the soil line and tumble long distances with the wind,

widely dispersing seed for several kilometers (Stallings et al. 1995).

Farmers and scientists have many questions concerning mechanical vs. chemical methods for postharvest control of Russian thistle after wheat harvest. Given the large quantity of Russian thistle seed that is spread throughout the region every year, some question whether postharvest control is even practical. This study was conducted in consultation with an advisory committee of 22 regional dryland wheat farmers. The farmers asked for this research on postharvest ecology and control of Russian thistle.

Materials and Methods

Treatments. A 6-yr field study was conducted during the 2000 through 2005 crop years at the Washington State University Dryland Research Station at Lind, WA. The objective of the study was to compare postharvest control methods on the growth and seed production of Russian thistle, soil water dynamics, and subsequent effects on grain yield of continuous spring wheat. Treatments were (1) tillage at a depth of 7 cm with low-disturbance overlapping adjustable-pitch 81-cm-wide V-blade Haybuster[1] undercutter sweeps[1] on 63-cm centers conducted 7 d after wheat harvest, (2) application of 0.43 kg ai ha^{-1} paraquat + 0.21 kg ai ha^{-1} diuron with 0.47 L of T-11 nonionic surfactant in 190 L water ha^{-1} 7 d after wheat harvest, and (3) untreated check (do nothing after wheat harvest, let Russian thistle grow). The Haybuster undercutter retains more than 90% of wheat stubble on the soil surface because the wide, narrow-pitch, overlapping V-blades slice through the soil with minimum lifting and stirring compared with traditional sweep implements. Paraquat + diuron (Surefire[2]), at the rate used in this experiment, is the most widely recommended and commonly used herbicide for postharvest control of Russian thistle in the inland Pacific Northwest (J. P. Yenish, personal communication). All three treatments provide excellent control of wind erosion by providing year-round vegetative surface cover.

* Department of Crop and Soil Sciences, Washington State University, Dryland Research Station, P.O. Box B, Lind, WA 99341. Corresponding author's E-mail: schillw@wsu.edu

Table 1. Precipitation at Lind, WA, during six crop years (2000 to 2005) compared with the 85-yr average.

	Precipitation					
Year	August–March	April	May	June	July	12-mo. total
	mm					
2000	192	11	18	20	12	253
2001	141	29	7	20	1	198
2002	166	9	23	19	9	226
2003	181	29	5	0	0	215
2004	151	15	16	7	0	189
2005	133	9	24	10	9	185
6-yr average	161	17	16	13	5	211
85-yr average	176	18	20	20	7	241

The experimental design was a randomized complete block with four replications and 7 by 60-m plots. Treatments were maintained continuously on the same parcel of land throughout the study to determine the cumulative long-term effects of the three postharvest treatments in annual spring wheat production. The soil is a Shano silt loam (coarse-silty, mixed, superactive, mesic Xeric Haplocambids) that is more than 2 m deep with no rocks or restrictive layers, and slope was < 1%. Mean (85 yr) annual crop–year (1 September to 31 August) precipitation is 242 mm (Table 1). Crop–year precipitation during the 6-yr study was 88% of the long-term average and below the long-tem average during all but one year (Table 1).

Field Layout. In late February or early March, 0.32 kg ae ha^{-1} glyphosate was applied across the entire experiment area to control winter-annual grass weeds and volunteer wheat. Between March 10 and March 25, the entire experiment area was uniformly planted with no prior tillage to 'Alpowa' soft white spring wheat at 67 kg ha^{-1} (approximately 200 seeds m^{-2}) with a custom-built no-till drill equipped with cross-slot notched-coulter openers on 20-cm-wide row spacing. Liquid fertilizer and seed were delivered simultaneously in the same row with fertilizer placed 2 cm below and 3 cm to the side of the seed. Over the 6 crop years, an average fertilizer rate of 21 kg N, 14 kg P, and 7 kg S ha^{-1} was applied based on available soil water in March and soil fertility test. Excellent wheat stands were achieved every year.

