Managing Invasive Range Plants in Beef-Cattle Grazing Systems: The Tale of Sericea Lespedeza (*Lespedeza cuneata*) in Native Tallgrass Prairie[2]

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ABSTRACT: North-American tallgrass prairie provides an array of ecosystem services including carbon sequestration, biodiversity preservation, and forage for grazing livestock. Once covering 68 million ha, only 4% remains today. The largest remnant (~1.5 million ha) lies in the Kansas Flint Hills, home to ~1.3 million yearling cattle and ~90,000 beef cows annually. Unfortunately, the functionality of this ecosystem is threatened by an exotic invader - sericea lespedeza (*Lespedeza cuneata*). Known colloquially as sericea, it is a perennial forb with prodigious capacity to proliferate. Sericea selection by grazing cattle is poor; condensed-tannin concentrations in wild-type sericea can approach 20% of plant DM. Total-tract N digestibility by beef cows consuming sericea-contaminated tallgrass-prairie hay was documented at < 0%; moreover, adaptability of beef cattle to high-tannin diets appears to be limited. Sericea control has been attempted using herbicides. This has not limited proliferation and has resulted in collateral damage to non-target lifeforms. Attempts to naturalize sericea to the ecosystem via enhanced herbivory were evaluated. Supplementation of beef cow diets with tannin-binding feedstuffs resulted in ≥ 29% increases in sericea selection compared with non-supplemented cows. Co-grazing beef cows and goats was associated with > 20% more defoliation of sericea than beef-cow grazing alone. Sequential grazing of yearling steers followed by mature ewes resulted in > 92% defoliation of sericea compared with < 2% in pastures grazed by steers alone. Unfortunately, widespread adoption of these techniques by the ranching community hasn't occurred because of increased costs or logistical constraints. More recently, prescribed fire as a low-cost means of control was evaluated. Prescribed fires in late summer greatly diminished sericea proliferation compared with prescribed fires in spring (i.e., the traditional prescribed-fire season). No changes in peak forage biomass or C4 grass-species abundance were observed; moreover, native legumes and nectar-producing forbs increased ≥ 2-fold in response to summer fire. Cultural acceptability of prescribed fire in the region is high; significant adoption by the ranching community has been observed.

Key words: condensed tannins, invasive plants, *Lespedeza cuneata*, native tallgrass prairie

INTRODUCTION

Sericea lespedeza (*Lespedeza cuneata* [Dumont] G. Don; hereafter **sericea** or **sericea lespedeza**), a perennial, warm-season, leguminous forb, was introduced into the United States in the late 19th century from the Sino-Indian region of Asia for its soil conservation properties on farmland and mine spoils and perceived value for wildlife habitat (Mosjidis, 1997). The plant was introduced into the American Midwest in the 1930's to reclaim strip-mined land (Ohlenbusch et al., 2007). In the ensuing decades, sericea propagated, adapted environmentally, and moved westward into the tallgrass

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prairie region of Kansas and Oklahoma (Hobbs and Humphries, 1995). In the lag between introduction of sericea and public awareness of its invasive tendencies, sericea seed was harvested inadvertently from infested rangelands and planted on land enrolled in the U. S. Department of Agriculture Conservation Reserve Program (Eddy et al., 2003). The subsequent and continued spread of sericea in pastoral lands of the tallgrass prairie region is of ongoing concern because it threatens to alter fundamentally one of the most endangered ecosystems on earth (Sampson and Knopf, 2018).

Sericea tends to be a highly-competitive invader in the tallgrass prairie region for a variety of reasons: lack of sufficient grazing pressure, mild allelopathy, canopy dominance, environmental adaptability, and high fecundity. Dietary selection of sericea by beef cattle grazing native rangelands is limited due to its elevated condensed tannin content (Preedy et al., 2013b; Sowers et al., 2019); therefore, control of propagation via grazing is unlikely because pastoral production systems in the tallgrass prairie region are overwhelmingly dominated by beef cattle (USDA, 2017). When condensed tannin levels in cultivated varieties of sericea reached 5 to 12% of plant dry matter, depressed intake, diet digestibility, and animal productivity were documented (Mosjidis, 1997; Aerts et al., 1999). Preedy et al. (2013b) reported that condensed-tannin concentration in *wild-type* sericea ranged from 10 to 19% of whole-plant plant DM during the growing season.

