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ABSTRACT: Growers in low-precipitation (< 300 mm annual) dryland areas of the inland Pacific Northwest of the USA practice a wheat (Triticum aestivum *L.) - fallow rotation where only one crop is grown every two years. When wheat yields are low, it is difficult to maintain adequate surface residue for erosion control during the ensuing fallow cycle. Russian thistle* (Salsola iberica) *is a major broadleaf weed in low-crop-production years, and it often produces more dry matter by grain harvest than the wheat crop it infests. In a 4-yr study, the effect of 3 tillage management treatments on retention of above-ground wheat residue and dead Russian thistle plants or "skeletons" during fallow was determined. Treatments were: 1) traditional (tillage), 2) minimum (herbicides and tillage), and 3) delayed minimum (herbicides and delayed tillage). Russian thistle infestation occurred 2 of the 4 yr when winter wheat failed and was replaced by spring wheat. Russian thistle skeletons were preserved as an important source of surface cover during fallow using minimum tillage, whereas they were wind-blown from the field or buried with traditional tillage. Minimum tillage also increased surface wheat residue compared to traditional tillage on all sampling dates. Results show the value of conserving Russian thistle skeletons for erosion control in low crop residue situations when this weed is likely to be present in large amounts.*

Key words: Conservation tillage, drought, erosion, fallow, residue, Pacific Northwest, Russian thistle, wheat.

Wind and water erosion are major agronomic and environmental concerns in the low-precipitation (<300 mm annual) dryland wheat production region in eastern Washington and north central Oregon. A biennial wheat-summer fallow rotation has been practiced in this 1.7-million ha region since native bunch grass and sagebrush was plowed in the 1880s. In drought years, or when winter wheat is replaced by a spring crop, residue production is low, and growers frequently have difficulty conserving sufficient surface cover to retard erosion during the subsequent fallow cycle. The most effective management practice for protecting soil from erosion during fallow is to maintain adequate surface residue (Horning and Oveson 1962). Detailed descriptions of the relationship between soil cover and wind erosion loss have been reported by Bilbro and Fryrear (1994). Maximum levels of surface residue during the fall and winter reduces water runoff during the winter and increases over-winter soil water storage, which benefits subsequent grain yield (Lindstrom 1974; Ramig and Ekin 1991; Wilkins et al. 1988). Tillage channels or slots are effective for increasing water infiltration when rain or snowmelt occur on frozen soils (Zuzel and Pikul 1987).

Russian thistle is a summer annual weed, first reported in the United States in South Dakota in 1877 (Dewey 1893). By the 1890s, the weed had spread to the Pacific Northwest (Young 1991), where it quickly became the dominant broadleaf weed in low-precipitation dryland wheat areas.

Russian thistle grows during both the crop and fallow cycles. A uniform and well-established stand of winter wheat will suppress Russian thistle. On the other hand, spring wheat or drought stressed winter wheat are much less competitive and more subject to thistle infestation. Growers plant spring wheat to replace winter wheat because of: 1) inadequate fall stand establishment, 2) winter kill, and 3) the need to control winter annual grassy weeds (Cook and Veseth 1991). Russian thistle infestation is frequently acute in spring wheat due to less early growth and less canopy closure compared to winter wheat (Young 1986). Spring wheat yield depression due to Russian thistle is most severe during drought years (Young 1988). Russian thistle has an efficient C_4 photosynthetic pathway with high water use efficiency (Fowler and Hageman 1978).

Russian thistle rapidly produces dry matter and sets seed after wheat harvest (Young et al. 1995), by extracting soil moisture below the available limit for wheat. The optimum time for post-harvest control of Russian thistle is 10 to 14 days after harvest. Growers generally either till the soil with V-shaped sweeps or use herbicides after grain harvest to control Russian thistle. After primary tillage in the spring, rodweeders are used as secondary tillage to control thistles and other weeds. Rodweeders operated at depths greater than 7 cm retain surface residue and roughness more effectively for erosion control compared to shallow depths (Schillinger and Papendick 1997).

Although Russian thistle often has negative agronomic effects, it has some beneficial attributes. During the dust bowl years in the 1930s, Russian thistle was used as emergency forage for cattle (Cave et al. 1936). Protein in Russian thistle hay can be as high as 23% (Boerboom 1993), and the plant has potential as an energy source as processed pellets and compressed fireplace logs (Foster et al. 1980).