In-crop broadleaf herbicides were applied with a commercial-size spray applicator across the entire experiment area between the spring wheat tillering and jointing stage (Large, 1954) in May. Weeds present were Russian thistle with lesser quantities of tumble mustard (*Sisymbrium altissimum* L.), tansy mustard (*Descurainia pinnata* Walt.), horseweed (*Conyza canadensis* L.), prickly lettuce (*Lactuca serriola* L.), and common lambsquarters (*Chenopodium album* L.). In crop herbicides used were 0.5 kg ai ha^{-1} bromoxynil (2000), 0.49 kg ae ha^{-1} 2,4-D ester + 0.07 kg ae ha^{-1} dicamba (2001, 2003, and 2005), and 0.014 kg ai ha^{-1} carfentrazone + 0.07 kg ae ha^{-1} dicamba (2002 and 2004). These herbicide combinations, rates, and year-to-year rotation of herbicides with different modes of action, are commonly used by regional farmers for in-crop broadleaf weed control in dryland wheat. All weeds (except Russian thistle) were, in essence, completely controlled with the in-crop broadleaf herbicide, whereas approximately 70% of Russian thistle plants were killed and the remainder severely stunted. Stunted Russian thistle tended to renew growth within 2 to 4 wk after application of the in-crop broadleaf herbicide. In addition, new flushes of Russian thistle germinated and emerged following rainfall events of 3 mm or more in late April, May, and early June. Downy brome (*Bromus tectorum* L.), the most troublesome annual grass weed in winter wheat, was completely controlled with glyphosate before planting spring wheat and was not a factor in the study.

Grain Yield and Russian Thistle Measurements. In late July to early August, spring wheat grain yield was determined by harvesting a swath through each 60-m-long plot with a Hege[3] 140 plot combine with 1.5-m-wide cutting platform operated 20 cm above the ground. The plot combine was equipped with a custom-built blowing air system to uniformly distribute straw and chaff. Immediately thereafter, a commercial combine equipped with a straw chopper and chaff spreader was used to harvest the entire experiment area cutting 20 cm above the ground. The top of some Russian thistle growing in the wheat crop was cut off during harvest.

Within 2 d following grain harvest, the aboveground portion of all Russian thistle within a 1-m-diam sampling hoop randomly positioned in each plot were clipped, gathered, placed in paper bags, allowed to air dry in a low-humidity greenhouse, and weighed. This same procedure was repeated in mid-to-late October after Russian thistle had been killed by frost. After weighing, the early August samples (taken before seed production) were discarded. Russian thistle from the mid-to-late October sampling was hand threshed and screened and seed was collected, cleaned, and counted. For samples with more than 500 seeds, 500 seeds were counted and weighed and their weight was then divided into the total seed weight to determine seed produced per sample (i.e., per unit area). Seed germination was determined by placing 50 seeds from each sample between two sheets of moistened germination paper (pH 7.0) in a petri dish and storing in a darkened 21 C enclosure for 7 d. Germination was considered to have occurred when the seeds uncoiled and the cotyledon and radical emerged.

Soil Water Measurement. Following the application of the postharvest tillage and herbicide treatments 7 d after harvest, three neutron probe access tubes were installed at distances of 15, 30, and 45 m from the edge of each plot (total of 36 access tubes). A water-absorbing bentonite material was applied around each access tube to prevent movement of precipitation down the outside surface of the tube during the wet winter months. The inner surface of each access tube was sealed with a rubber stopper throughout the winter. Soil water content was measured to a depth of 180 cm in early August soon after grain harvest, in late October after Russian thistle was killed by frost, and again in mid March just before spring planting. Volumetric soil water content in the 30 to 180-cm depth was measured in 15-cm increments by neutron thermalization (Hignett and Evett 2002). Volumetric soil water content in the 0 to 30-cm depth was determined from two 15-cm core samples using gravimetric procedures as described by Top and Ferre (2002). Access tubes were removed from the experiment site before planting spring wheat.

