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Lanceleaf Sage (*Salvia reflexa*) Interference in Sugarbeet

Dennis C. Odero, Abdel O. Mesbah, Stephen D. Miller, and Andrew R. Kniss*

Field studies were conducted in Powell, WY, in 2006 and 2007 to determine the influence of season-long interference of various lanceleaf sage densities and durations of interference on sugarbeet. The rectangular hyperbola model with the asymptote (*A*) constrained to 100% maximum yield loss characterized the relationship between lanceleaf sage density and sugarbeet yield loss. The estimated parameter *I* (yield loss per unit weed density as density approaches zero) was 3% for both root and sucrose yield loss. Increasing duration of lanceleaf sage interference had a negative effect on sugarbeet root yield. The critical timing of weed removal to avoid 5 and 10% root yield loss was 37 and 52 d after sugarbeet emergence, respectively. Lanceleaf sage interference did not affect percentage of sucrose content. These results indicate that lanceleaf sage is not as competitive as other weeds but that appropriate control measures should be undertaken to minimize sugarbeet yield loss from interference.
Nomenclature: Lanceleaf sage, *Salvia reflexa* Hornem. SALRE; sugarbeet, *Beta vulgaris* L.
Key words: Competition, timing of removal, weed density, rectangular hyperbolic model.

Se llevaron al cabo estudios de campo en 2006 y 2007 en Powell, WY. para determinar la influencia de la interferencia a lo largo de la temporada de varias densidades de *Salvia reflexa* y la duración de la interferencia en la remolacha azucarera (*Beta vulgaris* L.). El modelo de hipérbola rectangular con la asíntota(*A*) restringida al 100% máximo de pérdida de rendimiento caracterizó la relación entre la densidad de *Salvia reflexa* y la pérdida del rendimiento de la remolacha azucarera. El parámetro estimado *I* (pérdida del rendimiento por unidad de densidad de la maleza conforme la densidad se acerca a cero) fue 3% tanto para la pérdida de la raíz como la pérdida de la producción de sucrosa. El incremento en la duración de la interferencia de la *Salvia reflexa* tuvo un efecto negativo en el rendimiento de la raíz de *Beta vulgaris* L El tiempo crítico de remoción de maleza para evitar entre el 5 y 10% de pérdida del rendimiento de la raíz fue a los 37 y 52 días después de la emergencia de la remolacha azucarera, respectivamente. La interferencia de *Salvia reflexa* no afectó el porcentaje del contenido de sucrosa. Estos resultados indican que la *Salvia reflexa* no es tan competitiva como otras malezas, pero deben realizarse medidas de control apropiadas para minimizar la pérdida del rendimiento de la remolacha azucarera a partir de la interferencia.

Lanceleaf sage, a member of the Lamiaceae family (Stubbendieck et al. 2003), is an important weed in the United States (Baskin and Baskin 1971; Nussbaum et al. 1985), Australia, and New Zealand (Holm et al. 1979). In northern Wyoming, the occurrence and abundance of lanceleaf sage has increased rapidly in sugarbeet fields. Sugarbeet is cultivated in 10,400 ha in this region accounting for 87% of its total production in the state (WASS 2009).

Several factors including seed dormancy (Weerakoon and Lovett 1986a), the ability to emerge within a broad temperature range (Weerakoon 1981), and low water potential (Weerakoon and Lovett 1986b) have enabled lanceleaf sage to be a troublesome weed in many cultivated crops. However, yield reduction in crops as a result of lanceleaf sage interference has not been well documented. Lovett and Speak (1979) reported that increasing wheat density reduced the competitiveness of lanceleaf sage. Similarly, Weerakoon and Lovett (1986c) reported that lanceleaf sage plants became much smaller and with poor competitive ability as wheat density increased. In contrast, several studies have evaluated the relationship between the density of various weeds and sugarbeet and reported yield losses of up to 73% (Mesbah et al. 1994, 1995; Schweizer 1981, 1983; Schweizer and Bridge 1982; Schweizer and Lauridson 1985).

