Effects of late-season sheep grazing following intensive-early steer grazing on population dynamics of sericea lespedeza (*lespedeza cuneata*)

by

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B.S., Kansas State University, 2013

A THESIS

submitted in partial fulfillment of the requirements for the degree

MASTER OF SCIENCE

Department of Animal Sciences and Industry
College of Agriculture

KANSAS STATE UNIVERSITY
Manhattan, Kansas

2021

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Abstract

Mature ewes were used in a 2-yr experiment to evaluate effects of intensive late-season grazing with sheep on vigor of sericea lespedeza (*Lespedeza cuneata*; hereafter **sericea**) in native tallgrass prairie. Pastures (n = 8; 31 ± 3.6 ha) infested with sericea (initial basal frequency = 1.4 ± 0.81%) were assigned randomly to 1 of 2 treatments: early-season grazing with beef steers (1.1 ha/steer; initial BW = 258 ± 1.7 kg) from 15 April to 15 July followed by 60 d of rest (control; **STR**) or steer grazing from 15 April to 15 July followed by intensive grazing with mature ewes (0.2 ha/ewe; **SHP**) from 1 August to 1 October. Ewes (initial BW = 65 ± 3.1 kg) were assigned randomly to graze 4 of 8 pastures; remaining pastures were not grazed from 1 August to 1 October. Vegetation responses to treatment were measured along 4 permanent 100-m transects in each pasture. Herbivory of sericea was monitored weekly in each pasture from 21 July to 7 October. Herbivory of sericea in SHP and STR on 21 July was not different ($P = 0.51$). Herbivory of individual sericea plants was greater ($P < 0.01$) in SHP than in STR by the end of wk 1 of the sheep-grazing period (10.6 vs. 0.5%); moreover, herbivory of sericea lespedeza steadily increased ($P \leq 0.01$) such that 92.1% of sericea lespedeza plants had been grazed in SHP compared to 1.4% in STR by wk 8 of the sheep-grazing period. Whole-plant DM weight of sericea lespedeza at dormancy was less ($P < 0.01$) in SHP than in STR. Additionally, annual seed production by sericea lespedeza was less ($P < 0.01$) in SHP than in STR (114 vs. 864 seeds/plant). Pasture forage biomass was not different ($P = 0.76$) between SHP and STR after the steer-grazing period on 21 July. Conversely, STR had more ($P < 0.01$) residual forage biomass than SHP at the end of the sheep-grazing period (i.e., on 7 October). Growth performance of beef steers grazing from 15 April to 15 July annually was not different ($P \geq 0.59$) between treatments. Our results were interpreted to suggest that intensive late-season grazing by sheep decreased vigor of sericea lespedeza but did not affect growth performance of grazing steers. Although late-season sheep grazing decreased residual forage biomass by 904 kg DM/ha compared with late-season rest, residual biomass was likely adequate to prevent soil-moisture loss and erosion during the dormant season and was sufficient to allow prescribed fire application in the following spring seasons.

Keywords: biological weed control, grazing, *Lespedeza cuneata*, sheep, tallgrass prairie

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Acknowledgements

First and foremost, I would like to thank God. Without His grace, mercy, and love none of this would have been possible or had any meaning. I think Paul said it best in his letter to the Philippians, “For me to live is Christ and to die is gain” Philippians 1:21. Thank you to my wife, Kayla Lemmon, for your patience, kindness, love, and understanding as I have worked through this research project, my degree, and working full time to manage the Cow-Calf Unit. The encouragement and support from you has helped me grow more than you will ever know. You are truly a Proverbs 31 woman, and I cannot wait to raise our family together. I would also like to thank my family; thank you Mom and Wyatt for your support and encouragement and thank you Anna for helping me collect and record data. Thank you Dad and Jane for always having a word of encouragement, a place to stay during my research, a hearty meal, and the willingness to drive two hours to the project site to pull the research project out of the mud. I will forever treasure the fun memories I have collecting and recording data, as well as clipping samples with Dad and Blue. Thank you for teaching me the value of hard work, helping when no one else could, and making it a fun experience.

I would like to thank my committee members Dr. Walt Fick and Dr. Justin Waggoner for your technical support and guidance throughout this process. I would also like to thank my friends Jon Alexander, Jake Bohi, Arlan Newby, and Mark Spare for their willingness to help, providing wisdom and insight, and always being joyful and full laughter as we worked. Thank you to the KSU Cow-Calf Unit team for their support, especially Gary Ritter and Wayne Adolf; I have learned much from each of you and will not forget it. Thank you for the hard work and dedication from every undergraduate research assistant, especially Bobby Mullett and Ethan Sylvester. Without your willingness to step up and take care of the livestock and the ranch, I would have never been able to step away to write my thesis. Your ability to creatively problem solve never ceases to amaze me.

Finally, thank you to my advisor, Dr. K.C. Olson. I appreciate the opportunity to pursue a master's degree and conduct this research. I greatly appreciate you sharing your passion of range management with me and guiding me as a researcher and range scientist.

Dedication

I am dedicating this work to those who are in the arena and choose not to quit.

"It is not the critic who counts; not the man who points out how the strong man stumbles, or where the doer of deeds could have done them better. The credit belongs to the man who is actually in the arena, whose face is marred by dust and sweat and blood; who strives valiantly; who errs, who comes short again and again, because there is no effort without error and shortcoming; but who does actually strive to do the deeds; who knows great enthusiasms, the great devotions; who spends himself in a worthy cause; who at the best knows in the end the triumph of high achievement, and who at the worst, if he fails, at least fails while daring greatly, so that his place shall never be with those cold and timid souls who neither know victory nor defeat." - Theodore Roosevelt

Chapter 1 - Review of Literature

Introduction

Sericea lespedeza (*Lespedeza cuneata;* hereafter **sericea**) is an invasive forb in the tallgrass prairie region of the Great Plains (Eckerle et al., 2010). This is a matter of concern because the tallgrass prairie is one of the most endangered ecosystems on earth (Sampson and Knopf, 1994). In the state of Kansas, sericea infests over 254,000 ha of both native and cultivated grasslands, predominately in the Flint Hills region of the state (KDA, 2018). Infestations can reduce production of desirable plants by up to 92% through a combination of canopy dominance, prolific seed production, aggressive growth, and allelopathy (Eddy et al., 2003). The combination of these factors has allowed sericea infestations to increase steadily over time (Kalburtji and Mosjidis, 1992; Dudley and Fick, 2003; Eddy et al. 2003). Specialty herbicides have been shown to retard the spread of sericea; however, application is expensive and labor-intensive (Eddy et al., 2003). Furthermore, herbicides are typically lethal to ecologically-important, non-target plant species. This method of control is widely used by land managers (Kettenring and Adams, 2011).

Applying increased grazing pressure to sericea by beef cattle may slow its spread and expedite some measure of biological control; however, mature plants contain high levels of condensed tannins which are a strong deterrent to beef cattle (Jones and Mangan, 1977; Eckerle et al., 2011a, 2011b, 2011c; Preedy et al., 2013a, 2013b). Conversely, small ruminants appear to have a greater tolerance for condensed tannins than beef cattle (Robbins et al., 1991; Hart, 2001; Pacheco et al., 2012; Sowers et al., 2019). Sheep, in particular, appear less susceptible to certain plant toxins than beef cattle and may be useful to selectively pressure noxious weeds like sericea through grazing (Ralphs et al., 1991; Henderson et al., 2012).

The predominant grazing management practice in the Flint Hills region of Kansas involves annual spring burning followed by intensive grazing with yearling beef cattle from April to August (Owensby et al., 2008). During seasonal grazing, 40 to 60% of annual graminoid production is removed and pastures remain idle for the remainder of the year. Concurrent with this prevailing management practice, invasion by sericea into the tallgrass prairie biome has steadily increased (Eddy et al., 2003). Sericea flowers and produces seed in late summer (August to October; Cope and Burns, 1974; Koger et al., 2002; Eckerle et al., 2010). The absence of grazing pressure during this interval strongly promotes seed production and continued invasion of the Flint Hills ecoregion by this noxious weed.

Lespedeza cuneata

Invasive plants have the potential to reduce and alter the biodiversity of native ecosystems (Kettenring and Adams, 2011). When an invasive species is detected soon after initial establishment, eradication is possible; however, once an invasive species becomes environmentally adapted and is self-sustaining, eradication is usually not possible (Swanton and Booth, 2004). Sericea lespedeza is a high-tannin, invasive, perennial legume that threatens the native tallgrass prairie ecosystem, one of the most endangered ecosystems on earth (Henderson et al., 2018).

Sericea lespedeza is drought tolerant and adaptable to poor soils; it also has aggressive growth characteristics, including canopy dominance, prolific seed production, and allelopathy (Kalburtji and Mosjidis, 1992; Dudley and Fick, 2003; Eddy et al. 2003; Eckerle et al., 2010). It was first introduced in the United States in 1896 from Southeast Asia as a potential forage crop for livestock; it was subsequently introduced into Kansas for the purposes of erosion control (Ohlenbusch et al., 2007). The subsequent spread of sericea was expedited when seeds were unintentionally harvested and combined with seed mixes planted on Conservation Reserve Program lands (Silliman and Maccarone, 2005). Due to the invasiveness and poor palatability of sericea, it has since been recognized as a noxious weed in the state of Kansas (Dudley and Fick, 2003). Cummings et al. (2007) estimated that sericea basal cover in the tallgrass prairie region increased at a rate of 2% per year.

Seed Production

The success of many invasive plants can be attributed to seed production and seed characteristics. Invasive plants tend to produce large amounts of small seeds that can remain non-germinated and viable for years in the soil bank. Invasive-plant seeds tend also to germinate more readily than native-plant seeds (Ferreras and Galetto, 2010). Sericea lespedeza exhibits these characteristics.

An established, pure stand of sericea can produce 340 to 670 kg of seeds per ha, with over 770,000 seeds per kg (Guernsey, 1970). Sericea lespedeza seed is small, hard, smooth, and oval in shape. Thompson et al. (1993) noted that seeds similar in size, shape, and hardness to those of sericea were likely to build persistent seed banks in the soil. Although sericea was reported to have modest germination rate of 10 to 20% annually, the number of seeds produced may overwhelm the soil seed bank over time (Pieters, 1939).

Walters et al. (2005) successfully germinated sericea seed that was approximately 40 yr old. This raises the possibility that sericea seeds may remain viable in the soil seed bank for extended periods of time. The sporadic nature and unpredictability of latent germination contributes to several long-term problems with weeds like sericea (Kremer, 1993). Management strategies that target seed prevention or cause seed mortality tend to be more effective means of weed control than those that focus on elimination of mature plants only (Jordan et al., 1995; DiTomaso, 2000).

Early detection of noxious weeds followed by long-term seed bank management are fundamental to comprehensive and satisfactory control of noxious weeds (Swanton and Booth, 2004; Farney et al., 2017). Seedbank management requires a multi-year effort and must include the following: 1) depletion of existing seeds in the soil by creating favorable conditions for germination, 2) elimination of resulting juvenile plants, and 3) prevention of contamination by exogenous sources of seed (Kremer, 1993). While many methods can be used to manage the seed bank, they can be categorized in one of four general approaches: mechanical control, chemical control, prescribed burning, and targeted grazing.