Statistical Procedures. ANOVA was conducted for (1) Russian thistle dry matter on both early August and mid-to-
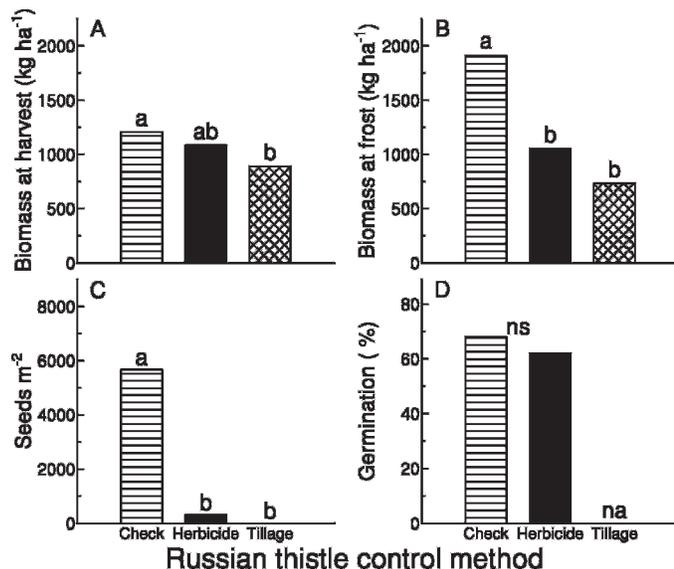
Figure 1. Growth of Russian thistle as affected by three postharvest control methods: (A) dry biomass at time of wheat harvest in late July or early August, (B) dry biomass after killing frost in October, (C) seed produced between wheat harvest and killing frost, and (D) seed germination percentage. Six-year averages followed by the same letter are not significantly different at P < 0.05. Abbreviations: ns, not significant; na, not applicable.
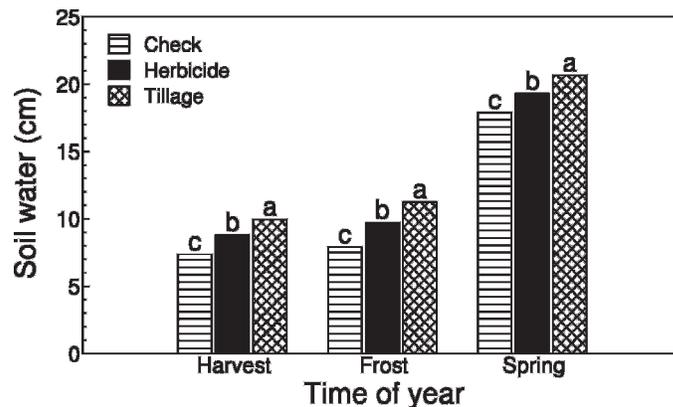

Figure 2. Water content in the 180-cm soil profile in early August, just after wheat harvest; at time of killing frost in mid-to-late October; and in early spring as affected by three postharvest Russian thistle control methods. Within-time period averages followed by a different letter are significantly different at P < 0.05. Data are the average for the 6-year study.

late October sampling dates, (2) Russian thistle seed production, (3) germination percentage of Russian thistle seed, (4) volumetric water content in the 180-cm soil profile in early August, late October, and mid March, and (5) grain yield of spring wheat. As the treatments were kept on the same plots for the entire study (i.e., no rerandomization of treatments occurred from year to year), a repeated-measures analysis was conducted with years as the repeated measure. Repeated measures refer to multiple measurements on the same experimental unit. Treatment means were considered significantly different at P < 0.05.

Results and Discussion

Ecology of Russian Thistle. Average Russian thistle dry biomass at time of grain harvest ranged from 890 kg ha^{-1} for the tillage treatment to 1,200 kg ha^{-1} for the check (Figure 1A). The greatest Russian thistle dry biomass at grain harvest in all treatments was produced in 2002 (average of 1,930 kg ha^{-1}), presumably because of emergence flushes after ample May and early June rainfall (Table 1). Russian thistle will frequently produce greater dry biomass than the spring wheat crop that it infests by time of grain harvest (Schillinger et al. 1999).