The root system and seed coat of sericea lespedeza have mild allelopathic properties that reduced growth and productivity of both cultivated grasses and native grasses (Logan et al., 1969; Kalburtji and Mosjidis, 1992; Dudley and Fick, 2003; Coykendall and Houseman, 2014). The influence of this allelopathy on forb and shrub growth has not been widely investigated. In addition, sericea tends to produce a robust canopy when mature that prevents sunlight from reaching understory plants (Ohlenbusch et al., 2007; Vermeire et al., 2007; Allred et al., 2010); it can also thrive in shallow and acidic soils that will not support vigorous populations of native plants (Mosjidis, 1997).

Natural characteristics of sericea have led researchers to make generalizations about its environmental adaptability. Ohlenbusch et al. (2007) indicated that herbivore avoidance of individual plants with naturally greater condensed-tannin concentrations may have led to selection for elevated condensed-tannin levels in wild-type sericea. It produces both self-fertilizing (i.e., cleistogamous) flowers and flowers that require cross-pollination (i.e., chasmogamous). The latter allow sexual recombination of genetic material between diverse parent plants and are a possible reason why sericea has adapted so quickly to the tallgrass prairie region (Donnelly, 1979; Mosjidis, 1997).

Finally, sericea is a prolific seed producer (Ohlenbusch et al., 2007). Lemmon et al. (2017) indicated that single stems produced an average of 864 seeds annually over a 4-yr period. Notably, non-scarified sericea seed may remain viable in the soil for many yr, leading to prolonged germination (Cummings et al., 2006).

To date, sericea has degraded more than 2,500 km^2 of native tallgrass prairie (KDA, 2016). In pastoral beef production systems of the region, this degradation has manifested itself as diminished carrying capacity (Preedy et al., 2013b; Sowers et al., 2019); however, detrimental effects of invasion on grassland fauna have also been documented. Eddy and Moore (1998) observed decreased invertebrate diversity in sericea-invaded tallgrass prairie. Similarly, Brooke et al. (2016) reported disproportionate placement of nests by Northern bobwhite (*Colinus virginianus*) in areas relatively free of sericea, whereas Ogden (2016) documented habitat degradation for certain upland-nesting songbirds and grassland-obligate pollinators in areas moderately infested with sericea.

The role of fire in sericea lespedeza ecology has received only limited attention to date. Fire likely plays a critical role in scarification and subsequent germination of its seed. Herranz et al. (1998) indicated that dry or moist heat effectively scarified seeds of 7 leguminosae species. Subsequently, Vermeire et al. (2007) and Wong et al. (2012) indicated that prescribed fires common to the tallgrass-prairie region appeared to stimulate sericea germination; however, the season in which prescribed fire was applied may have influenced seedling survival. Cummings et al. (2007) reported that application of growing-season prescribed fire at 3-yr intervals decreased the rate of invasion in Oklahoma tallgrass prairie compared with application of dormant-season (i.e., spring) prescribed fire at 3-yr intervals.

The objectives of this manuscript are three-fold: 1) to provide a short overview of condensed-tannin effects on ruminal fermentation; 2) to provide a review of proposed control methods for sericea lespedeza in the tallgrass prairie region of North America; and 3) to make some concluding generalizations about approaches to controlling invasive range plants.

DISCUSSION

Condensed tannins and ruminal fermentation. Condensed tannins are flavonoid polymers with a high binding affinity for proteins (Waghorn, 2008). They are found in a wide variety of plants and are a biodefense mechanism against plant diseases, environmental stress, and herbivory (Min et al., 2003). Condensed tannins limit voluntary intake, diet digestibility, and ruminal protein degradation by ruminants due to formation of tannin-protein complexes *in vivo* (Makkar, 2003). Tannin-protein complexes form during mastication as condensed tannins are released from macerated plant cells (Min et al., 2003). These complexes are stable under ruminal conditions, rendering proteins non-degradable by microbial enzymes (Al-Dobaib, 2009; Hassanat and Benchaar, 2012). As a result, ruminal VFA production is sharply curtailed (Hoehn et al., 2018) and microbial growth rates therein are suppressed (Min et al., 2005).