Condensed Tannins

Tannins can be characterized into two different classes, hydrolyzable and condensed. Hydrolyzable tannins are present in plants as gallotannins or ellagitannins. They are composed of a polyol core and a hexose, usually glucose, esterified to gallic acid (Hartzfeld et al., 2002; Smith et al., 2005). Condensed tannins (**CT**) are found throughout dicotyledonous plant species. They are also called proanthocyanidins, due to the bright-red anthocyanadin that is expressed after treatment with an HCl - butanol solution (Waghorn, 2008). For the purposes of this literature review, CT only will be discussed.

Condensed tannins are diverse, polyphenolic plant compounds that vary in molecular weight and complexity. They are found throughout the world in woody-stemmed plants and broad-leaf forages. Condensed tannins bind with proteins and other macromolecules with hydrogen-rich side chains in aqueous solutions to form a leather-like precipitate (VanSoest, 1982; Aerts et al., 1999; Makaar, 2003; Shakik et al., 2006). Condensed tannins may comprise

2 to 20% of whole plant dry weight and concentrations within a single plant species can vary across geographical locations, climate regimes, and stages of plant maturity (Cope and Burns, 1974). Concentrations of CT in sericea lespedeza generally increase as the growing season progresses; peak concentrations are reached during the budding stage of development and decline thereafter (Eckerle et al., 2010; Preedy et al., 2013b).

Condensed tannins serve as a chemical defense mechanism for a multitude of plants. They deter herbivory by causing the plant to be unpalatable, by preventing ruminal metabolism of key nutrients, by causing distress to the gut epithelium, and, in some cases, by causing kidney or liver failure. Condensed tannins are released from plant cells during mastication, allowing their interaction with plant proteins (Min et al., 2003). Protein-CT complexes form though hydrogen bonding and are stable at neutral pH, rendering proteins unavailable for ruminal metabolism. The degree to which this occurs is dependent on the amount and concentration of CT in ingested plant material (Butler, 1989; Clausen et al., 1990; Schofield et al., 2001; Shimada, 2006; Waghorn, 2008). In general, the ability of CT to bind proteins increases as the growing season advances (Brooker et al., 1998; Eckerle et al., 2010; Preedy et al., 2013b).

When CT were added to ruminant diets or to in vitro fermentation systems, overall ruminal protein degradation was diminished (Terrill et al., 1994; Eckerle et al., 2011b; Hoehn et al., 2018). Condensed tannins also reduced ruminally-available ammonia; plant protein passage rates to the duodenum were subsequently increased (Waghorn, 2008). A lack of ruminally-available ammonia has been associated with, decreased microbial fiber digestion, declines in microbial growth, and BW loss by animals (Provenza and Malechek, 1984; Köster et al., 1996; Min et al., 2005; Hoehn et al., 2018).

Small ruminant tolerance to tannins

Condensed tannins have been shown to be a strong deterrent to intake by beef cattle. Eckerle et al. (2011a) demonstrated that beef cows offered hay contaminated by CT sharply reduced voluntary intake within a 96-h period. Subsequently, Eckerle et al. (2011b) reported that total-tract N digestibility of cattle fed CT-contaminated hay was less than zero, indicating that dietary N had extremely limited availability in the rumen. Although tannins may have detrimental effects on the gastrointestinal tract and may inhibit ruminal protein digestion, it appears some ruminants have adapted to overcome these barriers and remain largely unaffected or undeterred by this mode of plant defense (Ayres et al., 1997). These herbivores have been able to overcome these negative properties by either avoiding or limiting intake of CT-rich portions of the plant, or by physiologically adapting to limit the effects of CT during digestion and absorption (McArthur et al., 1991).

Small ruminants appear to be less susceptible to certain toxic plant compounds than large ruminants and monogastrics. (Jones and Mangan 1977; Makkar, 2003). For example, sheep and goats do not appear to be deterred from grazing plants containing CT. Sheep and goats were observed consuming portions of CT-producing plants that contained the greatest concentrations of CT (Waghorn, 2008). Reasons for high relative CT tolerance by sheep and goats remain unclear (Hoehn et al., 2018); however, many browsing ruminants have been found to have elevated secretion of proline-rich salivary proteins that preferentially bind CT, thereby promoting increased availability of dietary proteins in the rumen.

Proline-rich salivary proteins (**PRP**) are generally large in size, have simple three-dimensional structure, and have relatively generous proportions of hydrophobic amino acids (Hagerman and Butler, 1981; Clare et al., 1995). The structure of proline prevents it from cross-linking into an α-helix and allows it to form hydrogen bonds with the phenolic groups of CT (Mehanso et al., 1987; Mehanso et al., 1992). Goats and other browsing ruminants continuously secrete PRP in saliva; saliva from goats may bind up to 50% of CT ingested (Provenza and Malechek, 1984; Robbins et al., 1987; Austin et al., 1989; Mehansho et al., 1992;). Conversely, sheep do not continuously secrete PRP in their saliva. Secretion has been observed to be limited to circumstances in which they graze forages containing significant concentrations of CT (Frutos et al., 2004). Sheep have also been found to have proteolytic ruminal bacteria that are tolerant of CT and, in some cases, capable of degrading CT (McSweeney et al., 1999; Krause et al., 2005; Patra and Saxena, 2009). Sheep that were fed a diet containing CT had decreased enteric methane production (Waghorn, 2008). This may have indicated more efficient utilization of metabolizable energy.

Grazing systems

The tallgrass prairies of Kansas, known as the Flint Hills, constitute the largest tallgrass prairie remnant on earth, representing roughly 4% of the 167 million-acre original extent of tallgrass prairies in North American (Samson and Knopf, 1994). The tallgrass prairie is dominated by big bluestem (*Andropogon gerardi*), little blutstem (*Schizachyrium scoparium*), and Indiangrass (*Sorgastrum nutans*). Each grazing season, 2,000 to 3,000 pounds of vegetative dry matter are produced per ha (Anderson, 1953). This prairie adapted over time to frequent fire, caused by natural and anthropogenic means. Subsequent to fire, wild ungulates played an important role in establishing the tallgrass prairie. Bison would seek out and graze the nutritious regrowth of native vegetation following a burn. Native Americans noticed this close relationship between fire and habitat choice by wild ungulates and used it prescriptively as a means to attract these animals (Hoy, 1989; Coppedge and Shaw, 1998; Fuhlendorf and Engle, 2004; Middendorf and Beccera, 2009). Fires occurred regionally at 2 to 5 yr return intervals prior to European settlement (Hensel, 1923; Clark et al., 2007). The combination of fire and grazing are responsible for increasing vegetative biodiversity and ultimately responsible for developing the prairie ecosystem that exists today (Hamilton, 2007).

Subsequent European settlers to the region found the terrain unsuitable for tillage due to the steep terrain, shallow upland soils, and prevalence of limestone and chert. These geologic attributes are part of the reason the remaining tallgrass prairie exists today. Once settlers were unsuccessful in farming rocky uplands, they adopted the prescribed-fire practices of the native American peoples except they replaced wild ungulates with their own domesticated cattle. This is a common practice that has occurred in the grasslands of Kansas for more than 150 yr and has resulted in one of the largest geographic concentrations of grazing cattle in the United States (Kollmorgen and Simonet, 1965; Towne et al., 2005; Middendorf and Becerra, 2009). The state of Kansas currently supports roughly 6 million animal unit months annually on its native rangelands (Hickman et al., 2004)

Today, prescribed fire is still an integral part of land management in the Flint Hills. Many land managers burn pastures annually during the early spring and have replaced bison with yearling cattle as the predominant herbivore. Many of these herbivores intensively graze at a relatively high stocking rate from April to August, targeting the best nutritional quality and vegetative production of the prairie. This management system is known as intensive-early stocking (**IES**). In brief, IES is the practice of increasing the normal 180-d, season-long stocking density by 2 to 3 times, for a duration of only 90 d to 120 d, during which 40% to 60% of annual graminoid production is removed. This system has been documented to produce greater bodyweight gains per ha and more uniform grazing distribution that conventional season-long grazing. Extreme stocking densities are possibly because of the rapid rate of forage growth during May and June. Once the grazing period is over, the yearling-age cattle are generally shipped directly to a feedlot for finishing (Smith and Owensby, 1978; Owensby et al., 1988; Jensen et al., 1990; McCollum et al., 1990; Olson et al., 1993; Grings et al., 2002).

Long-term use of IES has been associated temporally with landscape homogeneity, declines in biodiversity, and increased invasion by sericea lespedeza (Robbins et al., 2002; Eddy et al., 2003; Fuhlendorf et al., 2006). Moreover, increased stocking densities may lead to overall decreased stability of plant communities through increased grazing pressure, soil disturbance, and increasing annual plant species (Hickman et al., 2004). Owensby et al. (1988) opined that the main objective of any grazing management plan should be to maximize the efficiency of converting available forage to an animal product; however, this should not be taken to mean that rangeland health is of secondary concern. If long-term rangeland productivity is jeopardized by short-term economic gains, ranching is not sustainable (White et al., 2000). Grazing management should strike a balance between economic performance and maintained or improved rangeland health. Successful grazing management optimizes the ecological and physiological requirements of forage plants (Anderson, 1953; Hanselka et al., 2002).

Targeted grazing, or prescription grazing, is the use of livestock to specifically target and suppress unwanted plant species by manipulating the stocking rate, the stocking density, and the timing of grazing bouts (Frost and Launchbaugh, 2003). Using livestock to control unwanted plant species can potentially convert weed management from a cost center to a profit center.

When implementing targeted grazing, it is important to choose a livestock class appropriate for the target plant. Cattle prefer graminoid species more strongly than sheep, whereas sheep prefer broad leaf plants more strongly than cattle (Popay and Field, 1996). In addition, sheep have certain anatomical features that lend themselves to targeted grazing. Sheep have a narrow muzzle, cleft upper lip, and a muscular pad on their upper jaw, allowing them to selectively strip leaves from stems and branches (Olson and Lacey, 1994; Frost and Launchbaugh, 2003; Rinella and Hileman, 2009). When leaves are selectively removed, photosynthetic capability is reduced and energy reserves are preferentially directed to restoring leaf area at the expense of seed formation. Continued herbivory leads to decreased seed production, root growth, and root carbohydrate storage (Detling et al., 1979; Belsky, 1987).

Small ruminants appear also to have a greater tolerance for condensed tannins and other plant toxins compared with beef cattle (Ralphs et al., 1991; Robbins et al., 1991; Hart, 2001; Pacheco et al., 2012; Henderson et al., 2012). Beef cattle avoid grazing leafy spurge (*Euphorbia esula*), whereas sheep willingly graze it and promote some level of control. In some cases, local or government programs incentivize land managers to graze leafy spurge with sheep (Launchbaugh and Walker., 2006). Similarly, Cummings et al. (2007) reported that targeted grazing by sheep appeared to limit the ability of sericea lespedeza to spread for several years.