No studies have evaluated the critical period of weed control (CPWC) for lanceleaf sage in sugarbeet. The CPWC represents the time interval between two discretely measured crop–weed competition components (Knezevic et al. 2002). The first component is 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, and the second component is the critical weed-free period or the minimum weed-free period required from the time of planting to prevent unacceptable yield reductions. The later component represents the time when weeds start having negative effects on the crop due to limitation of resources that both require for growth. The CTWR is very important in sugarbeet because early-emerging weeds are recognized to be more competitive against sugarbeet because of its slow growth and development early in the season (Milford 1973; Schweizer and May 1993; Scott and Wilcockson 1976).

Currently, no studies have been conducted to evaluate lanceleaf sage interference effects on sugarbeet in the absence of other weeds. An understanding of the density effects and critical timing of lanceleaf sage removal can provide a basis for planning effective control strategies in sugarbeet. Therefore, the objective of the study was to determine the effect of

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* Former Graduate Research Assistant, Research Scientist, Professor, and Assistant Professor. Department of Plant Sciences, University of Wyoming, Laramie, WY 82071. Corresponding author's E-mail: odero@uwyo.edu

lanceleaf sage density and duration of interference on sugarbeet root yield and sucrose content, and evaluate the influence of CTWR on sugarbeet root yield.

Materials and Methods

Field Operations. Field experiments were conducted at the Powell Research and Extension Center (PREC), Powell, WY, in 2006 and 2007. The soil type was a Garland loam (fine-loamy over sandy or sandy-skeletal, mixed, superactive, mesic Typic Haplargids) with pH 7.6 and 1.3% organic matter. Experimental plots were located in fields where barley (*Hordeum vulgare* L.) had been grown the previous year. All fields were conventionally prepared by moldboard plowing and leveling in the fall following barley harvest. Urea (112 kg N ha^{-1}) was broadcast-applied and incorporated; fields were subsequently bedded on 56-cm rows on March 28, 2006, and March 26, 2007. Lanceleaf sage seeds collected at the PREC fields in late summer of 2005 and 2006 were planted on the bedded fields on April 22, 2006, and May 4, 2007, respectively, using a one-row manual cone planter prior to planting sugarbeet. Sugarbeet 'Treasure' was planted at 111,000 seeds ha^{-1} on April 24, 2006, and May 10, 2007. The fields were later side-dressed with urea ammonium nitrate (135 kg N ha^{-1}). Weeds between the sugarbeet rows were controlled by cultivation using a six-row cultivator on June 17, 2006, and June 25, 2007. Cultivation was supplemented with hand-weeding to keep the plots free of undesired weeds. The plots were furrow-irrigated during the growing season to optimize growing conditions and ensure that moisture was not a limiting factor.

The experiments were established as a randomized complete block design with four replications for both the weed density and duration of interference studies. Experimental plots consisted of three sugarbeet rows, 7.6 m long and spaced 56 cm apart. Individual plots were established immediately after sugarbeet and lanceleaf sage emergence for both studies (sugarbeet and lanceleaf sage emerged at the same time in both years).

Density Study. An additive design was used to conduct the density study whereby sugarbeet density was constant with a variable lanceleaf sage density (Park et al. 2003). Lanceleaf sage was established in an 8-cm band over the sugarbeet rows both years by hand-thinning after emergence to achieve the desired densities of 0, 6, 12, 18, 24, and 30 plants m^{-1} of row. Sugarbeet was harvested from the center row of each plot on September 28, 2006, and October 1, 2007 using a one-row mechanical sugarbeet lifter. Sugarbeet root fresh weights were measured in the field, and a subsample was sent for quality analysis at the Western Sugar Tare Laboratory in Billings, MT.

Duration of Interference Study. The study was established in a manner similar to the density study. Shortly after emergence, the lanceleaf sage was thinned to a density of 18 plants m^{-1} of row in an 8-cm band over the sugarbeet rows both years. Lanceleaf sage was allowed to compete with sugarbeet for 0, 36, 50, 64, 78, 92, and 106 d after emergence (DAE) before removal by hand. A weedy control was included at the same density. Sugarbeet harvest was the same as the procedure described in the density study.

Statistical Analysis. All data were subjected to ANOVA using the MIXED procedure of SAS[1] at the 5% level of significance to assess the effect of lanceleaf sage density and duration of interference on sugarbeet yield components. Sugarbeet yield components included percentage of sucrose content, root yield, and sucrose yield. 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 interaction (McIntosh 1983).