Condensed tannins in forage crops are a strong deterrent to consumption by beef cattle (Eckerle et al. 2011a; Preedy et al., 2013b). This is likely related to a dearth of ruminally-available N and a corresponding decrease in microbial cell protein production. Non-supplemented beef cows fed a high-tannin forage had total-tract N digestibilities that were $< 0\%$ (Eckerle et al., 2011b). Prior exposure to dietary tannins did not meaningfully improve ruminal fermentation parameters (Hoehn et al., 2018). Small ruminants appear to have greater tolerance for condensed tannins than cattle (Pacheco et al., 2012; Lemmon et al., 2017); however, reasons for interspecies differences in tannin tolerance have not been fully elucidated (Robbins et al., 1991; McKiernan, 2015).

Wild-type sericea lespedeza is among the most tannin-dense herbaceous plants globally. Its condensed-tannin concentrations are reported to range from 10 to 25% of whole-plant plant DM during the growing season (Eckerle et al., 2010; Preedy et al., 2013b). Avoidance of wild-type sericea lespedeza by confined beef cattle consuming tallgrass prairie hay (Eckerle et al., 2011a and 2011b), by grazing beef cows (Preedy et al., 2013a and 2013b), and by grazing yearling beef steers (Sowers et al., 2019) has been reported. Eckerle et al. (2011b) reported that beef cows likely developed a flavor-related aversion to sericea lespedeza before a general ruminal malaise occurred. Condensed tannins are astringent and may be perceived by some herbivores as having a bitter flavor (Provenza et al., 1990; Hagerman et al., 1992). Grazing herbivores may learn to avoid sericea lespedeza because of the astringent flavor associated with condensed tannins rather than because of any detrimental effects of condensed tannins on ruminal N metabolism.

Herbicides. Early efforts to control sericea lespedeza were focused on specialty herbicides. Altom and Stritzke (1992) evaluated the efficacy of several post-emergent herbicides applied from mid-May through early June including: triclopyr, picloram, 2,4-D, metsulfuron methyl, dicamba, clopyralid, and fluroxypyr. One yr following treatment, sericea stem density in triclopyr- and fluroxypyr-treated plots ranged from 0 to 21% of non-treated control plots, whereas metsulfuron methyl-treated plots had sericea stem densities that ranged from 0 to 67% of non-treated controls. Other herbicides did not provide satisfactory control.

Koger et al. (2002) later determined the timing of herbicide application influenced sericea lespedeza survival. These researchers applied triclopyr or metsulfuron methyl at 3 different sericea growth stages including simple-stem (mid-June), branched-stem (mid to late July), or flowering (mid to late September). When triclopyr was applied at the simple-stem or branched-stem developmental stages, it routinely reduced sericea to less than 20% of pre-treatment stem density. Conversely, triclopyr was much less reliable when applied at the flowering stage of sericea development. Metsulfuron methyl was ineffective for sericea control when applied at the simple-stem stage of development; however, it proved to be a viable option for control when applied during the flowering stage. Following publication of this work, researchers and management agencies began to recommend what has since become the accepted paradigm for sericea control: apply triclopyr during the vegetative phase of sericea development and apply metsulfuron methyl during the reproductive phase (Ohlenbusch et al., 2007; Vermeire et al., 2007; Farris and Murray, 2009).

Subsequent reports touted success in controlling sericea lespedeza with specialty herbicides (Jordan et al., 2002; Emry, 2008); however, eradication was never realized. Eddy et al. (2003) reported that acreage in Kansas effected by sericea invasion increased 60-fold between 1988 and 2000, in spite of widespread regional herbicide usage during that period. Given the profound fecundity of sericea (Lemmon et al., 2017) and its sustained ability to sprout from the seed bank (Woods et al., 2009) and from existing plant crowns, herbicide treatments do not appear to be an effective means of long-term control.