Prescribed Burning

It is widely recognized that natural disturbances are an integral maintenance component of most ecosystems and tend to promote species diversity. Fire is one example of a natural disturbance that is essential to long-term maintenance of certain types of native grasslands (Russell et al., 1999; Brawn et al., 2001). Fire is one of the main factors that influences the species composition of grassland communities (Vogel et al., 2010). Burning promotes species that are adapted to a fire-rich environment, such as grassland birds and insects. If fire is removed from these ecosystems, woody-plant species generally increase, whereas the presence of grassland plant and animal species decreases (Coppedge et al., 2001). Therefore, prescribed fire provides land managers a cost-effective method to conserve and manage grasslands (DiTomaso et al., 2006; Vogel et al., 2010).

There are several factors to consider before conducting a prescribed burn in order to ensure safety (Fernandes and Botelho, 2003). It is imperative that certain weather conditions are met: wind speed 8 to 19 km/hr; wind direction steady; mixing height > 550 m; transport wind speed 12 to 32 km/hr; relative humidity 40 to 70%; temperature 12 to 27°C; clear to 70% cloud cover (Blocksome, 2017).

The tallgrass prairie grassland ecosystem developed under conditions in which fire was relatively frequent (Towne and Owensby, 1984). Today, the use of fire is still an integral part of land management in the tallgrass prairie (Bernardo et al., 1988). Prescribed burning reduces potentially dangerous fuel loads, it improves forage quality for herbivores, maintains grassland habitat for insects and birds, enhances plant species richness, reduces woody species basal cover, and may reduce certain noxious weeds (Bragg and Hulbert, 1976; Engle and Stritzke, 1992; DiTomaso et al., 2006; Alexander, 2018).

Under current grazing and prescribed burning management practices used in the tallgrass prairie, invasion by sericea lespedeza has steadily increased since the late 1980's (Eddy et al. 2003). Annual spring burning has been associated with increased germination of sericea seed (Vermeire et al., 2007); however, sericea lespedeza flowers and produces seed in late summer from August to October (Cope and Burns, 1974; Koger et al., 2002; Eckerle et al., 2010). The absence of prescribed burning during this interval strongly promotes seed production, seed distribution, and continued invasion of the tallgrass prairie ecoregion by this noxious weed. Conversely, if prescribed burning is applied during the time sericea is flowering or reproductive, seed production and growth characteristics are suppressed. Non-traditional, summer prescribed burns significantly reduced seed production by sericea, as well as basal frequency of mature plants (Alexander et al., 2017; Alexander, 2018).

Chemical Control

Herbicides are the one of the most widely-used means to control unwanted invasions of noxious weeds. Up to 25% of rangelands in the United States are treated with herbicides annually (Shaw, 1982; DiTomaso, 2000), even though herbicides can be expensive and arduous to apply in rangeland settings (Eddy et al., 2003; Farris and Murray, 2009).

Unfortunately, herbicides rarely offer long-term control when used alone; moreover, herbicides may harm ecologically-important, non-target grassland species. This unintended loss of biodiversity in rangelands can be very difficult to reverse (Marshall, 2001). Herbicide application may also cause contamination of ground or surface water (DiTomaso et al., 2010).

Herbicides have been used for decades to attempt control of sericea lespedeza. Some of these herbicides (i.e., 2,4-D, dicamba, and clopyralid) had no effect on sericea stem density and overall control rates were generally less than 50% (Fick, 1990; Altom and Stritzke, 1992). Similarly, Koger et al. (2002) reported that metsulfuron increased sericea biomass instead of reducing it; however, they also found that triclopyr and fluroxypyr effectively reduced stem densities in established stands and offered temporary control.

Decades of reliance on herbicides to combat sericea lespedeza have not resulted in satisfactory control (Wong et al., 2012). The plant seems to have been able to overcome repeated applications of herbicide with its aggressive growth characteristics, and prolific seed production. These factors have allowed sericea invasion to steadily increase over the last 50 yr (Kalburtji and Mosjidis, 1992; Dudley and Fick, 2003; Eddy et al. 2003).

Mechanical Control

Mechanical control (i.e., mowing) has long been used in integrated noxious weed management plans. It can reduce seed production and photosynthetically weaken noxious weeds. Success of mowing in this regard is dependent on several variables: the species being targeted, its growth cycle, the timing of mowing, the frequency of mowing, the logistics of conducting a mow, the risk of spreading seeds to adjacent areas, and overall cost (Sheley et al., 2003). Perennial plants tend to be more difficult to control with mowing than annual plants and may require treatment more frequently (Ntiamoah, 2017; Sheley et al., 2017). Inadequate contemplation of these factors can result in negative effects on plant community composition (DiTomaso, 1997).

It is especially critical to research the lifecycle of the plant to be controlled with mowing treatments. This may include mowing at times when the target plant is vulnerable in its lifecycle (e.g., early flowering) and desirable plants are not vulnerable (i.e., dormant). When the timing of mowing is optimal, it likely depletes root nutrient reserves and may reduce seed production. Conversely, mowing at an unwise time can strongly promote spread of the undesired target plant species through seed dispersal (Sheley et al., 1997; Sheley and Krueger-Mangold, 2003).

Frequency of mowing reportedly influenced the level of control achieved over sericea lespedeza. Mowing sericea once during June when the plant was in an immature growth stage only reduced stem densities by 6% (Guernsey, 1970; Blocksome, 2006). Cummings et al. (2017) also reported that one-time mowing was ineffective at controlling sericea lespedeza. In contrast, stem densities decreased and desirable plants had the opportunity to express when sericea was repeatedly mowed during early stages of growth (Guernsey, 1970; Blocksome, 2006). Mooers and Ogden (1935) had previously reported that continued mowing of sericea during mid- to late summer during the flowering stage of growth had negative effects on growth characteristics and reduced seed production.

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Chapter 2 - Effects of Intensive Late-Season Sheep Grazing Following Early- Season Steer Grazing on Population Dynamics of Sericea Lespedeza (*Lespedeza cuneata)*

Abstract

Our objective was to determine the effects of intensive late-season grazing by sheep on vigor of sericea lespedeza (*Lespedeza cuneata*; hereafter **sericea**) in native tallgrass prairie over a 2-yr period. Pastures (n = 8; 31 ± 3.6 ha), infested with sericea (initial basal frequency = 1.4 ± 0.81%), were assigned randomly to 1 of 2 treatments: early-season grazing with beef steers (1.1 ha / steer; initial BW = 258 ± 1.7 kg) from 15 April to 15 July followed by 60 d of rest (**STR**) or steer grazing from 15 April to 15 July followed by intensive grazing by mature ewes (0.2 ha / ewe; **SHP**) from 1 August to 1 October. Ewes (n = 813 / yr; initial BW = 67 ± 1.7 kg) were assigned randomly to graze 4 of 8 pastures; remaining pastures were not grazed from 1 August to 1 October. Vegetation responses to treatment were measured along 4 permanent 100-m transects and in 2 permanent 5 x 5-m grazing exclosures in each pasture. Weekly herbivory of sericea was estimated in each pasture from 21 July to 7 October. Herbivory of sericea in SHP and STR following steer grazing was not different (P = 0.26; 7.1 vs. 1.7% of all sericea-containing plant canopies, respectively). In contrast, sericea herbivory following sheep grazing was greater ($P \leq$ 0.01) in SHP than in STR (91.2 vs. 0.1% of all sericea-containing plant canopies). Herbivory of sericea steadily increased ($P \leq 0.01$) during the period of sheep grazing such that 89.4% of sericea plants were grazed in SHP compared to 2.0% in STR by wk 9 of the sheep-grazing period. Whole-plant mass (DM basis) of sericea at dormancy was less ($P \leq 0.04$; treatment × yr) in SHP than in STR both yr of the study. Additionally, annual seed production by sericea was

less ($P < 0.01$) in SHP than in STR (70 vs. 548 seeds / plant). Pasture forage biomass was not different ($P = 0.29$) between SHP and STR following the steer-grazing period. Conversely, STR had more ($P \leq 0.01$) residual forage biomass than SHP at the end of the sheep-grazing period (2,838 vs. 1,770 kg DM / ha). Under these conditions our results were interpreted to suggest that intense late-season grazing by sheep decreased vigor and reproductive capabilities of sericea. Late-season sheep grazing decreased forage biomass by 1,068 kg DM/ha compared with late-season rest; however, residual biomass on grazed pastures was likely adequate to prevent soil-moisture loss and erosion during the dormant season and was sufficient to allow prescribed fire application in the following spring seasons.

Introduction

Sericea lespedeza (*Lespedeza cuneata*; hereafter **sericea**) is a high-tannin, invasive forb in the tallgrass prairie ecosystem (Eckerle et al., 2010). In Kansas, sericea infests ~2,530 km^2 of pasture, primarily in the Flint Hills region (KDA, 2018). Sericea infestations reduce native grass production by up to 92% through a combination of aggressive growth, prolific reproduction, canopy dominance, and allelopathy (Kalburtji and Mosjidis, 1992; Dudley and Fick., 2003; Eddy et al. 2003). Herbicides retard the spread of sericea but application is laborious and expensive (Eddy et al., 2003); moreover, herbicides are lethal to ecologically-important, non-target plants.

Increased grazing pressure on sericea by domestic herbivores may slow its spread and facilitate some measure of biological control. Unfortunately, mature plants contain high levels of condensed tannins which are a strong deterrent to grazing by beef cattle (Jones and Mangan, 1977; Eckerle et al., 2011a, 2011b, 2011c; Preedy et al., 2013). Small ruminants have greater tolerance for condensed tannins than beef cattle (Robbins et al., 1991; Hart, 2001; Pacheco et al., 2012). Sheep, in particular, appear less susceptible to certain plant toxins than beef cattle and may be useful to selectively pressure noxious weeds like sericea (Ralphs et al., 1991; Henderson et al., 2012).

The predominant grazing management practice in the Flint Hills region of Kansas involves annual spring burning followed by intensive grazing with yearling beef cattle from April to August (Owensby et al., 2008). During seasonal grazing, 40 to 60% of annual graminoid production is removed and pastures remain idle for the remainder of the year. Concurrent with this prevailing management practice, sericea invasion into the tallgrass prairie biome has steadily increased (Eddy et al., 2003). Sericea flowers and produces seed in late summer from August to September (Cope and Burns 1974; Koger et al., 2002; Eckerle et al. 2010). The absence of grazing pressure during this interval strongly promotes seed production, seed distribution, and continued invasion of the Flint Hills ecoregion by this noxious weed. Therefore, the objective of our experiment was to evaluate the effects of late-season sheep grazing following locally-conventional steer grazing on vigor and reproductive capabilities of sericea lespedeza.

Materials and Methods

The Kansas State University Institutional Animal Care and Use Committee reviewed and approved all animal handling and animal care practices used in our experiment. All procedures involving animals were conducted in accordance with the Guide for the Care and Use of Animals in Agricultural Research and Teaching (FASS, 2010).