Cousens' (1985) hyperbolic model was used to describe sugarbeet yield as a function of lanceleaf sage density:

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

where Y is the sugarbeet yield (Mg ha^{-1}), Y_{wf} is the estimated weed-free yield, d is the weed density per meter of sugarbeet row, I is the initial slope or percentage of yield loss per unit weed density as density approaches zero, and A is the asymptote or percentage of yield loss as weed density approaches infinity.

Because crop yield loss cannot be observed directly, measured yield was used to estimate yield loss. Sugarbeet root and sucrose yield loss was calculated as $1 - (Y_{obs}/Y_{wf})$ where Y_{wf} is the weed-free yield estimated from all data rather than just from the weed-free control yields using Equation 1 and Y_{obs} the observed yield within a given density.

According to Cousens (1985), Equation 1 can also be expressed as a rectangular hyperbola to relate percentage of yield loss to weed density:

$$Y_L = Id/(1 + Id/A) \qquad [2]$$

where Y_L is the percentage of yield loss or reduction relative to the weed-free yield (Y_{wf}), and d, I, and A are the same as in Equation 1. The I and A parameters in Equation 2 are both easily interpreted in agronomic terms (Cousens 1985). Equations 1 and 2 were fitted to data using the drc package (Ritz and Streibig 2005) of the open source language R.[2]

A four-parameter logistic model was fit to assess the effect of duration of interference of lanceleaf sage on relative sugarbeet yield:

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

where Y is the relative root yield (percentage of season-long weed-free 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 required to reach the inflection point (where the inflection point occurs). Equation 3 was also fitted to data using the drc package of R.

Results and Discussion

Lanceleaf Sage Density. There was no effect of lanceleaf sage density on percentage of sucrose content, although percentage

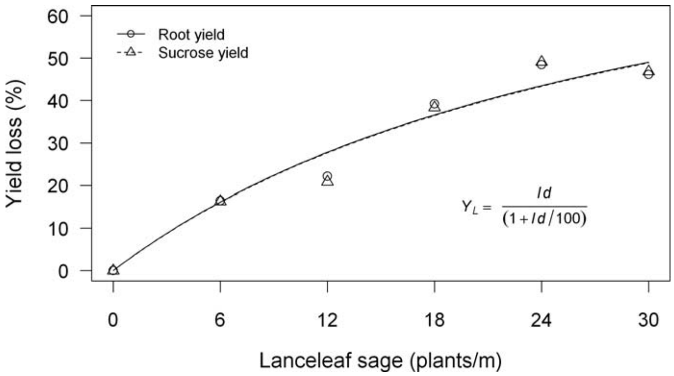

Figure 1. The effect of lanceleaf sage density on sugarbeet yield loss. Equation 2, where *d* is the lanceleaf sage weed density, *I* is the initial slope or percentage of yield loss per unit weed density as density approaches zero, and *A* is the asymptote or percentage of yield loss as weed density approaches infinity, was used to predict the relationship between sugarbeet yield loss and lanceleaf sage density. Parameter estimates and standard errors (in parentheses) were $I = 3.08$ (0.75) and $A = 110.16$ (35.25) for root yield; $I = 2.80$ (0.65) and $A = 128.13$ (49.81) for sucrose yield. When the *A* parameter was constrained to 100, parameter estimates and standard errors were $I = 3.30$ (0.34) for root yield, and $I = 3.29$ (0.33) for sucrose yield.

of sucrose was significantly higher in 2007 compared to 2006 (17.5 and 16.3%, respectively). Prevailing environmental conditions during the growing season probably resulted in the differences observed between years. Similarly, competition from varied densities of common lambsquarters (*Chenopodium album* L.) (Schweizer 1983), Powell amaranth (*Amaranthus powellii* S. Wats.) (Schweizer and Lauridson 1985), kochia [*Kochia scoparia* (L.) Schrad.], green foxtail [*Setaria viridis* (L.) Beauv.] (Mesbah et al. 1994), wild mustard (*Sinapis arvensis* L.), and wild oat (*Avena fatua* L.) (Mesbah et al. 1995) had no effect on percentage of sucrose content of sugarbeet. However, Schweizer and Bridge (1982) reported reduction in percentage of sucrose with increasing densities of velvetleaf (*Abutilon theophrasti* Medik.) and common sunflower (*Helianthus annuus* L.). These results demonstrate that the contrast in response among studies suggest that the effect of weed interference on percentage of sucrose may reflect a species by environment interaction.