Perhaps a more important issue ecologically is that attempts to control invasive forbs with herbicides have historically resulted in collateral damage to non-target native forbs. Use of herbicides in native grasslands for the control of broom snakeweed (McDaniel et al., 2000), leafy spurge (Rinella et al., 2009), smooth sumac (Tunnell et al., 2006), and sericea lespedeza (Gatson, 2018) reduced richness and evenness of native forbs. The severity of depressive effects was dependent on the invasive species, the herbicide, and the ecosystem in question. Therefore, the dearth of research on the effects of herbicides on non-target organisms should serve as impetus for further investigation.

Predation. Contemporary with the development of herbicide strategies, an attempt was also made to achieve biological control of sericea lespedeza using the lespedeza webworm (*Tetralopha scortealis* Lederer). The lespedeza webworm is the larval form of a moth native to the southeastern U.S. It forms a dense, silk-like web around sericea which limits photosynthetic activity. The larvae then defoliate the plant (Poos and Hetrick, 1945). Eddy et al. (2003) released lespedeza webworm at various locations in southeast Kansas and measured subsequent effects on sericea stands. Initially, webworm infestations decreased the average number of seeds produced per sericea stem from 644 seeds/plant to less than 6 seeds/plant. Unfortunately, webworms were unable to survive in dry conditions or through the winter. These authors concluded that lespedeza webworms were unlikely to play an important role in sericea control in the tallgrass prairie due to a lack of environmental fitness.

Herbivory. Schutzenhofer and Knight (2007) explored the theoretical possibility of controlling sericea invasions via herbivory. Sericea lespedeza plants of varying sizes were manually defoliated early in the growing season to simulate natural herbivory. Unfortunately, the population growth of sericea remained quite high, even when subjected to as much as 80% defoliation early in the growing season. This finding somewhat limited hopes that the rate of sericea invasion might be diminished if wild or domestic herbivores readily consumed the plant. Nevertheless, it remained plausible that more extensive, repeated, or temporally-targeted herbivory might contribute to a reduction in the abundance and vigor of the plant.

Condensed tannins in sericea lespedeza reduce its acceptability by beef cattle (Cope and Burns, 1971) and inhibit voluntary intake (Wilkins et al., 1953). In spite of these obstacles, there have been attempts to increase sericea consumption by grazing beef cattle. Mantz et al. (2009) demonstrated that feeding confined beef steers polyethylene glycol, a tannin-binding compound (Jones and Mangan, 1977), increased voluntary intake of freshly-cut sericea. Citing cost and regulatory restriction on the use of polyethylene glycol as a feedstuff, Eckerle et al. (2011b and 2011c) evaluated the value of corn steep liquor for the same purpose. They reported that it was likewise effective at increasing voluntary intake of sericea-contaminated prairie hay by beef cattle fed in confinement.

Recognizing the potential for controlling sericea lespedeza in addition to improving animal performance, Preedy et al. (2013a; 2013b) extended this line of research by measuring the effect of corn steep liquor supplementation on dietary selection of sericea by cattle grazing native tallgrass-prairie pastures. They reported increased voluntary intake of sericea during the months of August and September by beef cows supplemented with corn steep liquor compared with non-supplemented cows. Importantly, that time period corresponded with flowering and seed production by the plant. These authors speculated that the seed production would be reduced by increasing herbivory on the plant during that specific phenological stage.

The important work of Preedy et al. (2013a; 2013b) notwithstanding, evidence for slowing invasion and reducing existing infestations of sericea lespedeza through beef-cattle grazing alone remains limited. Although grazing of sericea by non-supplemented cattle is inhibited by high condensed tannin content (Wilkins et al., 1953; Cope and Burns, 1971), this may not be an impediment for domesticated small ruminants (Robbins et al., 1991; Hart, 2001). Accordingly, focused grazing with sheep or goats for inhibiting sericea proliferation has been investigated.