By the mid-to-late October killing frost, Russian thistle dry biomass in the untreated check had increased an average of 700 kg ha^{-1} (63% net gain) since grain harvest, considerably less than the sevenfold increase in postharvest dry biomass produced by individual Russian thistle plants reported by Schillinger and Young (2000) during years when overwinter precipitation and corresponding water infiltration deep into the soil profile were much greater than average. In all years, there was no increase in postharvest dry biomass in the herbicide treatment, and there was a decline in the tillage treatment because some dead Russian thistle plants were carried from the field by wind after their roots were severed by

the undercutter sweep implement (Figure 1A and 1B). There was no year by treatment interaction for either dry biomass obtained after harvest or after killing frost.

An average of 5,670, 310, and 0 Russian thistle seed m^{-2} was produced in the untreated check, herbicide, and tillage treatments, respectively, by the time of the killing frost (Figure 1C). Seed production in the check ranged from 1,550 (2005) to 16,500 (2003) seed m^{-2}. Most of the seed in the herbicide treatment was produced on the lower branches where the herbicide did not fully penetrate the canopy. There was no year by treatment interaction for Russian thistle seed production. Although not part of this experiment, the efficacy of two rates of glyphosate (0.44 and 0.64 kg ae ha^{-1}) and a high rate of 0.62 kg ai ha^{-1} paraquat + 0.31 kg ai ha^{-1} diuron with two nonionic surfactants were evaluated for postharvest control of Russian thistle at Lind in 2002. Although the glyphosate applications eventually killed the Russian thistle, a substantial quantity of viable seed was produced in all treatments (data not shown).

Russian thistle seed germination averaged 68 and 62% for the untreated check and herbicide treatments, respectively (Figure 1D). Russian thistle seed germination ranged from 40 to 88% over the 6 yr (data not shown), but there was no significant difference between the check and herbicide treatments in any year.

Young and Thorne (2004) suggested that Russian thistle may not be as problematic in no-till spring wheat compared with tilled spring wheat because tillage is more likely to stimulate Russian thistle germination. This does not appear to be the case in this or other related studies at Lind, where Russian thistle is always present in spring wheat regardless of tillage regime.

Soil Water. Soil water content among treatments at grain harvest was significantly different every year, except 2002, as well as the 6-yr average (Figure 2). The tillage and herbicide treatments had, on average, 2.59 and 1.45 cm more soil water, respectively, than the check.

At time of killing frost in October, the check, on average, had gained only 0.53 cm of soil water since grain harvest because Russian thistle had used residual soil water, as well as some of the rain that occurred after harvest, to produce additional dry biomass (Figure 1A and 1B). After grain
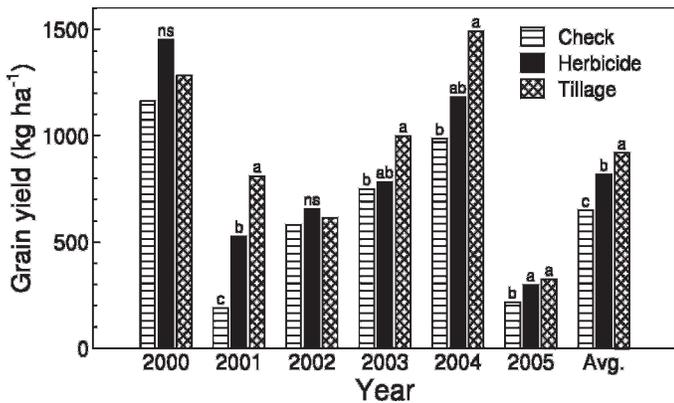
Figure 3. Spring wheat grain yield as affected by three postharvest Russian thistle control methods. Within-year and 6-year-averages followed by the same letter are not significantly different at P < 0.05. Abbreviation: ns, not significant.

harvest, Russian thistle dry biomass accumulation in the herbicide treatment ceased, but still gained less soil water (0.91 cm) from harvest to killing frost compared with the tillage treatment that gained 1.30 during the same period (Figure 2). This indicates that Russian thistle continued to extract soil water after herbicide application to produce seed (i.e., not vegetative biomass).

