EVALUATION OF ALTERNATIVE METHODS FOR LEAFY SPURGE CONTROL IN THE NORTHERN GREAT PLAINS

A Thesis
Submitted to the Graduate Faculty
of the
North Dakota State University
of Agriculture and Applied Science

By

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In Partial Fulfillment of the Requirements
for the Degree of
MASTER OF SCIENCE

Major Program:
Range Science

November 2018

Fargo, North Dakota

North Dakota State University
Graduate School

Title

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MASTER OF SCIENCE

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ABSTRACT

Leafy spurge (*Euphorbia esula* L.) is a costly noxious weed to manage in the Northern Great Plains; it invades rangelands and displaces native and desirable vegetation. Our first objective was to test the recommended full rate and half rate of selected herbicides applied in September following a spring burn on a leafy spurge invaded plant community. Our second objective was to determine if raffinate (desugared beet molasses) applied to leafy spurge invaded rangeland would attract cattle to consume leafy spurge. The aminocyclopyrachlor with chlorosulfuron treatment had the best leafy spurge control at the full rate, with stem density reductions of 95 percent for both sites nine and twelve months after treatment. The salt block treatment had the best success at reducing leafy spurge stem density. Herbicides can be the most common and effective type of management; however, manipulating livestock to graze noxious weeds converts a weed into a useable forage.

ACKNOWLEDGEMENTS

There are many people who have helped get me where I am today. I would like to first thank Dr. Kevin Sedivec, my major advisor, for sparking my interest in range science by guest lecturing in an undergraduate animal science class. He also has been an outstanding mentor and advisor over the past two years. I would like to thank Dr. Ryan Limb, my co-advisor, for his support and editing that he has provided throughout this journey. Thank you to Dr. Jack Norland for the many hours spent running data. Thank you to Dr. Joel Caton for being a mentor throughout my undergraduate degree and project, and the support and encouragement in completing my Masters of Science degree. Lastly, I would like to recognize and thank Dennis Whitted for the countless hours spent in the field collecting data and for the knowledge that I obtained working with him.

A huge thank you goes to my family, graduate students and friends for supporting me throughout the last two years as I couldn't have done it without them.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF ABBREVIATIONS

CGS .... Gilbert C. Grafton Army National Guard Training Base, South Unit

CSB .... Concentrated Separated By-Product

MAT .... Months after Treatment

MSO .... Methylated Seed Oil of Soybean

NIS .... Non-Ionic Surfactant

CHAPTER 1: LITERATURE REVIEW

Introduction

Noxious weeds have created an economic and ecological problem for land owners in North America for an extended period of time (Britton, 1921). Most noxious weeds are effective in out-competing native vegetation species. A few mechanism weeds have this advantage over native vegetation through faster reproduction, better colonization, and surviving harsher conditions (Sutherland, 2004). Exotic weed species (those plants not native to the historic plant community) impact the economic efficiency within the agricultural industry and forestry production (Pimentel et al., 2001). These species also negatively impact plant community species composition (diversity and richness), plant community function and structure of an ecosystem (Pimentel et al., 2001). However, "some exotic species, like corn (*Zea mays* L.), wheat (*Triticum* spp.), rice (*Oryza sativa* L.), plantation forests, and others are beneficial and provide more than 98% of the world's food supply" (Pimentel et al., 2001). When looking at monetary costs, more than 50,000 exotic species have invaded the United States and caused an upwards of $125 billion in annual losses, with management and control the biggest challenges (Pimentel et al., 2000; Allendorf and Lundquist, 2003). With the continued rise in noxious and exotic weed species, control and management strategies need to be implicated. It is often difficult to control many noxious and exotic species, with continued research needed to provide information on the best management strategies.

Leafy spurge is considered one of the most costly noxious weeds to control, impacting farmers and ranchers, as well as public land managers across the Northern Plains of the United States (Skinner et al., 2000). Leafy spurge has invaded over 840,000 ha of land in the upper Midwest states of North Dakota, South Dakota, Wyoming and Montana (Lym and Messersmith, 1994). Leafy spurge has caused an annual loss of $100 million across the four state region (Lym, 2000). Some of these losses are attributed to reduced livestock carrying capacity, decreased land value and direct cost of control (Lym, 2000). Leafy spurge can reduce the herbage production in a pasture or rangeland by as much as 75 percent, reducing the stocking rate of a pasture by 50-75 percent (Lym and Kirby, 1987). It is estimated that leafy spurge costs the cattle industry $7 million annual in lost income in North Dakota alone (Lym and Kirby, 1987). In 2016, leafy spurge infested over 370,000 ha of land in North Dakota and continues to be an economic and ecological pest to the state (North Dakota Department of Agriculture, 2017).

