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WEED MANAGEMENT

Soil Water Use and Growth of Russian Thistle after Wheat Harvest

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ABSTRACT

Russian thistle (*Salsola iberica* Sennen and Pau) is a major broadleaf weed in dryland crops (<300 mm annual precipitation) in the Pacific Northwest of the USA. Russian thistle frequently infests wheat (*Triticum aestivum* L.) and other spring-sown crops, especially during drought. Quantitative information on water use, biomass accumulation, and seed production of Russian thistle after wheat harvest is lacking. In a 2-yr field study at Lind, Washington, Russian thistle plants were allowed to grow yearly in spring wheat in a grid pattern without competition from other weeds. Individual Russian thistle plants used 70 L of soil water while growing with the crop. From wheat harvest in early August until killing frost in late October, each Russian thistle used an additional 100 L of soil water. Water use occurred within a 1.5-m radius of the Russian thistle. Spring wheat competed with Russian thistle for water at shallow soil depths; most water use by Russian thistle was from deeper than 1.0 m. Russian thistle dry weight increased from 170 to 1280 g per plant between grain harvest and killing frost. Russian thistle seeds were either not produced or germinable until mid-September. By late October, individual plants had produced 67 000 and 25 000 seeds in 1996 and 1997, respectively. In low crop residue situations, rapid post-harvest growth by Russian thistle (before seed production) provides valuable surface cover for erosion control, but with the prospect that soil water may be reduced for the subsequent crop.

Russian thistle is a summer annual weed that has long plagued crop production in arid and semiarid regions of the western United States and Canada (Dewey, 1893). It is the dominant broadleaf weed in the 1.8 million ha dryland (150 to 300 mm annual precipitation) crop production region of the inland Pacific Northwest. The traditional cropping system is winter wheat with tillage-intensive fallow in alternate years. Drawbacks to the wheat–fallow system include: (i) recurrent wind and water erosion (Papendick, 1998), (ii) decline in soil organic matter due to carbon loss by biological oxidation exceeding carbon input from residue (Rasmussen and Parton, 1994), and (iii) inefficient storage of precipitation in the soil during the spring–summer of the fallow cycle and the fall–winter of the crop cycle (Ramig and Ekin, 1991). Consequently, many growers in this dryland region are increasing the intensity of spring cereal cropping (i.e., decreasing the frequency of fallow) and reducing or eliminating tillage.

Russian thistle presents a formidable obstacle to successful dryland spring cropping. Spring wheat and spring barley (*Hordeum vulgare* L.) have less early growth and slower canopy closure compared with winter wheat, which grows vigorously in early spring. Infestation is most severe when 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. Grain yield of spring cereals may be reduced by 50% or more in severe infestations (Young, 1988). Grain quality also is diminished when green Russian thistle biomass and seed contaminate the grain and increase moisture (Holm et al., 1997). Russian thistle also infests broadleaf crops that are needed to diversify the present cereal-only cropping system. Herbicides for Russian thistle control in broadleaf crops are either not labeled, have rotational restrictions, or require incorporation and, therefore, are not compatible with no-till systems.

The root system of Russian thistle can extend 2 m deep and 5 m in diameter (Holm et al., 1997). Russian thistle is a C_4 plant with high water use efficiency (Dwyer and Wolde-Yohannis, 1972). When not controlled, mature plants dislodged from the soil by wind, decay, or tillage can scatter seed over several kilometers (Stallings et al., 1995). Growers typically either till with V-shaped sweeps or use herbicides for post-harvest Russian thistle control before the onset of seed production. Sweep tillage cuts the Russian thistle roots, but also buries some crop residue, and severed Russian thistle (tumble weeds) blow away. This is a concern in low-residue situations where Russian thistle stands have often produced more dry biomass than the crop by time of grain harvest in late July to early August (Schillinger et al., 1999). Therefore, dead Russian thistle may be an important source of surface cover for erosion control, especially if beginning a 13-mo-long fallow cycle. In addition, increased quantities of residue enhance over-winter water storage (Papendick and Miller, 1977). When post-harvest control is with herbicides, Russian thistle generally remains anchored in the soil or trapped by standing stubble or snow.