There was no significant lanceleaf sage density by year interaction for sugarbeet root and sucrose yield, thus data were combined over 2006 and 2007 for analysis. Lanceleaf sage density had an influence on sugarbeet root and sucrose yield. The weed-free sugarbeet root and sucrose yields were estimated to be 66.14 and 11.15 Mg ha^{-1}, respectively. There was a hyperbolic relationship between lanceleaf sage density and sugarbeet yield loss (Figure 1). Percentage of sugarbeet yield loss increased with increasing lanceleaf sage density. Parameter *A* (asymptote or maximum percentage of yield loss), was estimated to be 112 and 128% for root and sucrose yield loss respectively, and parameter *I*, which is an indicator of the potential weed competitiveness was estimated to be 3% for both root and sucrose yield. Such high asymptotic yield loss response occurs when the range of weed densities is restricted (Cousens 1985). Because yield loss can never exceed 100%, the asymptotic sugarbeet yield loss was constrained to 100% (Askew and Wilcut 2001; O'Donovan 1991; Streibig et al. 1989). Constraining the asymptote did not confound estimation of the parameter *I* (estimated to be 3% for both root and sucrose yield loss) because the *F* test for comparing the nonlinear models was not significant. Therefore, the predicted root and sucrose yield loss from season-long interference of 1 lanceleaf sage plant m^{-1} of sugarbeet row was 3% based on the parameter *I* estimate.

Predicted root yield loss from season-long interference of 6, 12, 18, 24, and 30 lanceleaf sage plants m^{-1} of sugarbeet row was 16, 28, 37, 44, and 49%. Because percentage of sucrose content was unaffected by lanceleaf sage density, sucrose yield loss estimates were similar. Interference from low-statured weeds resulted in similar sugarbeet yield reductions. Venice mallow (*Hibiscus trionum* L.) densities of 6, 12, 18, 24, and 30 plants m^{-1} reduced sugarbeet root yields 23, 33, 39, 42, and 45%, respectively (Odero et al. 2009). At similar densities, wild buckwheat (*Polygonum convolvulus* L.) reduced root yields 23, 33, 39, 43, and 46%, respectively (Odero et al. 2010). Similarly, several broadleaf competition studies in sugarbeet have shown increased yield reduction with increasing weed densities. Common lambsquarters densities of 0.2, 0.4, 0.6, and 0.8 plants m^{-1} of sugarbeet row reduced sugarbeet root yields 13, 29, 38, and 48%, respectively, and sucrose yield was reduced 11, 27, 37, and 46%, respectively (Schweizer 1983). At densities of 0.2, 0.4, 0.6, and 0.8 plants m^{-1}, Powell amaranth reduced sugarbeet root yields 8, 14, 24, and 25%, respectively, and sucrose yield 7, 13, 23, and 24%, respectively (Schweizer and Lauridson 1985). Schweizer and Bridge (1982) studied interference of sunflower and velvetleaf in sugarbeet, and established that at densities of 0.2, 0.4, 0.6, and 0.8 sunflower plants m^{-1} of sugarbeet row, root yields were reduced 40, 52, 67, and 73%, respectively. At similar densities of velvetleaf, root yields were reduced 14, 17, 25, and 30%, respectively. The greater yield reduction from these weeds compared to lanceleaf sage, which has a slow growth pattern (Nussbaum et al. 1985), is attributable to their ability to emerge early, grow tall, and produce a lot of biomass thus enabling them to completely shade the sugarbeet canopy during the growing season.

Critical Time for Lanceleaf Sage Removal. Duration of interference did not have a significant effect on percentage of sucrose content. However, percentage of sucrose was significantly higher in 2007 compared to 2006 (17.7 and 16.0%, respectively). Similar observations have been reported for kochia and green foxtail (Mesbah et al. 1994), as well as wild mustard and wild oat (Mesbah et al. 1995) duration of interference in sugarbeet. However, Weatherspoon and Schweizer (1969) reported a reduction in percentage of sucrose as duration of kochia competition increased. These observations demonstrate that the contrast in response among studies suggest that the effect of duration of weed interference on percentage of sucrose may reflect a species by environment interaction.