Leafy spurge was first introduced into the United States in the early 1800s. By early to mid-1900s, this weed made its way across the United States with the highest density populations found throughout the upper Midwest (Dunn, 1985). Leafy spurge was first documented in North Dakota in 1909 (Leitch et al., 1996). As the population of leafy spurge expanded throughout the 20th Century with limited success in control techniques, North Dakota listed it as a Noxious Weed.

Poor control of leafy spurge can be attributed to the plants ability to spread very rapidly, displace native vegetation and being resilient against many different management strategies (Leitch et al., 1996). Leafy spurge decreases the amount of native vegetation through competition, leading to an exotic grass species invasion. Soil disturbances are known places of infestation for leafy spurge. Few examples include road construction, trails, over grazed areas, cultivation, and track vehicle tracks (Belcher and Wilson, 1989).

There are many management strategies attempted over the years to control leafy spurge. Examples include fire, chemical, biological, and herbivory; or a combination of two or more methods (biological will not be discussed in this paper). Unfortunately, there is not one solution that works in every location.

Herbicide and Leafy Spurge

Herbicide use on leafy spurge has often been considered the most effective form of control. However, control of leafy spurge with herbicides can vary from year to year due to different environment conditions and locations of the infestation (Lym and Messersmith, 1985). Herbicide treatments should also be rotated, and a yearly application is often needed to maintain control. Many herbicides will only give one to three years of adequate control, depending on the application rates. Herbicide treatments aren't always cost effective and can be expensive in large infestations (Lym and Messersmith, 1990).

Lym and Messersmith (1990) compared the cost of herbicide treatments to effectiveness of control using picloram, dicamba, 2,4-D, and combinations of the three. "The most cost-effective treatment, considering both leafy spurge control and forage production, was picloram plus 2,4-D at 0.28 plus 1.1 kg ha^{-1} spring applied," (Lym and Messersmith, 1990). This herbicide combination provided a $284/ha net return and, over time, reduced the leafy spurge infestation by 70 percent. Other combinations had positive net returns but did not have as great of leafy spurge control.

Season of application (spring vs late summer) has also been studied to determine the best time to apply these herbicides. Herbicides that have been studied across different seasons include picloram, dicamba, quinclorac, 2,4-D, glyphosate, imazapic, and several others (Lym and Messersmith, 1985; Datta et al., 2013). Datta et al. (2013) reported that saflufenacil and imazapic applied together in the spring had 90 percent leafy spurge control for 24 months after treatment.

The fall application required a larger amount of saflufenacil to obtain similar leafy spurge control.

Herbicides used in our study included quinclorac, picloram, imazapic, 2,4-D, aminocyclopyrachlor and chlorosulfuron. Quinclorac is a broadleaf weed control herbicide and used for controlling annual grasses in rice fields (Kuehl and Lym, 1997). Picloram is generally the most effective herbicide for the control of leafy spurge and often paired with 2,4-D for better control (Lym and Messersmith, 1987). Aminocyclopyrachlor is used to aid in the control of broadleaf weeds on rangelands and can be paired with chlorsulfuron (Greet et al., 2016).

MSO (methylated seed oil of soybean) is an adjuvant that is added to herbicides to increase the effectiveness of the herbicide (Thompson et al., 1996). NIS (non-ionic surfactant) is a wetting agent that is added to herbicides to increase coverage, penetration and effectiveness (Hess and Foy, 2000). It has been suggested that herbicides used on broad-leaves can be more effective following a burn (Lesica and Martin, 2003).

Fire and Leafy Spurge

Prescribed fire is a management practice used on rangelands to manipulate the plant community and change grazing behavior of livestock and wildlife (Pierson et al. 2011). This plant community manipulation favors some plants while negatively impacting others. Studies have been conducted using fire as a tool to reduce the population of targeted plant species, while others have used fire to enhance the effectiveness of controlling targeted plant species with herbicides. The use of fire can reduce the emergence of leafy spurge seeds by 80-86 percent with a light fuel load (Vermeire and Rinella, 2009). Fuel load refers to the heat dosage that the plant or seed receives. Native species that have evolved with fire are generally more likely to be fire adapted and their seeds can avoid heat damage. Species that are fire adapted also tend to have a large seed bank and germination can even be enhanced with fire. Therefore, fire can be beneficial in reducing an exotic plants seed bank by increasing germination (Vermeire and Rinella, 2009).

