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Interference of Redstem Filaree (*Erodium cicutarium*) in Sugarbeet

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Redstem filaree is a troublesome weed for sugarbeet growers in northern Wyoming and southern Montana. Field studies were conducted in Powell, WY, in 2006 and 2008 to determine the influence of season-long interference of various redstem filaree densities and the duration of interference on sugarbeet. Root and sucrose yield decreased with increasing redstem filaree density. The rectangular hyperbola model with the asymptote (*A*) bounded at 100% maximum yield reduction characterized the relationship between redstem filaree density and sugarbeet yield reduction. The estimated parameter *I* (percent yield reduction per unit weed density as density approaches zero) was 5% for root and sucrose yield reduction. Sugarbeet root yield decreased as the duration of redstem filaree interference increased. The critical timing of redstem filaree removal to avoid 5 and 10% root yield reduction was estimated to be 25 and 32 d after sugarbeet emergence, respectively. Redstem filaree interference did not affect the sucrose content percentage. These results demonstrate that redstem filaree is competitive with sugarbeet and should be managed appropriately to reduce negative effects on yield.

Nomenclature: Redstem filaree, *Erodium cicutarium* (L.) L'Hér. ex Ait. EROCI; sugarbeet, *Beta vulgaris* L.

Key words: Competition, weed density, rectangular hyperbolic model, duration of interference, critical timing of weed removal.

Redstem filaree, a low-statured winter annual or biennial belonging to the Geraniaceae (Whitson et al. 2002), is becoming a serious weed problem for sugarbeet growers in northern Wyoming and southern Montana (Mesbah et al. 2004). It is a prolific seed producer and can quickly develop into dense infestations if not controlled (Blackshaw and Harker 1998). Blackshaw (1992) reported germination of redstem filaree at soil water content of -0.03 to -0.28 MPa and soil temperatures of 5 to 30 C (optimal at 5 to 15 C), suggesting that its ability to emerge over a broad range of soil temperature and moisture makes it capable of being a serious competitor with crops. Redstem filaree emergence is markedly affected by depth of burial. Optimal germination is at depth of 1 cm or less and progressively declines at depths below 1 cm until emergence is completely inhibited at 8 to 10 cm (Blackshaw 1992).

Sugarbeet is most sensitive to competition from early-emerging weeds because of the crop's slow growth and development early in the season (Milford 1973; Schweizer and May 1993; Scott and Wilcockson 1976). Weed competition can delay sugarbeet leaf emergence and development, consequently resulting in storage of lower amounts of sucrose in the root (Paolini et al. 1999). Sugarbeet yield reductions due to interference from tall-statured weed species such as kochia [*Kochia scoparia* (L.) Schrad.], common lambsquarters (*Chenopodium album* L.), redroot pigweed (*Amaranthus retroflexus* L.), Powell amaranth (*Amaranthus powellii* S. Watson), velvetleaf (*Abutilon theophrasti* Medik.), common sunflower (*Helianthus annuus* L.), and wild mustard (*Sinapsis arvensis* L.) have been reported (Mesbah et al. 1994, 1995; Schweizer 1981, 1983; Schweizer and Bridge 1982; Schweizer and Lauridson 1985). Reports of sugarbeet yield reductions due to interference of low-statured weed species are less common, but recent reports have demonstrated that weeds such as Venice mallow (*Hibiscus trionum* L.), wild buckwheat (*Polygonum convolvulus* L.), and lanceleaf sage (*Salvia reflexa* Hornem.) can also negatively affect sugarbeet yields (Odero et al. 2009, 2010a, 2010b). Yield reductions due to interference of redstem filaree in wheat (*Triticum aestivum* L.), oilseed rape (*Brassica rapa* L.), dry bean (*Phaseolus vulgaris* L.), and pea (*Pisum sativa* L.) have been reported (Blackshaw and Harker 1988; Harker et al. 2007).