Early research by Hart (2000; 2001) reported that grazing juvenile goats at a stocking rate of 10 goats/ha for 120 d for several consecutive years significantly suppressed sericea growth and seed production. The author indicated that goat grazing was an effective, sustainable, and income-generating method of rangeland improvement but opined that widespread adoption by beef producers of the region was unlikely. Cultural biases were cited as the main reasons for producer reluctance to adopt a small-ruminant grazing enterprise independent of a beef-cattle grazing enterprise (Hart, 2001). Subsequently, Pacheco et al. (2012) studied the effects of co-grazing goats and beef cows on herbivory of sericea. Livestock were grazed on sericea-infested native tallgrass pastures from June through October. Equivalent stocking rate complements of both species (i.e., 8 ha/AUM for cattle and 8 ha/AUE for goats) were evaluated. At the conclusion of the study period, a greater proportion of sericea stems in co-species pastures showed evidence of herbivory than in cattle-only pastures. Final biomass of sericea entering the dormant season, however, was not different between treatments. This may have been an indication that, although goats increased grazing pressure on sericea, the stocking rate of goats must be very high before the total biomass of sericea in a heavily-infested pastures could be meaningfully reduced.

The most popular grazing management practice in the Flint Hills of Kansas involves annual spring burning followed by intensive grazing with yearling beef cattle from April to August (Owensby et al., 2008). Rangelands are then rested for the balance of the growing season. Accordingly, Lemmon et al. (2017) evaluated a leader-follower grazing system in which sheep were grazed subsequent to yearling cattle. In a 4-yr experiment, yearling cattle were grazed on eight 31-ha pastures from mid-April to mid-July at a rate of 235 kg of live weight/ha. Mature ewes were then grazed on half of the pastures for 60 d, while remaining pastures were rested until the following spring. Ewes were stocked at a rate of 325 kg of live weight/ha.

When compared to pastures grazed by yearling cattle only, pastures with added late-season grazing by sheep had substantially increased percentages of sericea plants showing evidence of herbivory (92.1 vs. 1.4%) at the end of the sheep-grazing period (Lemmon et al., 2017). Whole-plant mass of sericea stems entering the dormant season (1,443 vs. 4,424 mg/plant; DM basis) and sericea seed production (114 vs. 864 seeds/plant) were greatly reduced. The authors interpreted these results to indicate that late-season sheep grazing decreased the vigor of existing sericea plants at a phenologically-critical time for the plant and limited the proliferation of new plants via seed. At the conclusion of the study, basal frequency of sericea in pastures grazed by both cattle and sheep was less than that in pastures grazed by yearling cattle alone. Year-end residual biomass was 904 kg DM/ha less on pastures grazed using the leader-follower system compared with those grazed only by beef cattle; however, authors indicated that sufficient biomass was present on all pastures to prevent soil-moisture loss and to allow prescribed burning the subsequent spring.

In spite of substantial evidence to support the soundness of the approach, adoption of small-ruminant grazing enterprises in the tallgrass prairie region for the purpose of sericea lespedeza control has been modest. Cultural biases cited by Hart (2001) may explain part of the regional reluctance to use small ruminants to control sericea; however, other legitimate challenges exist. Kansas has fewer than 124,000 small ruminants (USDA, 2017) and approximately 250,000 ha of native tallgrass prairie that has been degraded by sericea lespedeza (KDA, 2016). Considering the small-ruminant stocking rates suggested by Hart (2001), Pacheco et al. (2012), and Lemmon et al. (2017), 1.25 to 2.5 million small ruminants would be required for adequate sericea lespedeza control through targeted grazing. Adding to this logistical difficulty are issues related to limited market access for small-ruminant products, increased fencing costs compared with beef cattle, and losses due to predation.

Prescribed Fire. The role of fire in sericea lespedeza ecology has received only limited attention to date. Fire likely plays a critical role in scarification and subsequent germination of its seed (Herranz et al., 1998; Vermeire et al., 2007). Traditional spring-season burning of the tallgrass prairie has not resulted in control of sericea and may, in fact, have exacerbated the problem (Cummings et al., 2007; Ohlenbusch et al., 2007). Although burning during the spring may serve to promote invasion, burning during more sensitive times in the life cycle of sericea may have an inhibitory effect. Two recent studies conducted in the tallgrass prairie region have explored this possibility.