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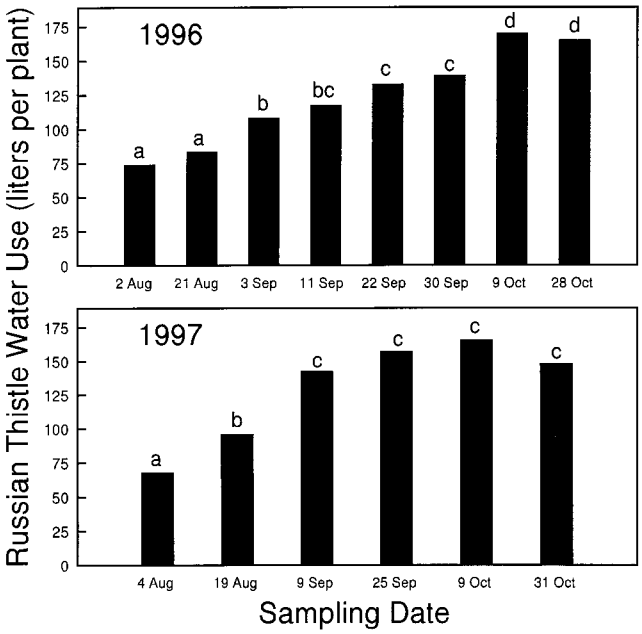

Fig. 1. Post-harvest soil water use by undisturbed Russian thistle in spring wheat stubble from wheat harvest in early August until killing frost in late October in 1996 and 1997. Within-year means followed by the same letter are not significantly different at the 0.05 probability level using Fisher's protected least significant difference.

For growers to convert from traditional winter wheat–fallow to more intensive farming involving spring crops, further understanding of the ecology and management of Russian thistle is needed. The objective of this study was to determine the effects of individual Russian thistle plants when allowed to grow uncontrolled in spring wheat and after crop harvest on: (i) the extent and pattern of soil water extraction and effect on over-winter soil water content, (ii) post-harvest Russian thistle dry biomass accumulation, and (iii) timing and magnitude of Russian thistle seed production.

METHODS AND MATERIALS

Overview and Field Layout

A 2-yr field study was conducted from February 1996 to March 1998 at the Washington State University Dryland Research Station at Lind, WA. The soil is a deep (>2 m to bedrock) Shano silt loam (coarse-silty, mixed, superactive, mesic Xeric Haplocambids) with <1% organic matter in the surface 0.1 m. Mean annual precipitation is 244 mm, which is less than any other state or federal nonirrigated crop research facility in the United States.

In late February of 1996 and 1997, 0.32 kg acid equivalent (ae) ha^{-1} glyphosate [N-(phosphonomethyl)glycine] was applied (in stubble) to control winter annual grass weeds and volunteer wheat before planting spring wheat. Plots were tilled with a duck-foot cultivator with an attached 4-bar harrow and fertilized with a liquid urea–ammonium nitrate solution (320 g N kg^{-1}) plus ammonium polyphosphate and ammonium thiosulfate at 56 kg N, 18 kg P, and 11 kg S ha^{-1}, with shanks spaced 0.3 m apart. In mid-March of each year, hard red spring wheat (cv. Butte 86) was sown at 78 kg ha^{-1} with a double-disc drill in 150 mm-wide rows. When wheat tillered in mid-to-late April, paper cups were placed over 100 juvenile Russian thistles in a 6 x 6-m grid (one plant every 36 m^2). Unprotected Russian thistle were killed with 0.42 kg a.i. ha^{-1} bromoxynil (3,5-dibromo-4-hydroxybenzonitrile). Russian thistle that germinated later were removed by hand. Wheat was harvested with a combine cutting 0.3 m above the ground on 1 August both years. About 20% of total Russian thistle green biomass was removed from the top of each of the 100 plants during harvest.

Soil Water Use

Within 2 d after wheat harvest, aluminum access tubes were installed at distances of 0.3, 0.6, 0.9, 1.5, and 3.0 m from the base of individual Russian thistle plants. The experimental design was a randomized complete block with 6 replications (i.e., individual Russian thistle plants), with each block containing the set of 5 access tubes. The access tube located 3.0 m from each plant was the control treatment from which we assumed no water extraction by Russian thistle would occur.