Generally, one burn will not control the infestation of an exotic species (DiTomaso et al., 2006). Results of the effectiveness of fire on controlling a targeted plant species will vary depending on fuel load and mortality rate of seeds (Vermeire and Rinella, 2009). To obtain the best results in negatively impacting targeted plant species with fire, either several years of burning is needed or applying an herbicide treatment the following year of the burn is recommended (DiTomaso et al., 2006). Fire also removes the aboveground biomass (Hulbert, 1988), increasing the direct effect of the herbicide on the targeted species.

Grazing and Leafy Spurge

Cattle diet selection is often a learned behavior and a function of palatability. Cattle seek high quality forage areas by both sight and sound (Launchbaugh and Howery, 2005). Cattle develop diet preferences early in life, starting when a calf is grazing with its dam. Not only do they select for high quality forage, but also select away from potentially toxic, less digestible or less palatable forages (Launchbaugh et al., 2001). Cattle associate positive and negative post-ingestive feedback with taste, developing a preference and aversion to form their diet selection (Launchbaugh and Howery, 2005). When cattle consume feeds that upset their stomach, a negative post-ingestive feedback response occurs that they associate with plant's taste, avoiding future consumption (Kronberg et al., 1993).

Cattle generally avoid eating leafy spurge because of the milky sap, or latex that the plant produces. This latex has been known to be toxic and produces a negative post-ingestive feedback in cattle (Heemstra et al., 1999). The milky latex contains an alkaloid euphorbon that has a chemical composition of $C_{29}H_{36}O_7$ (Nellis, 1997). Generally, cattle are known to avoid grazing leafy spurge and areas highly invaded with this plant (Kirby and Lym, 1987); whereas, sheep and goats may actually select for the plant (Heemstra et al., 1999). Interestingly, leafy spurge is comparable to alfalfa in forage nutritional quality (Fox et al., 1991).

Behavior of foraging cattle can be changed if a general understanding of how these behaviors were formed and how they are kept in place. Altering foraging behavior can aid in land management while meeting the nutritional demands of livestock. One method land managers have attempted to change foraging behavior is to place salt in areas where heavy grazing is more desired. This offers a reward to the cattle in a less desirable area of grazing and can attract the cattle to that area (Martin and Ward, 1973; Launchbaugh and Howery, 2005). Another way of changing foraging behavior is to apply a palatable supplement, such as molasses and raffinate, to the desired forage area.

Conclusion

Leafy spurge is unfortunately here to stay so as land owners and managers, we must use the tools we have to minimize and manage its detrimental effects to native plant communities. There is a knowledge gap when reviewing the use of herbicides and fire, and the effects on leafy spurge control. There is also limited findings on how to get cattle to consume leafy spurge effectively as a control method.

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CHAPTER 2: EFFECTS OF APPLIED RAFFINATE TO LEAFY SPURGE INVADED RANGELANDS ON CATTLE GRAZING USE AND IMPACTS TO THE PLANT COMMUNITY

Introduction

Altering grazing behavior of livestock can have many benefits to rangelands. Some of these benefits may include a more evenly grazed pasture, reduction of rangeland degradation or erosion, and prescription grazing of weeds (Bailey and Welling, 1999; Frost and Launchbaugh, 2003). Land managers and ranchers can change the grazing distribution or livestock grazing behavior by using molasses, salt, or nutrient supplements like low moisture blocks (Martin and Ward, 1973; Bailey and Welling, 1999; Bailey et al., 2008).

Low moisture blocks and nutrient supplements are usually palatable and contain an outside source of protein and other nutrients for livestock. Placement of these supplements in less desirable areas attract cattle and increase time spent grazing in these areas (Bailey et al., 2008). This practice can alter the grazing distribution further from a water source, away from riparian zones, within higher terrain, or in less palatable forage.

Using salt as an attractant can alter grazing distribution (Martin and Ward, 1973); however, when salt was used in combination with nutrient supplementation or low moisture blocks, salt was less effective (Bailey et al., 2008). This effect could be due to salt being used in nutrient supplements as a limiting factor to prevent over consumption, thus cattle did not need or prefer salt blocks (Martin and Ward, 1973). Using one of these methods to alter livestock grazing distribution can be paired with spraying attractants like molasses and raffinate to promote prescription grazing of a weed.