Between late October and mid March, slightly more precipitation was stored in the untreated check compared with the herbicide and tillage treatments. This compensated for some of the water used by Russian thistle in the check from August to October and was probably because of two factors (1) a dry soil will store a greater portion of overwinter precipitation than a wetter soil, and (2) overwinter precipitation storage will generally increase with added surface residue (in this case dead Russian thistle plants) (Papendick and McCool 1994). Overwinter precipitation storage efficiency (the percentage of precipitation that occurred from grain harvest until mid March that was stored in the soil) was 66% for all treatments when averaged over the 6 yr. Thus, the significant differences in soil water content among treatments that occurred beginning in year 1 of the experiment remained proportionally the same from grain harvest until mid March throughout the 6 yr (Figure 2).

Wheat Grain Yield. Annual crop–year precipitation during the study ranged from 173 to 237 mm and averaged 209 mm compared with the 85-yr-average of 242 mm (Table 1). Growing-season (April, May, June) precipitation, which is more important than stored soil water for wheat grain yield (Leggett 1959), was also only 79% of the long-term average (Table 1).

The 6-yr average spring wheat grain yield was 914, 813, and 645 kg ha^{-1} for the tillage, herbicide, and check treatments, respectively (Figure 3). A significant year by treatment interaction was observed for grain yield. Because of this interaction, grain yield data are presented for each year. Drought curtailed grain yield in all years, especially in 2005 (Table 1; Figure 3). Although there were no differences in grain yield among treatments in 2000 and 2002, the trend is clearly reflected in the 6-yr average where tillage, herbicide, and check treatments were significantly different from each other. A simple linear regression coefficient of determination for the relationship of water content and grain yield showed (P < 0.001) that 51% of the difference in spring wheat grain

yield among treatments was attributable to soil water content at time of planting in mid March.

Although economic assessment was not included in this study, production of continuous annual spring wheat was clearly not viable economically during the drought years of the study. During the same years, winter wheat–summer fallow grain yield averaged 2,400 kg ha^{-1} (one crop every other year) in adjacent fields. In a long-term dryland cropping-system experiment located 16 km northeast of the Lind Research Station during the same years of this study, Nail et al. (2005) reported that continuous annual spring wheat was not economically viable compared with winter wheat–summer fallow when annual precipitation is less than average. Schillinger (2005) recommended a minimum of 12.5 cm of plant-available soil water at time of planting for farmers to consider planting dryland spring cereals in the inland Pacific Northwest. This equates to 21.5 cm of total water in a 150-cm soil profile because spring wheat generally does not extract water below 6% by volume, i.e., it is less efficient at extracting water than winter wheat (Schillinger et al., 2007). Below this soil water level, farmers are encouraged to summer fallow in lieu of planting spring cereals. This minimum recommended level of plant-available soil water for planting spring wheat was not present in any year of the study.

Conclusions

Postharvest use of low-disturbance undercutter sweeps retained more than 90% of wheat stubble on the soil surface and provided 100% control of Russian thistle with significant soil water savings and enhanced grain yield of the subsequent wheat crop compared with the other treatments. Paraquat + diuron at 0.43 + 0.21 kg ha^{-1}, the most widely used herbicides by regional farmers for postharvest control of Russian thistle, damaged the upper and middle branches and halted dry biomass production. However, Russian thistle continued to deplete soil water and to produce an average of 310 seed m^{-2} before killing frost. The untreated check had the greatest postharvest soil water use, Russian thistle dry biomass, and seed production (5,670 seeds per m^{-2}), and the lowest wheat grain yield.

Spring wheat can be successfully produced in the inland Pacific Northwest. However, farmers should not plant spring wheat if < 12.5 cm of plant-available water is present in the soil; conservation tillage summer fallow is more appropriate. Effective postharvest control of Russian thistle is a prerequisite for successful spring wheat production.

Sources of Materials

Acknowledgments

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