Because Russian thistle often produces substantial dry matter both before and after wheat harvest, it is possible that the weed could be an important source of surface cover for erosion control during the fallow cycle. No previous research has been reported on possible benefits of Russian thistle in conservation systems. The objective of this study was to 1) document the extent of Russian thistle infestation in marginal wheat production years and, 2) determine if dead thistles can be conserved during fallow as a significant source of surface cover in low crop residue situations.

Methods and materials

A 4-yr tillage management study was conducted between August 1993 and September 1997 at the Washington State University Dryland Research Station at Lind, Wash. Long-term (82-yr) average annual precipitation at the station is 240 mm. The soil is Shano silt loam (coarse-silty, mixed, mesic Xerollic Camborthid) with <1% organic matter in the surface

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10 cm. Soil depth is >180 cm. Wind tunnel tests have shown that this soil, when left unprotected (i.e., bare, tilled, dry, non-crusted), is one of the most susceptible to wind erosion and suspended dust emissions within the Columbia Plateau of eastern Washington (Saxton et al. 1996).

The experimental design was a randomized complete block of three tillage management treatments replicated four times. Each plot was 46 by 18 m, which allowed use of commercial-size farm equipment. Paired adjacent parcels of land were used so that data could be collected from both crop and fallow phases of the study each year.

Tillage management treatments. The three tillage management systems compared in this study were:

1) *Traditional tillage* — Conventional frequency and timing of tillage operations using implements commonly used by growers;

2) *Minimum tillage* — Conventional frequency and timing of tillage operations, but herbicides were substituted for tillage when feasible and a non-inversion V-sweep implement was used for primary spring tillage, and

3) *Delayed minimum tillage* — Similar to minimum tillage, except primary spring tillage with a non-inversion V-sweep was delayed until at least late May. A list of field operations and timing for the study are shown in Table 1.

In traditional tillage, post-harvest tillage was conducted in August of 1993, 1994, and 1995 with overlapping 36-cm-wide V-sweeps to kill Russian thistle by severing the tap root. Russian thistle was not present in August 1996 and post-harvest sweeping was not required. Plots were chiseled in October after fall rains to a depth of 25 cm with straight-point shanks spaced 60 cm apart to create channels for controlling frozen soil runoff during the winter. Plots were sprayed with glyphosate [N-(phosphonomethyl) glycine] herbicide in late winter to control weeds. Primary tillage was conducted in March with two passes of a duck foot cultivator with an attached harrow, or one pass with a tandem disc (Table 1). Plots were fertilized with anhydrous ammonia nitrogen in late spring and rodweeded three times to control weeds during the summer. Winter wheat was planted in 0.4 meter rows in early September all years with a John Deere HZ deep furrow drill.

Minimum tillage treatments were sprayed with a nonselective herbicide for post-harvest control of Russian thistle in lieu of tillage with sweeps in August (Table 1). In October, the plots were chiseled to depths ranging from 25- to 40-cm with straight-point shanks spaced 120 cm apart (i.e., twice the shank spacing as for traditional tillage). Chiseling was not conducted in 1996. Glyphosate was applied in late winter, and primary tillage was with a non-inversion sweep implement equipped with 80-cm-wide overlapping V-blades. A rotary harrow was attached behind the wide-blade sweep to break up large clods and fill air voids. The plots were rodweeded three times during late spring and summer and fertilized with aqua ammonia nitrogen injected between the rows of the deep furrow grain drill when planting winter wheat in early September.

The delayed minimum tillage treatment was identical to the minimum tillage treatment except that: 1) primary spring tillage was delayed until late May or early June, and; 2) only two rodweedings were conducted during late spring and summer.

All treatments were planted at the same time. Due to inadequate fall stands of winter wheat, all plots were replanted to hard red spring wheat in March of 1993 and 1995 (Table 1). Cultivar 'Butte 86' was sown @67 kg/ha in 0.15-m rows with a disc drill.