“Prescription grazing is the application of livestock grazing at a specified season, duration and intensity to accomplish specific vegetation management goals,” (Frost and Launchbaugh, 2003). There are two common methods of prescription grazing that can be used, graze the plant when it is most vulnerable and manipulate livestock grazing behavior to target the specific weed (Frost and Launchbaugh, 2003). Spraying a weed with molasses or a sweetener is one method of prescription grazing and can increase its palatability to livestock (Olson, 1999). Since leafy spurge is not a preferred forage for cattle, the application of a sweetener may increase preference due to palatability.

Raffinate, or concentrated separated by-product (CSB), is the final by-product of a process that desugarizes beet molasses. It is generally used to increase the palatability of feed for livestock due to the residual sugar left in the raffinate, but it is also a very good source of protein and energy. Raffinate is very cost effective at around $20 per 908 kg (Polematidis et al., 2010).

This study evaluated the effects of using white salt blocks for altering grazing distribution and spraying large leafy spurge patches with raffinate to aid in prescription grazing of leafy spurge. The specific objectives were to determine if raffinate applied at two different ratios and an application of a high rate of white salt blocks would attract cattle to consume leafy spurge. Our research objectives were: 1) applying raffinate to leafy spurge infested rangeland will encourage cattle to consume leafy spurge and increase forage selectivity of cattle, and 2) distributing a high level of salt blocks to leafy spurge infested rangeland will encourage cattle to consume leafy spurge.

Materials and Methods

Study Site

The study was conducted in east-central North Dakota on the Gilbert C. Grafton Army National Guard Training Base, South Unit (CGS). The study location is approximately 64.4 km southeast of Devils Lake, ND (Barker et al., 2001). This training base is 3764 ha of mostly uncultivated rangeland (Barker et al., 2001). This study was located in three different pastures and grazed by different cattle herds creating three independent study blocks that were used as replicates. Each pasture is approximately 60 to 200 ha in size. Throughout the duration of the study, the pastures were rotationally grazed with cow calf pairs.

Camp Grafton South is located within the Transitional Grasslands Prairie of the Northern Great Plains (Barker and Whitman, 1989). The Transitional Grasslands Prairie is an interface of the Mixed Grass and Tall Grass Prairies (Whitman and Wali, 1975; Barker and Whitman, 1989). The study sites consisted of cool and warm season grasses, both native and exotic species present. The most abundant grasses were Kentucky bluegrass (*Poa pratensis* L.), smooth bromegrass (*Bromus inermus* L.), quackgrass (*Elymus repens* (L.) Gould), green needlegrass (*Nassella viridula* (Trin.) Barkworth), little bluestem (*Schizachyrium scoparium* (Michx.) Nash), needle and thread (*Hesperostipa comate* (Trin. & Rupr.) Barkworth), porcupinegrass (*Hesperostipa spartea* (Trin.) Barkworth), prairie sandreed (*Calamovilfa longifolia* (Hook.) Scribn.), and western wheatgrass (*Pascopyrum smithii* (Rydb.) Á. Löve) (USDA-NRCS, 2018a).

There was a high diversity of native and exotic forb species found throughout CGS. Leafy spurge (*Euphorbia esula* L.) was the primary forb present on the study sites. White sagewort (*Artemisia ludoviciana* Nutt.), common ragweed (*Ambrosia psilostachya* DC.), oval-leaf milkweed (*Asclepias ovalifolia* Decne.), common dandelion (*Taraxacum officinale* F.H.

Wigg.), and smooth horsetail (*Equisetum laevigatum* A. Braun) were forbs found on the study sites. Western snowberry (*Symphoricarpos occidentalis* Hook.) (USDA-NRCS, 2018a) was the common shrub species found on the study sites.

Camp Grafton South is located in Major Land Resource Area 55B, the Central Black Glaciated Plains (USDA, 2006) The dominant soil order found on the study area was Mollisols. Dominant soil textures found at CGS were fine sandy loams and loamy fine sands (USDA-NRCS, 2018b). A pre-dominant soil series found on the study sites are Embden-Heimdal complex, Embden-Egeland, Maddock-Hecla, Maddock, and Maddock-Serden. The topography is generally rolling hills in the glaciated till plain (USDA, 2006).