Wong et al. (2012) conducted 2 field experiments designed to evaluate the effects of fire timing on sericea lespedeza seed germination and seedling survival. The results of their first field experiment indicated that burning in early November after seed dispersal had occurred decreased the rate of sericea establishment. The authors attributed this result to a direct reduction in the viability of seed exposed to a November fire. In the second experiment, 90 individual 1-m^2 plots were established and sowed with sericea seed in late March. Fifteen individual plots were then burned on 1 of 6 different dates: 21 April, 25 May, 21 June, 21 July, and 4 September of year 1 and 21 April of year 2. Independent of prescribed-fire timing, burning was a strong stimulator of sericea seed germination. This effect may be responsible in part for the rapid increase of sericea in tallgrass prairie pastures that are burned annually in early spring. Seedling survival was much greater in plots burned early in the growing season than those burned in the summer. Although the late-summer burns also stimulated germination of sericea seeds, few late-germinating seedlings survived to the second growing season.

Alexander et al. (2017) took the next steps in applying these observations to the control of sericea lespedeza on a larger scale. Their trials were conducted on a native tallgrass prairie in the northern Flint Hills with a moderate to heavy infestation of sericea. This research was conducted on 9 paddocks (~ 5 ha) that were burned annually for 4 consecutive yr in either early April (i.e., the traditional burning season in the region), early August, or early September. Paddocks burned in early August or early September had precipitous declines in sericea seed production and whole-plant mass at dormancy when compared with paddocks burned in April. This suggested the possibility that late-summer burning could substantially curb the reproductive capabilities of the plant. More importantly, the basal frequency and total biomass of sericea at the conclusion of the experiment were an order of magnitude less in areas treated with August or September fire compared to those treated with April fire (Alexander, 2018). This may be an indication that late-summer fires increased the mortality of mature sericea lespedeza crowns in addition to inhibiting seed-based and vegetative reproduction.

Cultural acceptability of prescribed fire in the tallgrass prairie ecoregion is high; moreover, costs of prescribed fire application are relatively small compared with herbicide-based approaches to sericea lespedeza control (Olson, 2019). As a result of the work of Alexander et al. (2017) and Alexander (2018), there have been noticeable changes in prescribed fire use among tallgrass-prairie land managers, as well as meaningful changes to regional and national conservation policies to promote use of summer-season prescribed fire for sericea lespedeza control. Users of the technique report that summer-season prescribed burns are less complicated to control than comparable early-spring prescribed fires. They also report that summer-season burns are more compatible with ranch labor availability and coincide with more favorable atmospheric conditions for prescribed fire compared with spring-season burns. Significant adoption of the technique by the ranching community has been observed.

Conclusions. The search for a means to naturalize wild-type sericea lespedeza to the tallgrass prairie ecoregion is 4 decades old. Herbicides, insect predation, herbivory by domestic ruminants, and prescribed fire have all shown promise as methods of control and, thus, naturalization. Interestingly, each of these potential control mechanisms was linked to one or more specific life-cycle characteristics of sericea, making temporal aspects of treatment application critical to treatment efficacy. In effect, control strategies were developed based on a gradual growth in the understanding of the basic biology of wild-type sericea lespedeza.

Although several sericea-lespedeza control techniques have been successful from a scientific and statistical viewpoint, not all produce a result that is satisfying from a sensory perspective. Whether or not the *applied-science* community is willing to admit it, we are in the business of attempting to change human behavior. Statistical tests can be a critical component of behavior change; however, long-term adoption of new management practices may rest with users' ability to perceive, visually or otherwise, improvements in ecosystem condition within a short time of making a change in practice. As with other invasive organisms, no single approach is likely to provide user-defined satisfactory control of sericea lespedeza. Multi-faceted control strategies are desirable not only to develop comprehensive and satisfying control but, perhaps more importantly, also to encompass an inclusive range of land-management goals.

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