At about 13-d intervals from the first week of August until after killing frost in late October, soil volumetric water content was measured in 0.15-m increments to a depth of 1.8 m by neutron attenuation (Gardner, 1986). Overall mean water use by the six individual Russian thistles on each sampling date was determined by summing water depletion for each distance (compared with the control treatment located 3.0 m from the target Russian thistle) and using conversion factors to calculate the surface area represented by the respective access tubes. Neutron access tubes located 0.3, 0.6, 0.9, and 1.5 m from individual Russian thistle plants represented surface areas of 0.66 m^2, 1.17 m^2, 1.75 m^2, and 3.72 m^2, respectively (7.30 m^2 collectively). Access tubes remained in place over the winter, until soil water recharge was measured in late February or in March of the following year.

An analysis of variance (ANOVA) was conducted for soil water on every measurement date for each 0.15-m depth increment as well as the entire 1.8 m soil profile. Treatments were considered significantly different at $P < 0.05$. Treatment means for all ANOVA in this study were separated using Fisher's protected least significant difference.

Dry Biomass Accumulation, Seed Production, and Germination

On the same dates soil water was measured, change over time in dry biomass accumulation, seed production, and germination percentage (1997 only) of Russian thistle was determined using a completely randomized experimental design with sampling dates as treatments and Russian thistle plants as replications. On each sampling date, the above-ground portions of six Russian thistle plants of similar size and shape to those used for water use measurements were collected from the 6 x 6 m grid, bagged (without seed shatter), and placed in a low-humidity greenhouse. In January, plants were weighed, hand-threshed, and screened and seed was collected, cleaned, and counted. When <500 seeds were produced by a plant, seeds were counted individually. For plants with >500 seeds, 500-seed-samples were counted and weighed for each Russian thistle, then the weight divided into the total seed weight to determine seed produced per plant. Seed germination was measured in January for all plants collected on each date (1997 only) by placing 50 seeds from each plant between two sheets of moistened germination paper (pH 7.0) and storing them in a darkened 21°C enclosure for 7 d (Wallace et al., 1968). Germination was considered to have occurred when the seeds