The critical timing of weed removal (CTWR), or the maximum amount of early-season weed competition that the crop can tolerate before it suffers irrevocable yield reduction, is an important component of the critical period for weed control (Knezevic et al. 2002). The CTWR is usually related to days after emergence (DAE), stage of crop development (Norsworthy and Oliveira 2004), or growing degree days (Bukun 2004). Mesbah et al. (1994, 1995) reported sugarbeet yield reduction as a result of duration of interference effects of kochia, green foxtail [*Setaria viridis* (L.) Beauv.], wild mustard, and wild oat (*Avena fatua* L.). Similarly, Odero et al. (2009, 2010a, 2010b) reported increasing sugarbeet yield reduction as the duration of Venice mallow, wild buckwheat, and lanceleaf sage interference increased. Blackshaw and Harker (1988) reported wheat, oilseed rape, pea, and dry bean yield reductions as the number of weeks of redstem filaree interference increased. However, no studies report the effect of redstem filaree interference on sugarbeet. Therefore, the objective of the study was to determine the effect of redstem filaree density and duration of interference on sugarbeet root yield and sucrose content.

Materials and Methods

Field Operations. Field experiments evaluating redstem filaree interference in sugarbeet were conducted in 2006 and 2008 at the Powell Research and Extension Center in Wyoming. The soil type was a Garland loam (fine-loamy over sandy or sandy-skeletal, mixed, superactive, mesic Typic Haplargid) with pH 7.6 and 1.3% organic matter. Experimental plots were infested with redstem filaree and had been planted to barley (*Hordeum vulgare* L.) the previous year. Fields were moldboard plowed and leveled in the fall following barley harvest. Urea in prill form was broadcast applied and incorporated at the rate of 112 kg N ha^{-1}, and fields subsequently bedded on 56-cm rows on March 28, 2006, and April 2, 2008. Sugarbeet 'Treasure' was planted on

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April 24, 2006, and 'HM9025' on April 24, 2008, at the rate of 111,000 seeds ha^{-1}. The plots were subsequently side dressed with 135 kg N ha^{-1}, using urea ammonium nitrate applied with a spoke wheel applicator, and cultivated on June 17, 2006, and June 28, 2008, to control weeds between the rows, using a six-row cultivator with 38-cm sweeps. Plots were also kept free of other weeds by hand removal throughout the growing season. All plots were furrow irrigated during the growing season to optimize growing conditions and ensure that moisture was not a limiting factor.

Individual plots for the weed density and duration of interference studies were established immediately after sugarbeet emergence. Experimental plots consisted of three sugarbeet rows 6.1 m long and spaced 56 cm apart arranged in a randomized complete block design with three replications for both studies.

Season-Long Density Study. An additive design was used to conduct the density study whereby sugarbeet density was constant with a variable redstem filaree density (Harper 1977; Park et al. 2003). Densities of 0, 6, 12, 18, 24, and 30 redstem filaree plants m^{-1} of row were established over the sugarbeet rows both years by hand thinning after emergence of sugarbeet and redstem filaree. Sugarbeet was harvested from the center row of each plot on September 28, 2006, and October 17, 2008, with a one-row mechanical sugarbeet lifter. Fresh sugarbeet roots were weighed, and a subsample was sent for quality analysis at the Western Sugar Tare Laboratory in Billings, MT.

Duration of Interference Study. Studies were established in a manner similar to the density study. Shortly after emergence, the redstem filaree was thinned to a density of 18 plants m^{-1} of row over the sugarbeet rows both years. Redstem filaree was allowed to compete with sugarbeet for 0, 36, 50, 64, 78, 92, and 106 DAE before hand removal both years. Full season redstem filaree duration of interference (133 and 146 DAE for 2006 and 2008, respectively) was included at the same density. Sugarbeet harvest was similar to the procedure described in the density study.