There was no significant duration by year interaction for relative sugarbeet root yield so data were combined over years for analysis. The four-parameter logistic model (Equation 3) provided the best fit to estimate the CTWR. Relative sugarbeet root yield decreased as the duration of interference increased (Figure 2). The predetermined acceptable yield loss

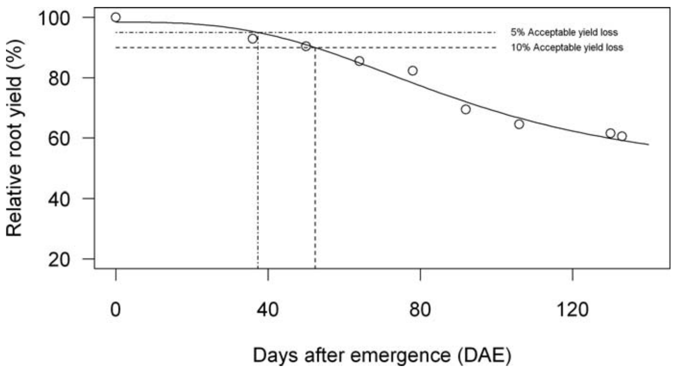

Figure 2. The influence of lanceleaf sage duration of interference on relative sugarbeet root yield. Equation 3, where *T* is the number of days after emergence (DAE), *b* is the slope at the inflection point, *c* is the lower limit, *d* is the upper limit, and *e* is the number of DAE required to reach the inflection point (where the inflection point occurs), was used to predict lanceleaf sage interference on relative sugarbeet root yield. Parameter estimates and standard errors (in parentheses) were $b = 3.00$ (2.18), $c = 46.80$ (26.91), $d = 98.40$ (4.88), and $e = 90.45$ (32.50).

values used to predict CTWR were 5 and 10%. The acceptable yield loss value can be adjusted depending on crop value, weed management cost, and expected economic return (Knezevic et al. 2002). The CTWR due to lanceleaf sage interference increased in sugarbeet as predetermined acceptable yield loss level increased from 5 to 10%. Using acceptable yield loss level of 5 and 10%, the CTWR for lanceleaf sage in sugarbeet was estimated to be 37 and 52 DAE, respectively. The CTWR was relatively long indicating that sugarbeet exhibited early-season tolerance to lanceleaf sage at the density used in this study.

Sugarbeet root yield reduction as a result of duration of interference from several weed species in sugarbeet has been reported. Weatherspoon and Schweizer (1969) reported that sugarbeet root yields were reduced by 25% with an additional week of kochia competition early in the growing season. Mesbah et al. (1994) evaluated the effects of mixed populations of kochia and green foxtail on sugarbeet, and determined that the minimum duration of time that 0.5 kochia and 3 green foxtail plants m^{-1} of row can interfere with sugarbeet before 2.5% yield reduction was 3.5 wk after emergence (WAE). Similarly, 0.8 wild mustard and 1 wild oat plant m^{-1} of row required a minimum of 1.6 WAE of sugarbeet to cause 5.5% yield reduction (Mesbah et al. 1995).

The results from this study demonstrate that lanceleaf sage interference has a negative impact on sugarbeet yield. Although lanceleaf sage is not as competitive as other weeds, appropriate control measures should be undertaken to minimize yield losses from interference and reduce weed seed production for future infestations because it is an abundant seed producer with prolonged and irregular emergence patterns (Freebairn and Strang 1974). Similarly, in irrigated cropping systems such as in northern Wyoming, where moisture is adequate and soil disturbances such as cultivation may accentuate lanceleaf sage germination from the soil seed bank, appropriate control measures should be applied to forestall the likelihood of infestation in sugarbeet or crops grown in rotation with it. Furthermore, results from this study suggest that sugarbeet can tolerate interference of lanceleaf sage for at least 37 d at the weed density used in the study depending on the yield loss a grower is prepared to accept, implying that control measures should be instituted before this period to prevent yield loss. These results provide valuable information upon which guidelines or recommendations specifically targeting management of lanceleaf sage infestation in sugarbeet can be based and developed.

Sources of Materials

[1] SAS®, version 9.1.3, 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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