Location

Our experiment was conducted during the 2013 and 2014 growing seasons at the Kansas State University Bressner Range Research Unit located in Woodson County, Kansas (37° 51’54.18” N, 95° 48’16.15” W). Native tallgrass pastures ($n = 8$; 31 ± 3.6 ha) infested with SL (initial basal frequency = 1.4 ± 0.81%) were burned annually in April. Pastures were randomly assigned to 1 of 2 treatments: early-season grazing with beef steers (1.1 ha/steer; initial BW = 258 ± 34 kg) from 15 April to 15 July followed by rest for the remainder of the year (control; **STR**) or steer grazing from 15 April to 15 July followed by intensive grazing with mature ewes (0.2 ha/ewe; **SHP**) from 1 August to 1 October. Ewes (n = 808 ± 6 annually; initial BW = 65 ± 1.7 kg) were allocated randomly to graze 1 of the 4 pastures assigned to SHP; remaining pastures were not grazed from 1 August to 1 October. Pasture treatment assignments were fixed for the 2-yr duration of the study.

Weather

Climatic data was collected from an on-site Kansas Mesonet weather station (Table 2.1). Monthly maximum and minimum temperatures and total monthly precipitation were presented in comparison to the 30-yr rolling averages between 1985 and 2014.

Animals

Yearling beef steers were obtained from various commercial cattle growers in southeastern Kansas in each grazing season. Steers were weighed individually before grazing began each April and were assigned randomly to pastures to create a stocking density of approximately 1.1 ha/steer. Steers were weighed individually again in late July.

Mature ewes were obtained from 2 commercial sheep ranches located in western Kansas. Ewes were transported to the research site on approximately 30 July each year; they were weighed collectively by pasture groups before grazing began on 1 August. Initial BW of sheep averaged 65 ± 3.1 kg and after grazing was halted on 1 October. Final BW of sheep averaged 72 ± 3.1 kg. Sheep were monitored daily to assure they remained in assigned pastures and that fresh water was available continually. Death loss was < 2% annually and was assumed to occur through predation or disease.

Vegetation Responses

Vegetation responses to treatment were measured along 4 permanent 100-m transects (100 × 30-cm^2 plot points / transect) and in 2 permanent 5 x 5-m grazing exclosures in each pasture. Transects were laid out on a north-south gradient; ends were marked using steel posts. Immediately before (i.e., mid-July and immediately after (i.e., mid-October) the sheep-grazing period, a 100-m measuring tape was stretched from the southern end to the northern end of each transect. At 1-m intervals along each transect, forage biomass was estimated using a visual obstruction technique (Robel et al., 1970). A 30 × 30-cm plot was placed on eastern side of transects at each point of measurement. Within each plot, canopy type (i.e., grass- or forb-dominated) was noted, presence of sericea was noted (e.g., yes or no), and evidence of herbivory was noted (i.e., obvious truncation of any leaves or stems).

Grazing exclosures were constructed using 4 welded-wire panels (5 m long × 1 m high). Corners were anchored using steel posts. Once annually following the steer-grazing period, forage biomass, per Robel et al. (1970), and sericea lespedeza aerial frequency (i.e., the percentage of 30 × 30-cm plots in which sericea was detected) were estimated at 25 randomly-selected points in each exclosure.

Weekly estimates of herbivory were conducted to evaluate grazing pressure on select forb species in each pasture. The species of interest were sericea lespedeza (*Lespedeza cuneata*), Baldwin's ironweed (*Vernonia baldwinii*), and ragweed species (*Ambrosia artemisiifolia, Ambrosia bidentata, and Ambrosia psilostachya*). Individuals of each species or group of species (n = 100 / pasture weekly) were evaluated at temporary point transects. Point transect locations were chosen randomly in control pastures. In treated pastures, point transects were located in areas where sheep grazing was observed to occur at the time of measurement. Evidence of herbivory (i.e., obvious truncation of leaves or stems) on individual plants was recorded.

Plant species composition and soil cover were evaluated annually utilizing a modified step-point technique (Owensby, 1973; Farney et al., 2017). A permanent 100-m transect was established in each pasture. Transects were laid out in areas with less than 2% slope. Endpoints of each transect were marked with steel posts. Along each transect, 100 points were independently and randomly selected using a step-point device. Each point was first categorized as a hit on bare soil, litter, or basal plant matter. Secondly, the closest rooted plant and the closest forb in a 180° arc in front of the selected point were recorded. These observations were then used to calculate the abundance of individual plant species via the method described by Farney et al. (2017). Plants were identified by species; pretreatment mean basal cover of individual plant species were expressed as a proportion of total basal plant area (Table 2.2). Plants were subsequently grouped into general categories for analysis. Graminoid categories were perennial graminoids, annual grasses, native graminoids, major warm-season grasses, introduced grasses, warm-season grasses, and cool-season graminoids. Forb and shrub categories were perennial forbs, annual forbs, native forbs, major wildflowers, introduced forbs, and shrubs.

Seed Production

A total of 100 mature sericea lespedeza stems were collected adjacent to permanent line transects in each pasture immediately after the first killing frost (approximately 1 November annually). Plants were placed into a labeled paper bag. Partial DM was measured using a forced-air oven (96 h; 55º C). Individual plants in each sample were defoliated manually; seeds, chaff, and stems were placed into a South Dakota Seed Blower (E.L. Erickson Products, Model B; 10-

cm tube) to separate seeds. Cleaned seed was weighed for each sample. Seed weight was converted to seed count assuming a density of 770 seeds/g (Vermeire et al., 2007; Vandevender, 2014). Average seed production was calculated by dividing the number of seeds by the number of sericea stems in each sample (n = 100).

Statistical Analyses

Line transect and exclosure data were analyzed as a completely random design with repeated measures (PROC MIXED, SAS Inst. Inc., Cary, NC). Class variables included pasture, yr, time (i.e., pre-treatment or post-treatment), treatment, and transect (or exclosure). The model contained terms for treatment, time, yr, and all possible 2-way and 3-way interactions. The repeated measure was yr. Weekly herbivory indices were also analyzed as a completely random design with repeated measures (PROC MIXED, SAS Inst. Inc., Cary, NC). Class variables included treatment, pasture, yr, and wk. The model contained terms for treatment, wk, yr, and all 2-way and 3-way interactions; yr was the repeated measure.

Exclosure data, sericea seed production, and sericea-stem weight were analyzed as a completely random design, with treatment, pasture, and yr as class variables (PROC MIXED, SAS Inst. Inc., Cary, NC). The model included effects for treatment, yr, and treatment × yr; the repeated measure was yr. When protected by a significant F-test ($P \leq 0.05$), means were separated using the method of Least Significant Difference. Least-squares means for the highest-order, significant ($P \leq 0.05$) interaction term were reported. No 3-way interactions were detected.

Steer BW and ADG were analyzed as a completely random design (PROC MIXED, SAS Inst. Inc., Cary, NC). Class variables were treatment, pasture, and yr. The model included a term for treatment only and yr was considered a random effect. When protected by a significant F-test

($P \leq 0.05$), means were separated using the method of Least Significant Difference. Least-squares means for the highest-order, significant ($P \leq 0.05$) interaction term were reported.

Results and Discussion

In areas excluded from grazing, estimated forage biomass and aerial frequency of sericea lespedeza were not different ($P = 0.13$) between treatments (Table 2.3); however, there were more ($P = 0.04$) forb-dominated plant canopies and fewer ($P = 0.04$) grass-dominated canopies in SHP than in STR. Estimated forage biomass was less ($P < 0.01$) in year 1 than in year 2 (3,428 vs. 4,816 kg DM/ha; data not shown).

Pasture forage biomass was not different ($P = 0.29$) between STR and SHP after steer grazing was halted and before sheep grazing began (Table 2.4). Conversely, pastures assigned to SHP had markedly less ($P \leq 0.01$) residual forage biomass than pastures assigned to STR at the end of the sheep-grazing period (1,770 vs. 2,838 kg DM / ha, respectively).

In spite of less residual biomass at the end of the growing season in pastures assigned to SHP, relatively few changes were observed in the plant community. Basal plant cover was greater ($P < 0.01$) in SHP than STR and proportions of bare soil and litter covers were not different ($P \geq 0.63$) between SHP and STR (Table 2.5). In addition, there were no treatment differences in proportional basal covers of shrubs (Table 2.6). Most general categories of forbs were not influenced by treatment; however, pastures assigned to SHP had greater ($P < 0.01$) basal covers of major wildflowers (i.e., combined basal covers of catclaw sensitivebriar [*Mimosa nuttallii*], dotted gayfeather [*Liatris punctata*], heath aster [*Symphyotrichum ericoides*], prairie coneflower [*Ratibida columnifera*], purple poppymallow [*Callirhoe involucrate*], purple prairieclover [*Dalea purpurea*], roundhead prairieclover [*Dalea multiflora*], and white prairie-clover [*Dalea candida*]) than pastures assigned to STR (Table 2.6). Likewise, most general categories of graminoids were not influenced by treatment. The exception was basal cover of major warm-season grasses (i.e., combined basal cover of big bluestem [*Andropogon gerardii*], little bluestem [*Schizachyium scoparium*], Indiangrass [*Sorghastrum nutans*], and sideoats grama [*Bouteloua curtipendula*]). Pastures grazed by steers and sheep had less ($P < 0.01$) combined basal cover of major warm-season grasses that pastures grazed by steers only; however, total basal covers of warm-season grasses and native grasses were not different ($P \geq 0.29$) between treatments.

More intense herbivory and greater defoliation in pastures grazed by both sheep and cattle compared with pastures grazed only by steers was associated with few changes to native vegetation during the course of our experiment. Furthermore, steer ADG was not different ($P = 0.89$; mean ADG = 1.16 ± 0.12 kg, data not shown) between SHP and STR pastures. We interpreted these data to indicate that late season grazing by sheep was reasonably consistent with responsible ecosystem stewardship and could be used to add an additional, sustainable income stream to an existing ranching enterprise.

After the steer grazing period ended and before the sheep-grazing period began, the number of grass-dominated plant canopies was greater ($P = 0.02$) and the number of forb dominated plant canopies less ($P = 0.02$) on STR than on SHP (Table 2.4). In contrast, proportions of grass- and forb-dominated canopies were not different ($P = 0.70$) between treatments at the end of the sheep-grazing period. The percentage of grass-dominated plant canopies that showed evidence of herbivory following steer grazing was relatively large and not different ($P = 0.67$) between STR and SHP; however, the percentage of grazed forb-dominated plant canopies following steer grazing was relatively small and slightly less ($P = 0.04$) on STR than on SHP. At the end of the sheep-grazing period, STR had fewer ($P < 0.01$) grass- and forb-dominated plant canopies that showed evidence of herbivory than SHP. We interpreted these data to indicate that steers strongly preferred to graze graminoid-dominated plant communities, whereas sheep did not appear to discriminate between plant canopy types. Popay and Field (1996) previously reported that cattle preferred graminoid species over broadleaf plants, whereas sheep preferred broadleaf plants over graminoid species. In contrast, Sowers et al. (2019) concluded that mature ewes did not manifest strong preferences for either graminoids or forbs and that dietary botanical composition reflected a relatively even balance between the two; however, these researchers also reported that yearling-steer diets were overwhelmingly dominated by graminoids.