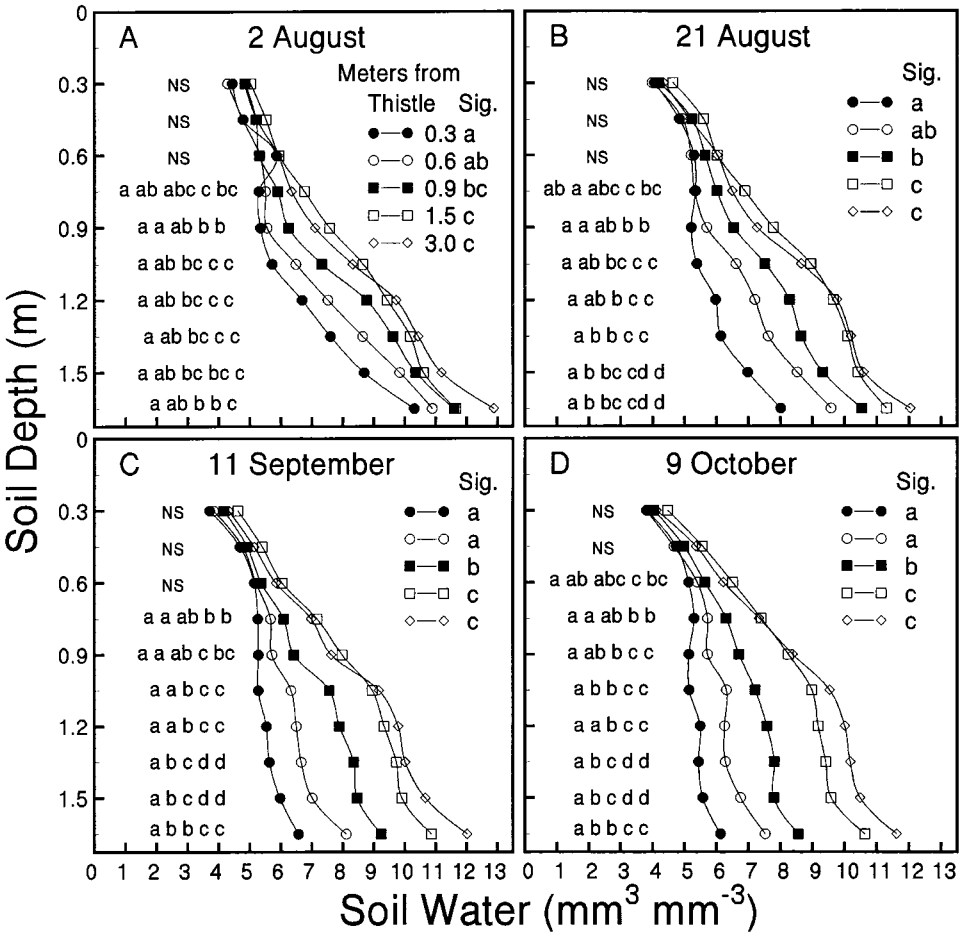

Fig. 2. Soil water use by Russian thistle to a depth of 1.8 m on 4 sampling dates in 1996. Neutron attenuation measurements were from 0.3, 0.6, 0.9, 1.5, and 3.0 m from the base of six individual Russian thistle plants. Letters in the column (in upper right corner for each date) show differences in the total 1.8 m soil profile, whereas letters in rows show differences at every sampling depth on each date. Means followed the same letter are not significantly different at the 0.05 probability level.

uncoiled and the cotyledon and radical emerged. Change in dry biomass accumulation, seed production, and germination percentage among sampling dates were considered significantly different at $P < 0.05$.

RESULTS AND DISCUSSION

Soil Water Use

At spring wheat harvest on 1 August in 1996 and 1997, individual Russian thistle plants had already used 70 L or more water (Fig. 1). Spring wheat competed with Russian thistle for water at shallow soil depths, as evidenced by no differences in soil water content among access tube treatments in early August until depths of 0.75 m in 1996 (Fig. 2a) and 1.2 m in 1997 (Fig. 3a). However, Russian thistle already had depleted soil water below these depths at harvest. These data agree with scanner rhizotron root observations in a separate study at Lind in 1997 showing prolific lateral rooting of Russian thistle at soil depths of 0.6 m and below (W.L. Pan, unpublished data).

Measured water extraction by Russian thistle was always greatest closest to the plant and decreased proportionate to distance from the plant on all August-to-October sampling dates during both years (Fig. 2 and 3). Whereas spring wheat extracts water relatively inefficiently from soil depths deeper than 1.0 m (W.F. Schillinger, unpublished data), Russian thistle aggressively reduced soil water content at 0.3 m from the plant to 5- to 6-mm^3 mm^{-3} throughout the entire 1.8-m profile in 1996 (Fig. 2c and 2d) and to a depth of 1.35 m in 1997 (Fig. 3c and 3d). Individual Russian thistles did not extract water beyond a 1.5-m radius of the base of the plant, as there were no significant water differences at any depth or on any sampling date between measurements obtained 1.5 m and 3.0 m from the Russian thistle plants (Fig. 2 and 3). In both years, Russian thistle depleted soil water until killed by hard (−4°C) frost on 23 October 1996 and 25 October 1997 (Fig. 1, 2, and 3). Individual plants had removed an average of 170 L of residual soil water by late October (Fig. 1), in addition to most of the August-through-October precipitation (62 mm in 1996 and 46 mm in 1997). The 170 L amounts to 23 mm of soil water from within the 7.3-m^2 extraction zone of each Russian thistle, or 233 000 L ha^{-1} if plants were uniformly spaced 3.0 m apart. The loss of this