Residue measurement. Surface residue remaining from the previous crop cycle was measured several times throughout the fallow period by gathering all above ground dry matter within a 1-m diameter hoop. Three samples were obtained from each plot. Wheat straw and Russian thistle skeletons were separated, placed in paper bags, and allowed to air dry in a low-humidity greenhouse before weighing. An analysis of variance was conducted for both wheat straw

Table 1. Calendar of field operations for three tillage systems during four fallow cycles at Lind, WA, 1993-1997

Date	Traditional tillage	Minimum tillage	Delayed minimum tillage
Aug	Sweep - 30 cm shank spacing. Sweeping was not conducted in 1996.	Herbicide - Glyphosate + 2,4-D @ 3.5 L/ha in 1993; Glyphosate @ 2.3 L/ha in 1994 and 1995. Not required in 1996.	Herbicide - Glyphosate + 2,4-D @ 3.5 L/ha in 1993; Glyphosate @ 2.3 L/ha in 1994 and 1995. Not required in 1996.
Oct	Chisel - 60 cm shank spacing	Chisel or subsoiler - 120 cm shank spacing. Not conducted in 1996.	Chisel or subsoiler - 120 cm shank spacing. Not conducted in 1996.
Feb	Herbicide - Glyphosate @ 0.9 L/ha	Herbicide - Glyphosate @ 0.9 L/ha	Herbicide - Glyphosate @ 0.9 L/ha
March	Primary tillage - cultivator + harrow (two passes). Tandem disk (one pass) in 1997.	Primary tillage - undercutter + rolling harrow	
April	Anhydrous NH_3 injection @ 45 kg/ha		
May	First rodweeding	First rodweeding	Primary tillage - undercutter + rolling harrow
June	Second rodweeding	Second rodweeding	First rodweeding
July	Third rodweeding	Third rodweeding	Second rodweeding
Sept	Planted to winter wheat @ 45 kg/ha. Replanted to spring wheat @ 67 kg/ha in March 1993 and 1995.	Planted to winter wheat @ 45 kg/ha + aqua NH_3 injection @ 45 kg/ha. Replanted to spring wheat @ 67 kg/ha in March 1993 and 1995.	Planted to winter wheat @ 45 kg/ha + aqua NH_3 injection @ 45 kg/ha. Replanted to spring wheat @ 67 kg/ha in March 1993 and 1995.

and Russian thistle skeletons on each sampling date. Treatment means were considered significantly different if the P value was <0.05, using Fisher's protected least significant difference.

Results and discussion

Russian thistle produced significant biomass during 2 crop cycles when spring wheat replaced winter wheat due to inadequate seed zone moisture for stand establishment. Spring wheat residue at the beginning of both the 1993-1994 and 1995-1996 fallow cycles was 1,500 kg/ha, whereas Russian thistle dry matter was 1,750 kg/ha (Figures 1 and 2). These data agree with other studies showing Russian thistle capable of producing more total dry matter than the spring wheat crop it infests (Young 1988).

In traditionally-tilled plots, post-harvest tillage reduced surface wheat residue and Russian thistle skeletons compared to minimum tillage where Russian thistle was killed by post harvest application of herbicides (Table 1, Figures 1 and 2). During the fall and winter, the majority of Russian thistle skeletons were wind-blown from the field in traditionally-tilled plots because the tap root had been severed by the post-harvest sweep operation. Conversely, when herbicide was used for post harvest control in the minimum-tilled treatments, most Russian thistle plants remained anchored in the soil or trapped by standing wheat stubble. (Figures 1 and 2).

Surface wheat residue and Russian thistle skeletons were always lower in the traditional tillage than in minimum tillage throughout the spring and summer in both the 1993-1994 and 1995-1996 fallow cycles (Figures 1 and 2). Highest retention of surface residue in the spring was achieved with delayed minimum tillage. Differences in residue levels between minimum and delayed-minimum treatments did not persist until the end of the fallow cycle (Figures 1 and 2). A benefit of delayed minimum tillage compared to minimum tillage was the need for one less rodweeding operation during the summer (Table 1), which conserves energy and labor.

At the end of the 1993-1994 fallow cycle, only 260 kg/ha of wheat residue and 60 kg/ha of Russian thistle skeletons remained on the soil surface in traditionally tilled plots (Figure 1). Wheat growers in the dryland areas of the Pacific Northwest are required to maintain a minimum of 390 kg/ha surface residue on highly erodible land in order to participate in government farm programs. With traditional tillage, this requirement could not be met in the 1993-1994 fallow cycle. In contrast, residue compliance was easily met with combined wheat residue and Russian thistle skeletons exceeding 830 kg/ha in the minimum and delayed-minimum tillage treatments. Residue compliance was marginally met (430 kg/ha) with traditional tillage at the end of the 1995-1996 fallow cycle (Figure 2), but residue was likely reduced a further 20% after planting winter wheat with deep furrow drills (McClellan 1988). More than 840 kg/ha combined surface cover remained with minimum and delayed-minimum tillage at the end of the 1995 to 1996 fallow cycle (Figure 2).