Statistical Analysis. Analysis of variance was performed on all data using the MIXED procedure in SAS[1] at 5% level of significance to assess the effect of redstem filaree density and duration of interference on sugarbeet yield components. Sugarbeet yield components included percent sucrose, root yield, and sucrose yield. Sucrose yield was a function of root yield and percent sucrose. For the density study, year was considered a random variable, and the density main effects were tested for error associated with the appropriate year by density interaction. Similarly, year was considered a random variable for the duration of interference study, and duration main effects were tested for error associated with appropriate year by duration of interference interaction (McIntosh 1983).

Cousens (1985) hyperbolic model was used to describe sugarbeet yield as a function of redstem filaree density using the drc package (Ritz and Streibig 2005) of the open source language R[2]:

$$Y = Y_{\mathrm{wf}}[1 - Id/100(1 + Id/A)] \qquad [1]$$

where Y is sugarbeet yield (Mg ha^{-1}), Y_{wf} is the estimated weed-free sugarbeet yield, d is the redstem filaree density, I is the percentage sugarbeet yield loss per unit redstem filaree density as density approaches zero, and A is the asymptote or percentage sugarbeet yield loss as redstem filaree density approaches infinity. When fitting Equation 1, the A parameter was constrained to a maximum value of 100 because yield loss may not exceed 100% of Y_{wf}. The relationship between percent sugarbeet yield reduction and redstem filaree density was then plotted using Equation 2:

$$Y_{\mathrm{L}} = Id/(1 + Id/A) \qquad [2]$$

where Y_{L} is the percentage sugarbeet yield loss (% weed-free yield), and d, I, and A are the same as in Equation 1 (Y_{L} was estimated using parameter estimates from Equation 1).

A four-parameter logistic model was fitted to assess the effect of duration of redstem filaree interference on relative sugarbeet root yield (Seber and Wild 1989):

$$Y = c + (d - c)/1 + \exp\{b[\log(T) - \log(e)]\} \qquad [3]$$

where Y is the relative root yield (as % weed-free sugarbeet root yield), T is time expressed as DAE, b is the slope at the inflection point, c is the lower limit, d is the upper limit, and e is the number of DAE where the inflection point occurs. Equation 3 was also fit to data using the drc package of R. Root mean squared error (RMSE) was determined using the qpcR package of R (Ritz and Spiess 2008) to assess the goodness of fit of the nonlinear models.

Results and Discussion

Season-Long Interference from Various Redstem Filaree Densities. There was no effect of redstem filaree density on percent sucrose although percent sucrose was greater in 2008 compared to 2006 (17.9 and 16.5%, respectively). Similarly, season-long interference of Venice mallow (Odero et al. 2009), wild buckwheat (Odero et al. 2010a), and lanceleaf sage (Odero et al. 2010b) densities had no effect on percent sucrose in sugarbeet roots. Previous research also showed that competition from common lambsquarters (Schweizer 1983), Powell amaranth (Schweizer and Lauridson 1985), kochia, green foxtail (Mesbah et al. 1994), wild mustard, and wild oat (Mesbah et al. 1995) had no effect on percent sucrose. However, Schweizer and Bridge (1982) reported reduction in percent sucrose with increasing densities of velvetleaf and common sunflower. The contrast in response among studies suggests that the effect of weed interference on percent sucrose is probably influenced by weed species.

There was no year by redstem filaree density interaction for either sugarbeet root or sucrose yield reduction. Therefore, data were combined across years for analysis. The response of sugarbeet yield reduction in response to redstem filaree density was well described by the rectangular hyperbola model (Equation 1). The estimated weed free yield was 79.7 (± 5.94) and 13.8 (± 0.97) Mg ha^{-1} for root and sucrose yield, respectively. Percent sugarbeet yield reduction increased with increasing redstem filaree density (Figure 1). Based on the I value, predicted root and sucrose yield reduction from season-long interference of one redstem filaree plant per meter of sugarbeet row was 5%.