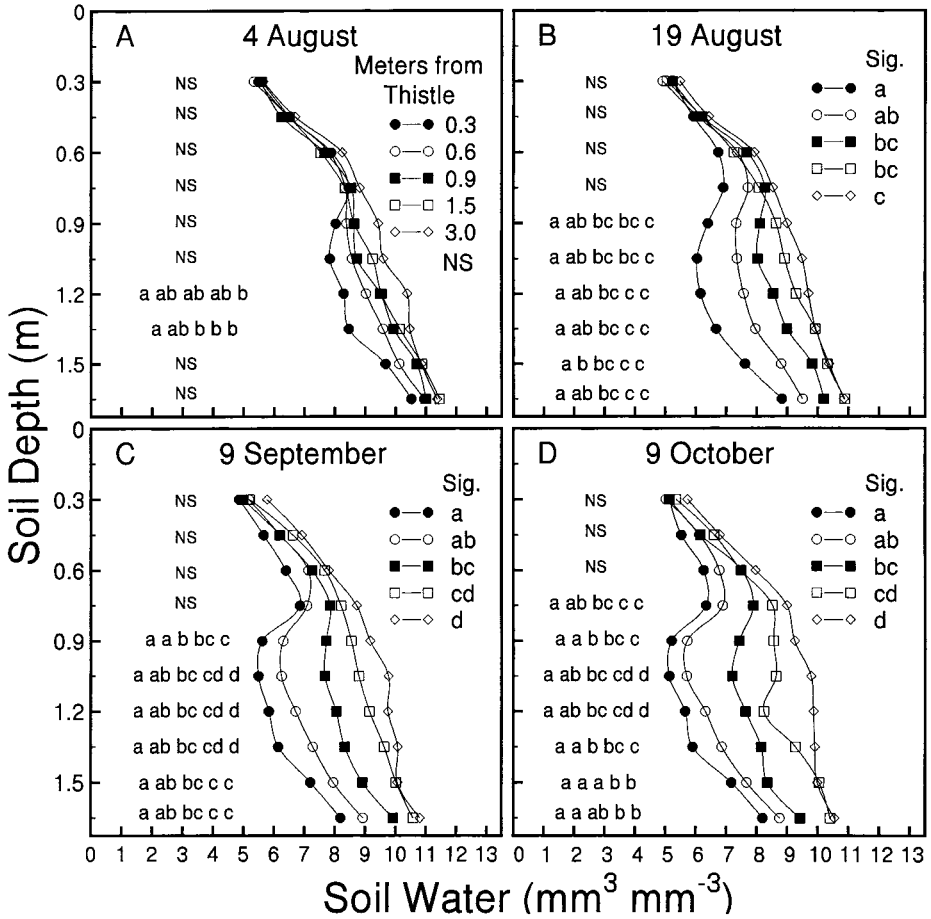

Fig. 3. Soil water use by Russian thistle to a depth of 1.8 m on 4 sampling dates in 1997. Neutron attenuation measurements were from 0.3, 0.6, 0.9, 1.5, and 3.0 m from the base of six individual Russian thistle plants. Letters in the column (in upper right corner for each date) show differences in the total 1.8 m soil profile, whereas letters in rows show differences at every sampling depth on each date. Means followed the same letter are not significantly different at the 0.05 probability level.

quantity of soil water would reduce grain yield of a subsequent wheat crop by ≈425 kg ha^{-1}, according to Leggett (1959).

Over-Winter Soil Water Recharge

In the Pacific Northwest, soil water recharge occurs during fall and winter. Precipitation at Lind between 1 October and 1 March was 241 mm in 1996–1997 and 140 mm in 1997–1998, compared with the 80-yr average of 134 mm. Surface soils were only briefly frozen during both winters and water did not runoff from the site either year. After the wet 1996–1997 winter, partial soil water recharge had occurred to a depth of at least 1.8 m and soil water content in the control treatment (3.0 m from the Russian thistle plant) was significantly higher than other treatments (Fig. 4a). We are uncertain why water differences occurred from 1.5 m and 3.0 m from Russian thistle in March 1997 (Fig. 4a) when there were no differences between these two treatments in October 1997 (Fig. 2d).

Precipitation between 1 October and 1 March was close to the long-term average in 1997–1998 and soil water recharge (Fig. 4b) was much less than in the previous wet winter (Fig. 4a). Uniform but meager water recharge occurred in all treatments in the top 0.75 m of soil, but decreased sharply below this depth (Fig. 4b). There were no significant differences at any depth or in total profile water among the treatments in late February 1998. Because Russian thistle extracts water from below the rooting depth of spring wheat, these data suggest that soil water storage may not be adversely affected by Russian thistle during *average* years when over-winter recharge occurs to only 1.0 m or less.