Pastures assigned to SHP had a greater ($P < 0.01$) percentage of plant canopies that contained sericea lespedeza than those assigned to STR after steer grazing and after sheep grazing (Table 2.4). Herbivory of sericea was not different ($P = 0.76$) between STR and SHP following steer grazing and was generally minor. Conversely, herbivory of sericea was much greater ($P < 0.01$) in SHP than in STR following sheep grazing. We interpreted these data to indicate that sheep displayed much greater willingness to graze sericea than steers.

This conclusion was supported by weekly estimates of herbivory during the sheep-grazing period (Table 2.7). Herbivory of sericea was not different ($P = 0.99$) and slight in STR and SHP immediately following the steer-grazing period. Similarly, Sowers et al. (2018) reported that sericea was detectable only in trace amounts in yearling steer diets. The lack of herbivory on sericea prior to the onset of sheep grazing in our experiment was anticipated based on earlier reports. Min et al. (2003) and Eckerle et al. (2011a) concluded that condensed tannins were a strong chemical deterrent to intake by beef cattle. Sowers et al. (2018) hypothesized that when yearling steers sampled small amounts of sericea while grazing, the condensed tannins therein caused a flavor-related aversion causing them to avoid sericea for the duration of the grazing season.

Following the onset of the sheep grazing period (i.e., 1 August), sericea lespedeza herbivory was greater ($P < 0.01$) in SHP than in STR by the end of the second week (14.5 vs. 0.8%; Table 2.7). Thereafter, herbivory of sericea by sheep steadily increased ($P < 0.01$) over time, such that 89.4% of sericea plants in point transects were grazed in SHP compared to 2.0% in STR by wk 8 of the sheep-grazing period. These findings likely indicated that sheep have a greater tolerance for condensed tannins compared with beef cattle and are able to consume high-tannin forages in significant quantities (Ralphs et al., 1991; Robbins et al., 1991; Hart, 2001; Pacheco et al., 2012; Henderson et al., 2012).

Sheep also appeared to preferentially select other robust forb species that steers avoided in our experiment. Herbivory on Baldwin's ironweed and ragweed spp. was not different ($P \geq 0.92$) in STR and SHP immediately following the steer grazing period (Tables 2.8 and 2.9, respectively). Conversely, herbivory of individual Baldwin's ironweed plants was greater ($P < 0.01$) in SHP than in STR by the end of wk 1 of the sheep-grazing period and was complete (i.e., 100%) by the end of wk 4. Sheep did not put a significant amount of grazing pressure on ragweed spp. until the end of wk 3 of the sheep-grazing period; thereafter, herbivory of ragweeds increased over time; 49.9% of ragweed plants were grazed in SHP ($P < 0.01$) compared to 0.8% in STR by the end of wk 9 of the sheep-grazing period. Previous reports indicated that sheep tended to prefer broadleaf plants over graminoids (Olson and Lacey, 1994; Frost and Launchbaugh, 2003; Rinella and Hileman, 2009) but this conclusion is not universal (Sowers et al., 2018). Yearling beef steer performance was not different (Table 2.10) between SHP and STR pastures with initial BW 253 kg ($P = 0.98$), and final BW 349 (P=0.96), as well as no difference in ADG 1.16 kg in STR and 1.17 kg in STR +SHP (P=0.88)

Whole-plant mass of sericea lespedeza immediately after the first killing frost was 2.3-fold less ($P = 0.03$) in SHP than STR following yr 1 and 3.6-fold less ($P \leq 0.01$) in SHP than STR following yr 2 (Figure 2.1). We interpreted this to be an indication that sericea vigor decreased as duration of treatment increased. In addition, annual seed production by sericea was markedly less ($P < 0.01$) in SHP than in STR at the end of the growing season of 2013 and 2014(Figure 2.2). We concluded that late-season, intense grazing by sheep may be an effective means for controlling sericea lespedeza spread and proliferation. This conclusion is supported by the work of Jordan et al. (1995) and DiTomaso (2000) who reported that management strategies targeting suppression of seed formation or causing seed mortality tended to be a more effective means of weed control than those that focused on elimination of mature plants only.

Condensed-tannin content of sericea lespedeza peaks during August and September (Eckerle et al., 2010; Preedy et al., 2013). According to Min et al. (2003), condensed tannins are released during mastication and rapidly bind to plant proteins, rendering them unavailable to most herbivores during ruminal fermentation. The likely aversion caused by this condition effectively protects the plant from herbivory by beef cattle prior to production and maturation of seed. In circumstances where beef cattle are the only significant source of herbivory, this allows sericea to produce seed unabated.

The success of many invasive plants can be attributed to the volume of seed produced and to seed characteristics. Invasive plants tend to produce large amounts of small seeds that can remain non-germinated and viable for long periods in the seed-soil bank. Invasive-plant seeds tend also to germinate more readily than native-plant seeds (Ferreras and Galetto, 2010). Sericea lespedeza exhibits these characteristics. Sericea lespedeza seed is small, hard, and smooth. Thompson et al. (1993) noted that seeds similar in size, shape, and hardness to those of sericea were likely to build persistent seedbanks in the soil. Established sericea lespedeza stands may produce 340 to 670 kg of seed / ha annually, with over 770,000 seeds / kg (Guernsey, 1970; Vermeire, 2007; Vandevender, 2014). Although sericea was reported to have modest germination rates of 10 to 20% annually (Pieters, 1939), the number of seeds produced may overwhelm the seed-soil bank over time. Forty-yr old sericea seed recovered from the seed-soil bank has been successfully germinated under laboratory conditions (Walters et al., 2005).

Without seed suppression, it may be impossible to eradicate noxious weeds like sericea lespedeza (Kremer, 1993). Early detection of noxious weeds followed by long-term seed bank management are fundamental to comprehensive and satisfactory control (Swanton and Booth, 2004). Seedbank management requires a multi-year effort and must include the following: 1) depletion of existing seeds in the soil by creating favorable conditions for germination, 2) elimination of resulting juvenile plants, and 3) prevention of contamination by exogenous sources of seed (Kremer, 1993). Targeted grazing by sheep may be useful in part for managing the sericea lespedeza seed bank in as much as it suppresses seed production and stresses existing plants.

Implications

Late-season, intensive sheep grazing following early-season steer grazing appeared to decrease vigor and reproductive capabilities of sericea lespedeza in native tallgrass prairie. Sericea seed production and whole-plant mass were sharply decreased in pastures grazed by steers and sheep compared with those grazed by steers alone. Sheep preferentially selected sericea, Baldwin’s ironweed, and ragweed spp., whereas steers appeared to avoid these plants.

Similarly, sheep demonstrated strong preference for grazing forb-dominated plant communities and steers appeared to prefer graminoid-dominated plant communities. We interpreted herbivory patterns in pastures treated with late-season sheep grazing to indicate that condensed tannins in sericea were not a deterrent to consumption by sheep. Late-season sheep grazing decreased forage biomass by 1,068 kg DM/ha compared with late-season rest; however, residual biomass on pastures grazed during the late growing season was likely sufficient to prevent soil-moisture loss during the dormant season. Furthermore, grazing pressure exerted by sheep was not associated with major changes to the native plant community nor did it alter performance of grazing steers. We concluded that late season grazing by sheep was consistent with responsible ecosystem stewardship and could be used to control sericea lespedeza and to add an additional, sustainable income stream to an existing ranching enterprise. Before implementing this management strategy, land managers should consider whether additional fencing and predator control may be indicated.

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Tables

Table 2.1 Growing season weather summary for Woodson County, KS (2000-2014)*

Item	April	May	June	July	August	September	October	Annual
2013								
Average high, ˚C	15.0	23.3	31.6	31.8	29.8	28.9	20.2	17.8
Average low, ˚C	4.2	12.2	20.4	19.0	19.2	15.4	7.1	5.7
Precipitation, cm	10.9	16.6	10.5	22.9	9.9	7.6	18.0	116.1
2014								
Average high, ˚C	20.2	25.7	26.9	29.3	33.1	26.9	22.4	18.9
Average low, ˚C	6.0	12.8	18.7	17.4	19.3	14.4	9.2	6.4
Precipitation, cm	5.1	14.0	21.9	4.1	3.5	8.5	11.6	79.3
1985 – 2014 mean								
Average high, ˚C	18.9	23.7	28.4	31.3	31.4	26.9	20.3	18.9
Average low, ˚C	5.8	12.1	17.1	19.8	18.8	13.8	7.6	6.7
Precipitation, cm	7.4	12.2	17.4	11.3	9.3	9.6	9.3	99.7

* Location near Yates Center, KS

Table 2.2 Botanical composition of native tallgrass pastures grazed by steers and sheep

Item		%
Graminoids		**85.95**
Big bluestem	*Andropogon gerardii*	24.55
Hairy crabgrass	*Digitaria sanguinalis*	3.90
Indiangrass	*Sorghastrum nutans*	9.85
Little bluestem	*Schizachyrium scoparium*	8.85
Plains lovegrass	*Eragrostis intermedia*	6.00
Prairie threeawn	*Aristida oligantha*	1.95
Purple lovegrass	*Eragrostis spectabilis*	3.35
Sedge	*Carex spp.*	8.20
Sideoats grama	*Bouteloua curtipendula*	5.10
Switchgrass	*Panicum virgatum*	3.70
Tall dropseed	*Sporobolus asper*	6.65
Other grasses	*n = 20*	3.85
Forbs		**14.05**
Baldwin's ironweed	*Vernonia baldwinii*	0.82
Common ragweed	*Ambrosia artemisiifolia*	0.41
Common yellow oxalis	*Oxalis stricta*	0.57
Heath aster	*Symphyotrichum ericoides*	0.38
Korean lespedeza	*Kummerowia stipulacea*	0.75
Sericea lespedeza	*Lespedeza cuneata*	1.38
Smoothseed wildbean	*Strophostyles leiosperma*	0.36
Western ragweed	*Ambrosia psilostachya*	6.00
Other forbs	*n = 48*	2.92
Shrubs		**0.44**
Leadplant	*Amorpha canescens*	0.42
Other shrubs	*n = 5*	0.04

Table 2.3 Forage biomass, plant canopy type, and aerial frequency of sericea lespedeza (*Lespedeza cuneata*) within grazing exclosures placed in native tallgrass prairie infested with sericea lespedeza (some pastures were grazed only during the early season by beef steers or grazed by beef steers during the early season and grazed by sheep during the late-season during 2013 and 2014)

Item	Steer grazing only*	Steer + sheep grazing†	SE	*P*-value
Forage biomass, kg DM/ha	3,770	4,474	448.7	0.13
Grass-dominated canopies, % of all plots	87.0	67.3	9.31	0.04
Forb-dominated canopies, % of all plots	13.0	32.7	9.31	0.04
Plant canopies with sericea lespedeza, % of all plots	10.8	33.0	10.77	0.13

*Yearling steers were grazed on 4 pastures from approximately 15 April to 15 July annually (1.1 ha/steer; initial BW = 258 ± 1.7 kg); pastures were not grazed for the remainder of the yr.