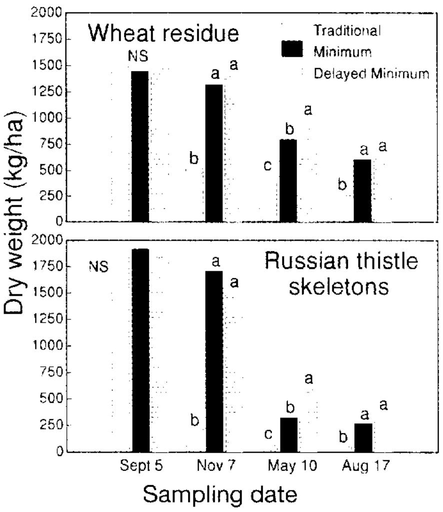

Fig. 1: Above-ground hard red spring wheat residue and Russian thistle skeletons during the 1993-1994 fallow cycle as affected by traditional, minimum, and delayed minimum tillage. Different letters within sampling dates indicates significant treatment differences (P < 0.05).

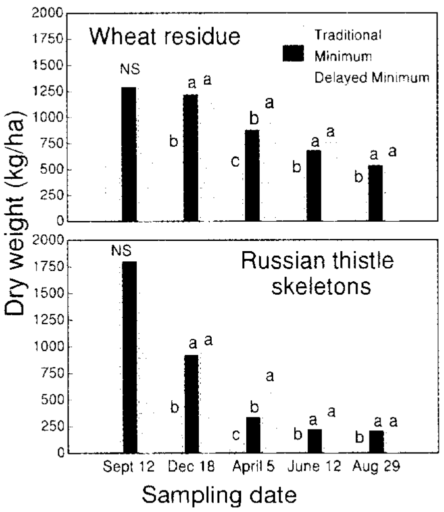

Fig. 2: Above-ground hard red spring wheat residue and Russian thistle skeletons during the 1995-1996 fallow cycle as affected by traditional, minimum, and delayed minimum tillage.

Russian thistle did not infest good stands of hard red winter wheat (cv. Buchanan) and soft white winter wheat (cv. Eltan) planted in early September of 1993 and 1995, respectively. Residue production from winter wheat exceeded 2000 kg/ha, and more than 600 kg/ha surface cover with traditional tillage, and more than 1,100 kg/ha for the minimum tillage treatments were maintained at the end of both the 1994-1995 and 1996-1997 fallow cycles (Figure 3).

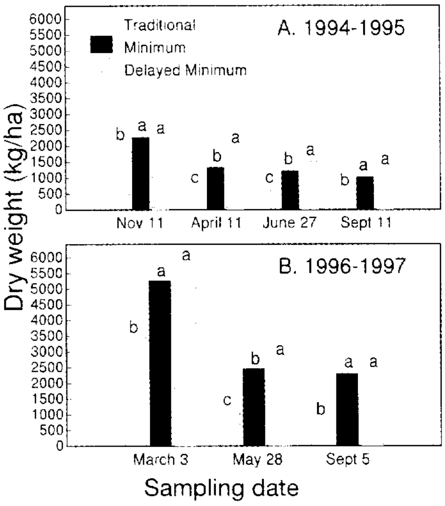

Fig. 3: Above-ground hard red winter wheat residue during the 1994-1995 fallow cycle (A), and soft white winter wheat residue during the 1996-1997 fallow cycle (B), as affected by traditional, minimum, and delayed minimum tillage.

Summary and conclusion

Tillage management affected surface wheat residue and Russian thistle skeleton retention throughout the fallow cycle. In low production years, Russian thistle produced more dry matter at grain harvest than the spring wheat crop it infested. By using herbicides rather than tillage for post-harvest thistle control and non-inversion sweeps for primary spring tillage, we consistently retained more wheat residue and Russian thistle skeletons on the soil surface throughout the fallow cycle than was possible with traditional tillage. We could not retain the minimum required quantity of surface residue for erosion control during the 1993-1994 fallow cycle using traditional tillage, but were able to meet this requirement with Russian thistle skeletons alone using minimum tillage.

Russian thistle did not infest well-established stands of winter wheat, and maintenance of adequate surface residue during the subsequent fallow cycle was achieved even with traditional tillage. Conserving dead Russian thistle plants in low crop-residue situations can be beneficial for meeting residue requirements and controlling both wind and water erosion.

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