Dry Biomass Accumulation, Seed Production, and Germination

Dry biomass of individual Russian thistle plants averaged over 2 yr was 170 g just after spring wheat harvest but increased rapidly thereafter (Fig. 5). In 1996, dry biomass accumulation peaked by 22 September, but continued steadily until late October in 1997. During both years, final dry weight exceeded 1250 g per plant.

Russian thistle did not produce seed until mid-to-late September in 1996, whereas plants had already produced some seed at the time of spring wheat harvest in early August 1997 (Table 1). Total Russian thistle seed production per plant in 1996 (58 350) and 1997 (25 070) were much greater than that reported following spring

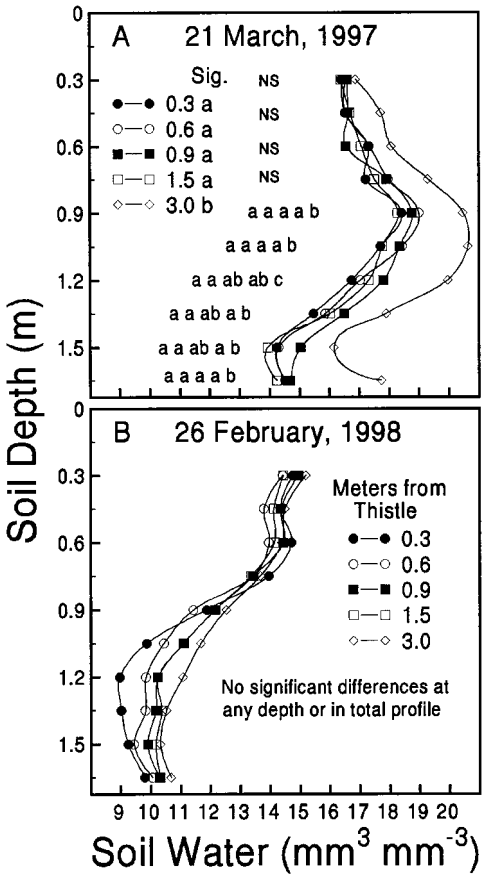

Fig. 4. Over-winter soil water recharge to a depth of 1.8 m measured on 21 March 1997 and 26 February 1998 as affected by distance from individual Russian thistle plants during the previous season. Measurements were obtained from access tubes located 0.3, 0.6, 0.9, 1.5, and 3.0 m from each Russian thistle plant. Letters in the column show differences in the total 1.8 m soil profile, whereas letters in rows show differences at every sampling depth.

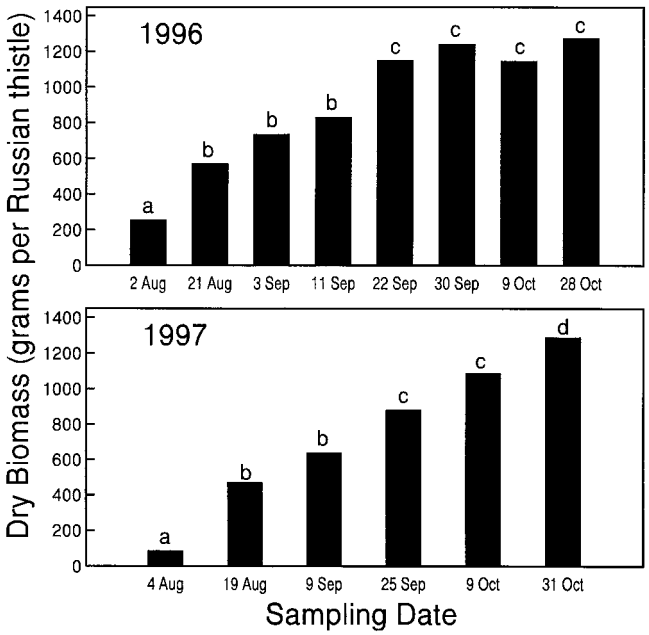

Fig. 5. Post-harvest dry biomass accumulation of Russian thistle plants when allowed to grow undisturbed and without competition in spring wheat stubble from early August until late October in 1996 and 1997.