†Yearling steers were grazed on 4 pastures (n = 8) from approximately 15 April to 15 July annually (1.1 ha/steer; initial BW = 258 ± 1.7 kg); mature ewes grazed these pastures from approximately 1 August to 1 October annually (0.2 ha/ewe; initial BW = 67 ± 1.5 kg).

Table 2.4 Effects of early-season grazing by beef steers followed by late-season grazing by sheep and time of measurement on pasture forage biomass, plant canopy type, and grazing activity in native tallgrass prairie infested with sericea lespedeza (*Lespedeza cuneata*)

	After steer grazing, before sheep grazing		After steer and sheep grazing		
Item	Steer grazing only*	Steer + sheep grazing†	Steer grazing only*	Steer + sheep grazing†	SE
Pasture forage biomass, kg DM/ha	2,357[a]	2,187[a]	2,838[b]	1,770[c]	159.8
Grass-dominated canopies, % of all plots	84.7[a]	74.2[c]	82.1[a, b, c]	83.8[a, b]	4.37
Forb-dominated canopies, % of all plots	15.3[a]	25.8[c]	17.9[a, b, c]	16.2[a, b]	4.37
Grazed grass canopies, % of grass-dominated canopies	60.2[a]	58.5[a]	5.8[c]	79.4[b]	4.08
Grazed forb canopies, % of forb-dominated canopies	19.5[a]	7.0[b]	6.9[b]	76.0[d]	5.98
Plant canopies with sericea lespedeza, % of all plots	9.3[a]	25.8[b]	12.9[a]	25.5[b]	5.45
Grazed sericea lespedeza, % of plots with sericea lespedeza	1.7[a]	7.1[a]	0.1[a]	91.2[b]	5.06

*Yearling steers were grazed on 4 pastures from approximately 15 April to 15 July annually (1.1 ha/steer; initial BW = 258 ± 1.7 kg); pastures were not grazed for the remainder of the yr.

†Yearling steers were grazed on 4 pastures (n = 8) from approximately 15 April to 15 July annually (1.1 ha/steer; initial BW = 258 ± 1.7 kg); mature ewes grazed these pastures from approximately 1 August to 1 October annually (0.2 ha/ewe; initial BW = 67 ± 1.5 kg).

[a, b, c]Within row, means with unlike superscripts are different ($P < 0.05$).

Table 2.5 Effects early-season grazing by beef steers followed by late-season grazing by sheep on occurrence of bare soil, litter cover, and basal plant cover in native tallgrass prairie infested with sericea lespedeza (*Lespedeza cuneata*)

Item	Steer grazing only*	Steer + sheep grazing†	SE	*P*-value
Bare soil, % of total area	29.9	29.5	3.30	0.91
Litter cover, % of total area	60.6	58.9	3.49	0.63
Basal vegetation cover, % of total area	9.6	11.6	0.75	< 0.01

*Yearling steers were grazed on 4 pastures from approximately 4/15 to 7/15 annually (1.1 ha/steer; initial BW = 258 ± 34 kg); pastures were not grazed for the remainder of the yr.

†Yearling steers were grazed on 4 pastures (n = 8) from approximately 4/15 to 7/15 annually (1.1 ha/steer; initial BW = 258 ± 34 kg); mature ewes grazed these pastures from approximately 8/1 to 10/1 annually (0.2 ha/ewe; initial BW = 65 ± 3.1 kg).

Table 2.6 Effects early-season grazing by beef steers followed by late-season grazing by sheep on proportions of total basal graminoid or forb cover occupied by specific plant classes

Item	Steer grazing only[*]	Steer + sheep grazing[†]	SE	*P*-value
Perennial grass cover, % of total grass cover	92.7	90.0	1.96	0.18
Annual grass cover, % of total grass cover	7.3	9.6	1.96	0.24
Native grass cover, % of total grass cover	91.6	88.8	2.63	0.29
Major warm-season grasses[‡], % of total grass cover	51.7	42.3	2.40	< 0.01
Introduced grass cover, % of total grass cover	8.4	11.1	2.61	0.29
Warm-season grass cover, % of total grass cover	80.4	80.0	1.71	0.81
Cool-season grass and sedge cover, % of total grass cover	19.6	20.0	1.71	0.81
Perennial forb cover, % of total forb cover	79.6	74.8	3.94	0.22
Annual forb cover, % of total forb cover	20.7	25.2	4.07	0.27
Native forb cover, % of total forb cover	69.9	72.3	3.66	0.53
Major wildflowers[§], % of total forb cover	5.1	9.6	1.53	< 0.01
Introduced forb cover, % of total forb cover	29.4	27.7	3.46	0.64
Shrub cover, % of total basal cover	0.05	0.04	0.030	0.82

[*]Yearling steers were grazed on 4 pastures from approximately 4/15 to 7/15 annually (1.1 ha/steer; initial BW = 258 ± 34 kg); pastures were not grazed for the remainder of the yr.

[†]Yearling steers were grazed on 4 pastures (n = 8) from approximately 4/15 to 7/15 annually (1.1 ha/steer; initial BW = 258 ± 34 kg); mature ewes grazed these pastures from approximately 8/1 to 10/1 annually (0.2 ha/ewe; initial BW = 65 ± 3.1 kg).

[‡]Combined basal cover of big bluestem (*Andropogon gerardii*), little bluestem (*Schizachyium scoparium*), indiangrass (*Sorghastrum nutans*), and sideoats grama (*Bouteloua curtipendula*).

[§]Combined basal cover of catclaw sensitivebriar (*Mimosa nuttallii*), dotted gayfeather (*Liatris punctata*), heath aster (*Symphyotrichum ericoides*), prairie coneflower (*Ratibida columnifera*), purple poppymallow (*Callirhoe involucrate*), purple prairieclover (*Dalea purpurea*), roundhead prairieclover (*Dalea multiflora*), and white prairie clover (*Dalea candida*).

Table 2.7 Effect[a] of late-season grazing by sheep on herbivory of sericea lespedeza (*Lespedeza cuneata*)

Item	Steer grazing only*	Steer + sheep grazing†	*P*-value
Pre-Treatment‡, % target species grazed	0.6	0.6	0.99
Week 1§, % target species grazed	0.6	5.0	0.16
Week 2§, % target species grazed	0.8	14.5	< 0.01
Week 3§, % target species grazed	0.9	40.6	< 0.01
Week 4§, % target species grazed	0.8	54.5	< 0.01
Week 5§, % target species grazed	1.0	65.0	< 0.01
Week 6§, % target species grazed	1.6	73.1	< 0.01
Week 7§, % target species grazed	2.3	83.6	< 0.01
Week 8§, % target species grazed	2.0	89.4	< 0.01

[a]Treatment × wk (SE = 3.10; $P < 0.01$).

*Yearling steers were grazed on 4 pastures from approximately 15 April to 15 July annually (1.1 ha/steer; initial BW = 258 ± 1.7 kg); pastures were not grazed for the remainder of the yr.

†Yearling steers were grazed on 4 pastures (n = 8) from approximately 15 April to 15 July annually (1.1 ha/steer; initial BW = 258 ± 1.7 kg); mature ewes grazed these pastures from approximately 1 August to 1 October annually (0.2 ha/ewe; initial BW = 67 ± 1.5 kg).

‡Percentage of sericea lespedeza plants showing evidence of defoliation immediately after yearling steers were removed and before sheep were allowed access to pastures.

§Percentage of sericea lespedeza plants showing evidence of defoliation each wk during a 60-d period in which mature ewes were grazed on 4 pastures.

Table 2.8 Effect[a] of late-season grazing by sheep on herbivory of Baldwin's ironweed (*Vernonia baldwinii*)

Item	Steer grazing only[*]	Steer + sheep grazing[†]	*P*-value
Pre-Treatment[‡], % target species grazed	11.0	11.0	0.99
Week 1[§], % target species grazed	11.5	77.4	< 0.01
Week 2[§], % target species grazed	20.9	86.1	< 0.01
Week 3[§], % target species grazed	13.0	99.9	< 0.01
Week 4[§], % target species grazed	14.1	100	< 0.01
Week 5[§], % target species grazed	14.3	100	< 0.01
Week 6[§], % target species grazed	14.0	100	< 0.01
Week 7[§], % target species grazed	21.6	100	< 0.01
Week 8[§], % target species grazed	25.9	100	< 0.01

[a]Treatment × wk (SE = 3.87; $P < 0.01$).

[*]Yearling steers were grazed on 4 pastures from approximately 15 April to 15 July annually (1.1 ha/steer;initial BW = 258 ± 1.7 kg); pastures were not grazed for the remainder of the yr.

[†]Yearling steers were grazed on 4 pastures (n = 8) from approximately 15 April to 15 July annually (1.1 ha/steer; initial BW = 258 ± 1.7 kg); mature ewes grazed these pastures from approximately 1 August to 1 October annually (0.2 ha/ewe; initial BW = 67 ± 1.5 kg).

[‡]Percentage of ironweed plants showing evidence of defoliation immediately after yearling steers were removed and before sheep were allowed access to pastures.

[§]Percentage of ironweed plants showing evidence of defoliation each wk during a 60-d period in which mature ewes were grazed on 4 pastures.

Table 2.9 Effect[a] of late-season grazing by sheep on herbivory of ragweed species (*Ambrosia psilostachya, Ambrosia bidentata, and Ambrosia artemisiifolia*)

Item	Steer grazing only[*]	Steer + sheep grazing[†]	*P*-value
Pre-Treatment[‡], % target species grazed	1.3	1.6	0.92
Week 1[§], % target species grazed	1.3	3.1	0.61
Week 2[§], % target species grazed	0.3	5.1	0.19
Week 3[§], % target species grazed	0.5	11.8	< 0.01
Week 4[§], % target species grazed	0.5	15.4	< 0.01
Week 5[§], % target species grazed	1.0	15.9	< 0.01
Week 6[§], % target species grazed	0.5	18.5	< 0.01
Week 7[§], % target species grazed	0.4	42.4	< 0.01
Week 8[§], % target species grazed	0.8	49.9	< 0.01

[a]Treatment × time (SE = 3.66; $P < 0.01$).

[*]Yearling steers were grazed on 4 pastures from approximately 15 April to 15 July annually (1.1 ha/steer;initial BW = 258 ±1.7 kg); pastures were not grazed for the remainder of the yr.

[†]Yearling steers were grazed on 4 pastures (n = 8) from approximately 15 April to 15 July annually (1.1 ha/steer; initial BW = 258 ± 1.7 kg); mature ewes grazed these pastures from approximately 1 August to 1 October annually (0.2 ha/ewe; initial BW = 67 ± 1.5 kg).

[‡]Percentage of ragweed spp. plants showing evidence of defoliation immediately after yearling steers were removed and before sheep were allowed access to pastures.

[§]Percentage of ragweed spp. plants showing evidence of defoliation each wk during a 60-d period in which mature ewes were grazed on 4 pastures.