Season-long interference from other low-statured weed species including Venice mallow (Odero et al. 2009) and wild buckwheat (Odero et al. 2010a) initially showed greater

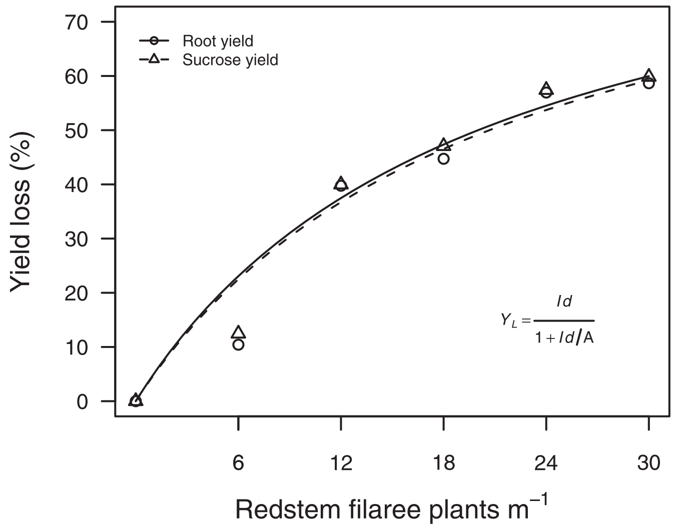

Figure 1. The effect of redstem filaree density on percentage sugarbeet yield reduction at Powell, WY, combined over 2006 and 2008. Equation 2, where *d* is the redstem filaree density used to predict the relationship between percentage sugarbeet yield reduction and redstem filaree density. Parameter estimates and standard errors (in parentheses) were I = 5.12 (1.64) and A = 100 (26.17) for root yield; and I = 4.94 (1.60) and A = 100 (27.96) for sucrose yield. RMSE was 16.24 and 15.78 for root and sucrose yield, respectively.

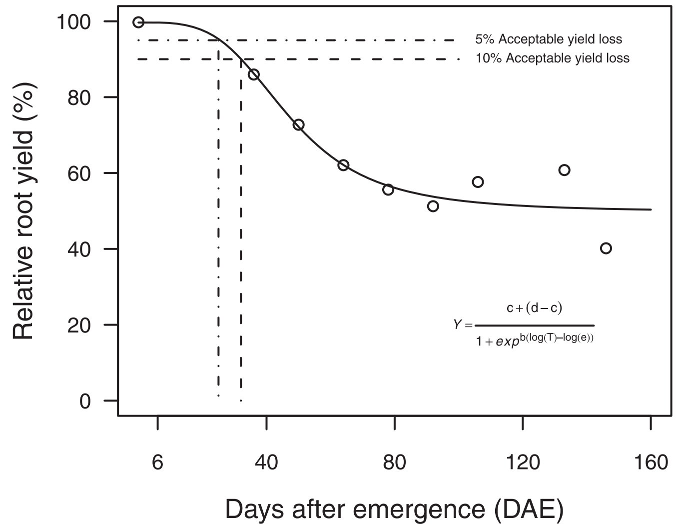

Figure 2. The influence of various redstem filaree duration of interference on relative sugarbeet root yield combined over 2006 and 2008 at Powell, WY. Equation 3, where T is the DAE used to predict redstem filaree interference on relative sugarbeet root yield. Parameter estimates and standard errors (in parentheses) were b = 3.68 (1.43), c = 49.79 (5.02), d = 99.66 (5.25), and e = 47.30 (5.22); RMSE = 11.23.

competitiveness (I = 6%) at low densities compared to redstem filaree. However, lanceleaf sage initial competitiveness (I = 3%) at low densities was less than redstem filaree (Odero et al. 2010b). Taller statured weeds including common lambsquarters, Powell amaranth, common sunflower, and velvetleaf (Schweizer 1983; Schweizer and Bridge 1982; Schweizer and Lauridson 1985) tend to be more competitive with sugarbeet compared to redstem filaree. Their greater sugarbeet yield reduction of up to 73% from competition of one plant per meter of row is attributable to their ability to grow taller and completely shade the sugarbeet canopy during the growing season. Redstem filaree has also been reported to cause yield reduction in several other crops. Redstem filaree densities of 100 to 200 plants m^{-2} reduced yields of wheat, oilseed rape, dry bean, and pea by 36, 37, 82, and 92%, respectively (Blackshaw and Harker 1988). Harker et al. (2007) reported 31% pea yield reduction due to competition from redstem filaree densities of 14 to 200 plants m^{-2}.