wheat at Lind (17 400) by Young (1986). In that (1986) study, a frost killed the Russian thistle plants on 23 September whereas the growing period extended until the end of October in both 1996 and 1997. Russian thistle is an indeterminate plant that will continue to grow and produce seed until the temperature drops to about −4°C for one night or just below 0°C for several successive nights (Young et al., 1995). Although Russian thistle produced seed by early August in 1997, seeds were not germinable until 9 September (Table 1). Germination increased from 23% for seed collected on 9 September to 48% for seed harvest on 31 October. Although the germination data were only obtained in one year, these results agree with other studies in the Pacific Northwest (Young and Whitesides, 1987) and other regions of the world (Holm et al., 1997; Young and Evans, 1972) that also found that germination increases with after-ripening in the field.

SUMMARY AND MANAGEMENT RECOMMENDATIONS

Water is the most limiting factor in dryland crop production regions where Russian thistle is the dominant broadleaf weed. Russian thistle aggressively extracted soil water, beyond the available range of spring wheat as well as from deeper soil depths than spring wheat, until the weed was finally killed by frost. Russian thistle plants produced an average 46 000 seeds between early August and late October, but seeds were either not produced or germinable in appreciable quantities until mid-September.

A management option for erosion control in extreme low crop-residue situations is to allow Russian thistles to grow for a period of time after wheat harvest prior to germinable seed production. In this study, an average of 720 g dry biomass per Russian thistle (≈990 kg ha^{-1}) was produced during this 5- to 7-wk post-harvest window. However, Russian thistle used 9 mm of soil water to produce this biomass, which could reduce the subsequent wheat yield by about 170 kg ha^{-1}.

In the wheat–summer fallow rotation, we feel the best post-harvest management strategy in low crop-residue situations with heavy Russian thistle infestation is to apply a fast-acting herbicide. Herbicide should be ap-

Table 1. Post-harvest seed production per plant (1996 and 1997) and seed germination (1997) of Russian thistle at Lind, WA.†

1996		1997		
Date	Seed production	Date	Seed production	Germ.
	no. plant^{-1}		no. plant^{-1}	%
2 August	0a	4 August	100a	0a
21 August	0a	19 August	190a	0a
3 September	0a	9 September	500b	23b
11 September	0a	25 September	7 600bc	30bc
22 September	4 530b	9 October	10 830c	40c
30 September	20 290b	31 October	25 070d	48d
9 October	67 400c			
28 October	58 350c			

† Within column means followed by the same letter are not significantly different at the 0.05 probability level.

plied 10 to 14 d after wheat harvest when Russian thistle begins rapid regrowth (Young, 1986). This will halt soil water use and seed production and dead Russian thistles will be kept in place as a source of residue for erosion control. In addition, over-winter soil water storage will likely be augmented due to the additional soil surface cover. Post-harvest sweep tillage to sever the roots of Russian thistle is not advised when residue is lacking, as dislodged plants will be wind-blown from the field. In the spring of the fallow cycle, primary tillage with noninversion wide-blade sweeps may be followed by 2 or 3 secondary tillage operations with rodweeders in late spring and summer to control Russian thistles and other weeds. This method has proven to consistently retain more than the minimum 390 kg ha^{-1} surface cover (Schillinger et al., 1999) required for highly erodible soils.

Post-harvest control of Russian thistle before germinable seed production is especially important when the ensuing crop will be spring wheat. Wind erosion is less a factor when spring cropping compared with summer fallow, thus either herbicide or sweep tillage are acceptable post-harvest Russian thistle management options. Spring wheat sown (i) early and with minimum soil covering the seed for fast emergence and (ii) on narrow (150 to 225 mm) row spacing will increase the crop's competitiveness with Russian thistle. Ongoing research to suppress Russian thistle by spring wheat cultivars with rapid and prostrate early growth habit and effective in-crop herbicides with short-term residual activity will help make spring cropping an increasingly viable option for inland Pacific Northwest drylands.

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