Table 2.10 Effects of early-season grazing by beef steers followed by late-season grazing by sheep on yearling beef steer performance

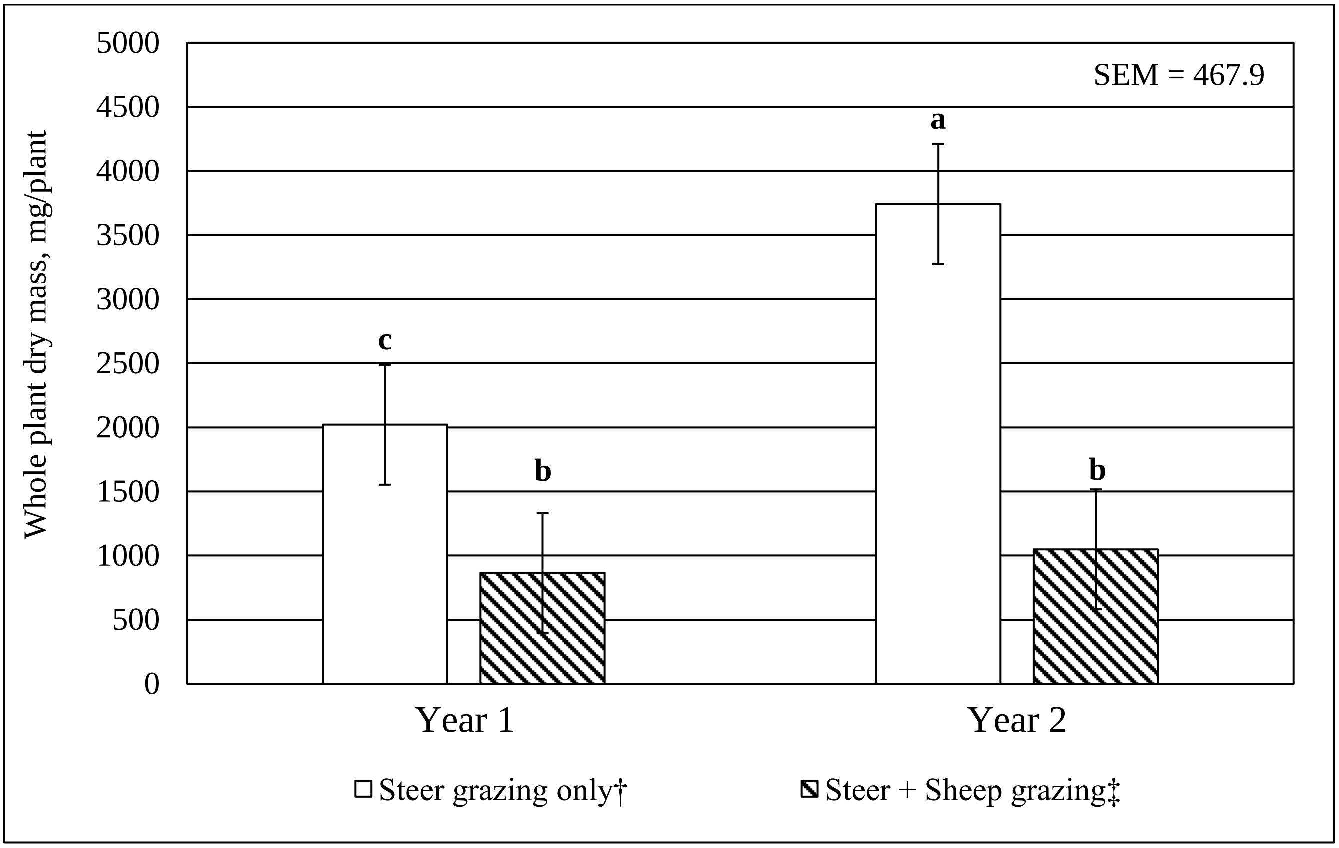
Item	Steer grazing only*	Steer + sheep grazing†	SE	*P*-value
Initial BW, KG	253	253	2.7	0.98
Final BW, KG	349	349	4.0	0.96
ADG, KG	1.6	1.17	0.038	0.88

*Yearling steers were grazed on 4 pastures from approximately 4/15 to 7/15 annually (1.1 ha/steer; initial BW = 258 ± 34 kg); pastures were not grazed for the remainder of the yr.

†Yearling steers were grazed on 4 pastures (n = 8) from approximately 4/15 to 7/15 annually (1.1 ha/steer; initial BW = 258 ± 34 kg); mature ewes grazed these pastures from approximately 8/1 to 10/1 annually (0.2 ha/ewe; initial BW = 65 ± 3.1 kg).

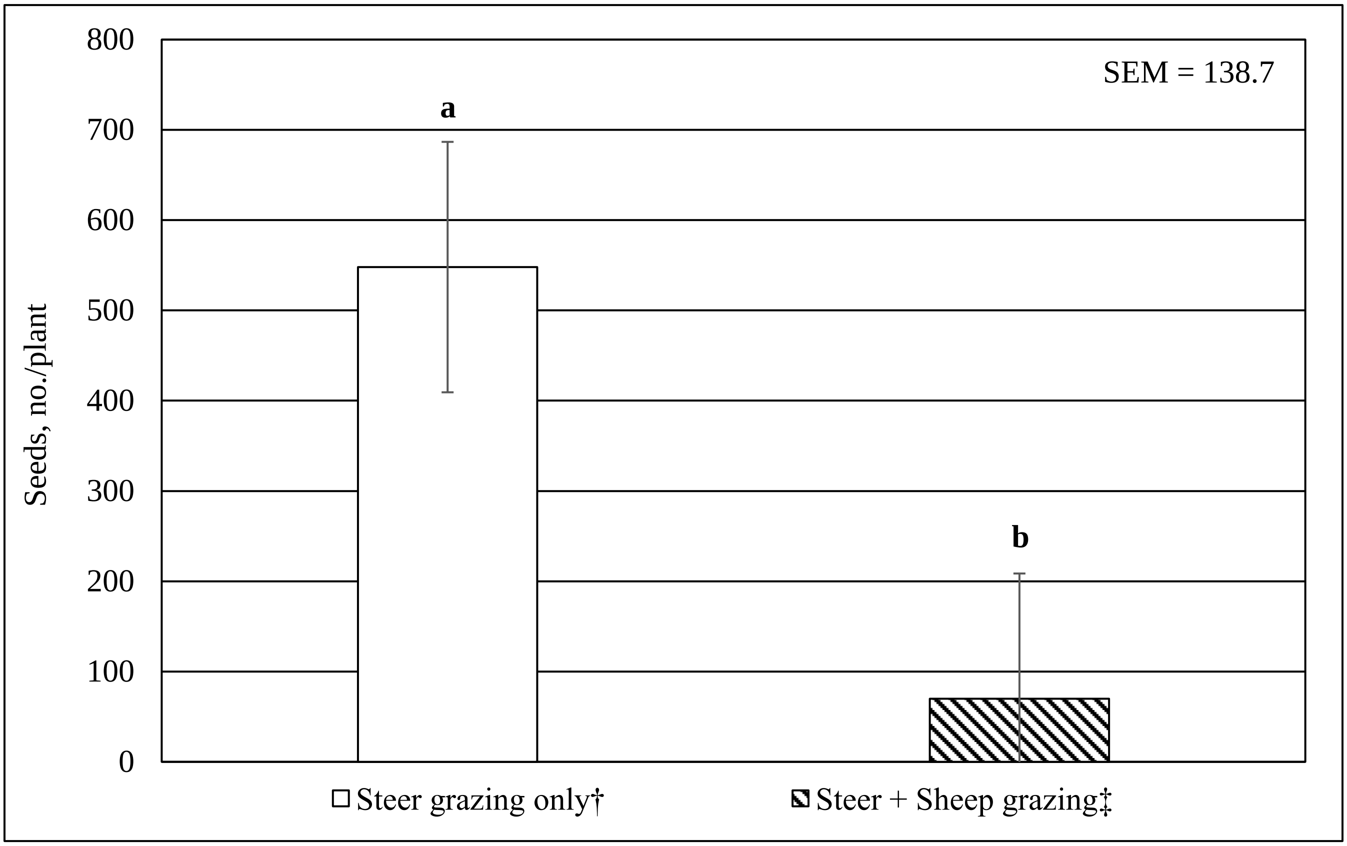
Figures

Figure 2.1 Effects* of year and early-season grazing by beef steers followed by late-season grazing by sheep on whole-plant mass (DM basis) of sericea lespedeza (*Lespedeza cuneata*), as measured immediately following a killing frost



*Treatment × yr ($P = 0.04$).
†Yearling steers were grazed on 4 pastures from approximately 15 April to 15 July annually (1.1 ha/steer; initial BW = 258 ± 1.7 kg); pastures were not grazed for the remainder of the yr.
‡Yearling steers were grazed on 4 pastures (n = 8) from approximately 15 April to 15 July annually (1.1 ha/steer; initial BW =258 ± 1.7 kg); mature ewes grazed these pastures from approximately 1 August to 1 October annually (0.2 ha/ewe; initialBW = 67 ± 1.5 kg).
[a.b.c]Within row, means with unlike superscripts are different ($P \leq 0.05$).

Figure 2.2 Effects* of early-season grazing by beef steers followed by late-season grazing by sheep on seeds produced per individual sericea lespedeza (Lespedeza cuneata) stem, as measured immediately following a killing frost



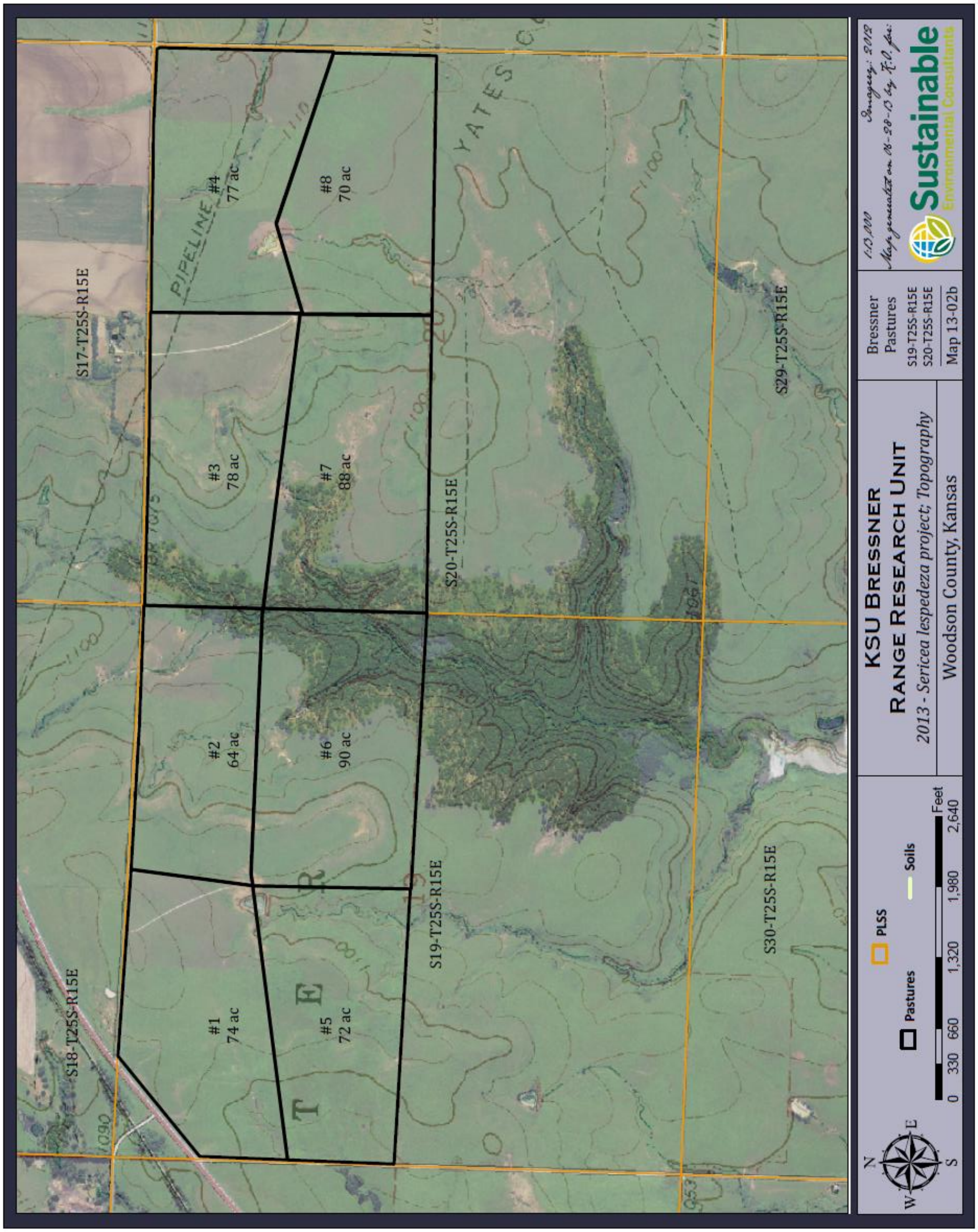
*Treatment × time ($P < 0.01$).