The A parameter was constrained to a maximum of 100 in this study which indicates that at very high densities, sugarbeet yield losses may approach 100% (Figure 1). In comparison, Venice mallow and wild buckwheat caused maximum yield loss of $<$ 65% (Odero et al. 2009; 2010a), while lanceleaf sage also caused yield loss approaching 100% at high densities (Odero et al. 2010b).

Critical Time for Redstem Filaree Removal. The duration of redstem filaree interference did not affect percent sucrose in sugarbeet roots. However, percent sucrose was greater in 2008 compared to 2006 (17.5 and 16.7%, respectively). Odero et al. (2009, 2010a, 2010b) also reported that the duration of interference of Venice mallow, wild buckwheat, and lanceleaf sage had no effect on percent sucrose in sugarbeet roots. Mesbah et al. (1994, 1995) reported similar observations for duration of interference of kochia and green foxtail as well as wild mustard and wild oat in sugarbeet. In contrast, Weatherspoon and Schweizer (1969) reported a reduction in percent sucrose as duration of kochia competition increased suggesting that the effect of duration of weed interference on percent sucrose probably varies with different weed species.

There was no year by duration interaction effect for relative sugarbeet yield, so data were combined across years. The four-parameter logistic model (Equation 3) provided a good fit to estimate the CTWR for redstem filaree based on relative sugarbeet root yield (RMSE = 11.23). Relative root yield decreased as the duration of interference increased (Figure 2). The CTWR to prevent 5 and 10% root yield reduction was 25 and 32 d, respectively. By the first removal timing of 36 DAE, yield reduction had already exceeded 10% suggesting that sugarbeet is susceptible to redstem filaree interference early in the season. Previous studies on similar low-statured weed interference in sugarbeet indicated that 5 and 10% yield reduction occurred between 30 and 52 DAE at similar densities (Odero 2009, 2010a, 2010b). These results show that duration of redstem filaree interference had a more adverse effect on root yield compared to Venice mallow, wild buckwheat, and lanceleaf sage.

These results indicate that redstem filaree is an effective competitor with sugarbeet and can reduce sugarbeet yield when not managed appropriately in a timely manner. The adverse effects of redstem filaree on sugarbeet can be enhanced in years with low spring temperatures that slow the growth of sugarbeet because of the ability of redstem filaree to germinate and grow at relatively low soil temperatures (Blackshaw 1992). Based on the duration of interference results, sugarbeet does not exhibit early season tolerance to redstem filaree. Consequently, control measures should be implemented early in the growing season to minimize sugarbeet root yield reduction from redstem filaree interference. Multiple micro-rate sugarbeet herbicide treatments are the most effective at controlling redstem filaree from early in the season, with or without preplant herbicides (Mesbah et al. 2004). Blackshaw and Harker (1988) recommended planting barley in a rotation to suppress redstem filaree growth. Therefore, the rotation of sugarbeet with spring barley is a desirable cultural technique that can be used to augment the management of redstem filaree infestations. Redstem filaree favors overwintering of the beet leafhopper [*Circulifer tenellus* (Baker)] which transmits the beet curly top virus of sugarbeet (Al-Wahaibi and Walker 2000) making its management even more important.

Sources of Materials

[1] Statistical Analysis Systems®, version 9.1.3. 2005. SAS Institute Inc., SAS Campus Drive, Cary, NC 27513.

[2] R version 2.10.0. The R Foundation for Statistical Computing, Vienna, Austria.

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