†Yearling steers were grazed on 4 pastures from approximately 15 April to 15 July annually (1.1 ha/steer; initial BW = 258 ± 1.7 kg); pastures were not grazed for the remainder of the yr.

‡Yearling steers were grazed on 4 pastures (n = 8) from approximately 15 April to 15 July annually (1.1 ha/steer; initial BW = 258 ± 1.7 kg); mature ewes grazed these pastures from approximately 1 August to 1 October annually (0.2 ha/ewe; initial BW = 67 ± 1.5 kg).

[a.b.c]Within row, means with unlike superscripts are different ($P \leq 0.01$).

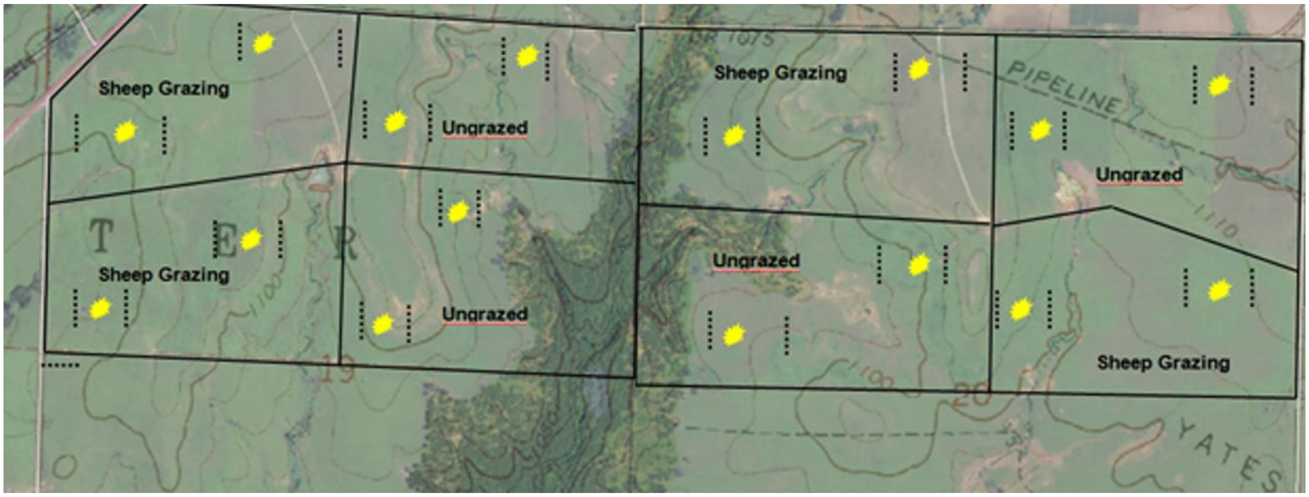
Study Site Map



Soils Map


KSU Bressner
Range Research Unit
2013 - Sericea lespedeza project; Soils
Woodson County, Kansas
Bressner
Pastures
S19-T25S-R15E
S20-T25S-R15E
Map 13-02c
Sustainable
Woodson County Soils
Map Unit Symbol
Map Unit Name
8735 Eram silty clay loam, 3 to 7 percent slopes
8749 Eram-Collinsville complex, 5 to 15 percent slopes
8300 Verdigris silt loam, channeled
8621 Bates loam, 1 to 3 percent slopes
8775 Kenoma silt loam, 1 to 3 percent slopes
MT255 Aliceville-Dwight complex, 0 to 1 percent slopes
8679 Dennis silt loam, 1 to 3 percent slopes
MT2508 Aliceville silty clay loam, 1 to 3 percent slopes
8911 Summit silty clay loam, 1 to 3 percent slopes
8877 Ringo-Sogn complex, 5 to 15 percent slopes
6952 Niotaze-Stephenville complex, 4 to 25 percent slopes
8871 Ringo silty clay loam, 3 to 8 percent slopes
8961 Woodson silt loam, 0 to 1 percent slopes
Pastures
PLSS
Soils
Feet
0 330 660 1,320 1,980 2,640
#1 74 ac
#2 64 ac
#3 78 ac
#4 77 ac
#1 70 ac
#5 72 ac
#6 90 ac
#7 88 ac
S17-T25S-R15E
S18-T25S-R15E
S19-T25S-R15E
S20-T25S-R15E
S29-T25S-R15E

Treatment, Transect, and Grazing Exclosure Map



Vegetation Responses

Procedure

Conducted immediately before and immediately after sheep grazing.

1. Measured along 4 permanent 100-m transects (100 × 30-cm^2 plot points/transect) and in 2 permanent 5 x 5-m grazing exclosures in each pasture (25 × 30-cm^2 plot points/exclosure).

2. Transects were laid out on a north-south gradient; ends were marked using steel posts labeled starting from east to west in the following order: white, pink, yellow, green.

3. Read transects in each pasture in the following order: white, pink, yellow, green
4. Stake free end of measuring line approximately 30cm from southern-most transect marker
5. Pull measuring tape out fully between the southern transect marker and the northern transect marker
6. At each 3-foot increment on the measuring tape, place the range stick on the eastern side of the measuring tape
7. Note the highest 0.5-inch graduation on the range stick that is completely visible (i.e., canopy height)
8. Visually project an area (1 square foot) that extends a) 1 foot eastward from the tape, b) 6 inches on either side of where the range stick is placed, and c) the eastern side of the measuring tape.
9. Note whether the canopy in the projected area is dominated by grasses (1) or forbs (0)
10. Note whether the projected area has been grazed, as evidenced by **ANY** stem or leaf truncation (1 = yes, 0 = no)
11. Note whether the projected area contains sericea lespedeza (1 = yes, 0 = no)

Vegetation Response Data Collection Sheet

1304 - Late-Season Sheep Grazing: Data Collection Sheet

Date ________
Pasture # ________
Transect ________
Treatment ________

Point Number	Canopy Height (in.)	Canopy Dominance (1 = Grass; 0 = Forb)	Grazing Evidence (1= Yes; 0 = No)	Sericea Lespedeza Frequency (1 = Yes; 0=No)	SL Grazed (1=Yes; 0 = No)	Point Number	Canopy Height (in.)	Canopy Dominance (1 = Grass; 0 = Forb)	Grazing Evidence (1= Yes; 0 = No)	Sericea Lespedeza Frequency (1 = Yes; 0=No)	SL Grazed (1=Yes; 0 = No)
1						51					
2						52					
3						53					
4						54					
5						55					
6						56					
7						57					
8						58					
9						59					
10						60					
11						61					
12						62					
13						63					
14						64					
15						65					
16						66					
17						67					
18						68					
19						69					
20						70					
21						71					
22						72					
23						73					
24						74					
25						75					
26						76					
27						77					
28						78					
29						79					
30						80					
31						81					
32						82					
33						83					
34						84					
35						85					
36						86					
37						87					
38						88					
39						89					
40						90					
41						91					
42						92					
43						93					
44						94					
45						95					
46						96					
47						97					
48						98					
49						99					
50						100					

Herbivory Index

Procedures

Conducted at weekly intervals

1. Observe locations where sheep are grazing in treated pastures

2. Locate, in these areas, 100 individuals of the following species or group of species: sericea lespedeza, ironweed, and ragweed spp. (i.e., western ragweed, annual ragweed, and lance-leaf ragweed).

3. Note whether the plants are grazed (1) or ungrazed (0)

4. In untreated pastures, view 100 individuals of the following species or group of species in any location of the pasture: sericea lespedeza, ironweed, and ragweed spp. (i.e., western ragweed, annual ragweed, and lance-leaf ragweed).

5. Note whether the plants are grazed (1) or ungrazed (0)

Weekly Herbivory Data Sheet

1304 - Late-Season Sheep Grazing: Weekly Herbivory Data Sheet						Date	
						Pasture #	
						Transect	
						Treatment	
(1 = Grazing Evidence; 0 = No Grazing Evidence)							
Point Number	Sericea Lespedeza	Ragweed species	Ironweed	Point Number	Sericea Lespedeza	Ragweed species	Ironweed
1				51			
2				52			
3				53			
4				54			
5				55			
6				56			
7				57			
8				58			
9				59			
10				60			
11				61			
12				62			
13				63			
14				64			
15				65			
16				66			
17				67			
18				68			
19				69			
20				70			
21				71			
22				72			
23				73			
24				74			
25				75			
26				76			
27				77			
28				78			
29				79			
30				80			
31				81			
32				82			
33				83			
34				84			
35				85			
36				86			
37				87			
38				88			
39				89			
40				90			
41				91			
42				92			
43				93			
44				94			
45				95			
46				96			
47				97			
48				98			
49				99			
50				100			

Photographs

Figure H.1 Non-grazed sericea lespedeza (left) compared with grazed sericea lespedeza (right)

Figure H.2 Non-grazed ragweed (left) compared with grazed ragweed (right)

Figure H.3 Grazed Baldwin's ironweed (left) compared with non-grazed Baldwin's Ironweed (right).

Figure H.4 Seed production (100 plants/pasture) over a 3-yr period comparing grazed by steers only (top) pastures with pastures grazed by sheep following steer grazing (bottom).

Figure H.5 One sericea lespedeza seed compared to one U.S. Quarter.

Figure H.6 Mature Ewes grazing a sericea lespedeza infestation in Woodson County, KS.