The climate is sub-humid continental. This is characterized by cold winters with warm summers. Most of the precipitation comes in the form of rainfall during the growing season late April through October (NDAWN 2018). Weather data was collected throughout the study period (NDAWN, 2018; NOAA, 2018). The North Dakota Agriculture Weather Network (NDAWN, 2018) does not record precipitation in the form of snow, so the National Oceanic and Atmospheric Administration (NOAA, 2018) was used as a second weather source to collect nearby winter precipitation data. The 30-year average annual precipitation for CGS was 485 mm per year (NDAWN 2018). In 2016, CGS received 540 mm of annual precipitation; however, only 60 percent of the average was received in 2017 at 288 mm. The mean annual air temperature for CGS was 6 ºC and 5 ºC in 2016 and 2017, respectively (NDAWN 2018).

Experimental Design 2016

The experimental design was a randomized block design with three replicates. Study treatments included: white salt blocks, 100% raffinate, 50% raffinate:50% water, and a non-treated control (Figure 2.1). Three different locations (blocks) were systematically selected for a high density of leafy spurge and grazed by different cow/calf herds. Each block was 40 m by 60 m in size and split in four equal sized 10 m by 60 m plots for the plots. Each treatment and the control were randomly assigned to one of the four plots. Each block was sprayed with the two raffinate treatments and had a salt block treatment (10 salt blocks) that were evenly distributed. Each treatment was applied three times during the growing season (June, July and mid-September).

50 % Raffinate: 50 % Water	Raffinate	Salt	Control

Figure 2.1. Example design of the raffinate and salt treatments on a leafy spurge patch in 2016.

Experimental Design 2017

The experimental design was a randomized block design with two replicates. Study treatments included: white salt blocks, 100 percent raffinate, and a non-treated control (Figure 2.2). A second control (Control B) was located 50 m from each study block to compare the main study block control (Control A) that was commonly affected by cattle walking across and trampling leafy spurge. The 2017 plots and 2016 plots are different sites located within the same pasture. Although three different locations (blocks) were systematically selected for a high density of leafy spurge and grazed by different cow/calf pair herds, only two blocks received the grazing treatment. Each block was 30m by 60m in size and split in three equal sized 10 m by 60 m for the plots. Each treatment and the control were randomly assigned to one of the three plots.

Each block was sprayed with the 100 percent raffinate treatment and the 10 salt block treatment that were evenly distributed three times during the growing season (June, July and mid-September).

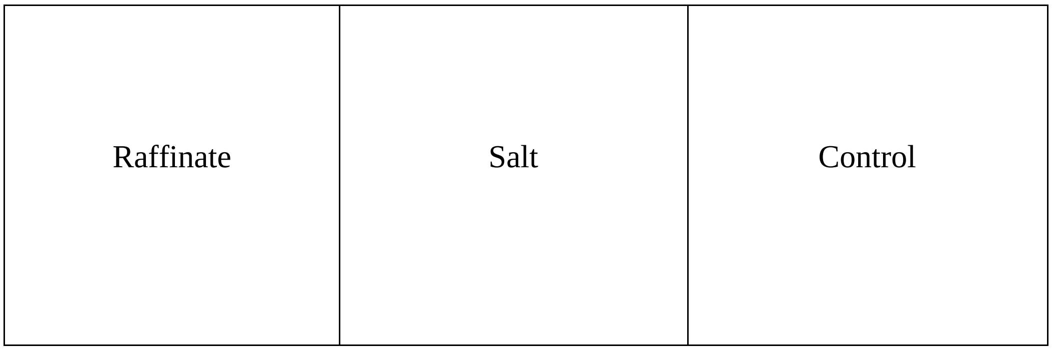

Figure 2.2. Example design of the raffinate and salt treatment on a leafy spurge patch in 2017.

Treatment Application

The raffinate treatments were applied with an electric sprayer mounted to a four-wheel ATV (Figure 2.3). The 100 percent raffinate treatment was sprayed at 8 km/hr and applied at 9.6 liters per 0.06 ha or 160 liters per ha. The 50 percent raffinate: 50 percent water treatment was sprayed at 8 km/hr and applied at 4.8 liters of raffinate: 4.8 liters of water per 0.06 ha or 80 liters of each per ha. The first application of treatments occurred in mid-June, second in mid-July and third in early September. These three seasonal time periods allowed for treating at differing physiological growth stages of leafy spurge. Figure 2.4 shows the spray cover on a leafy spurge plant.

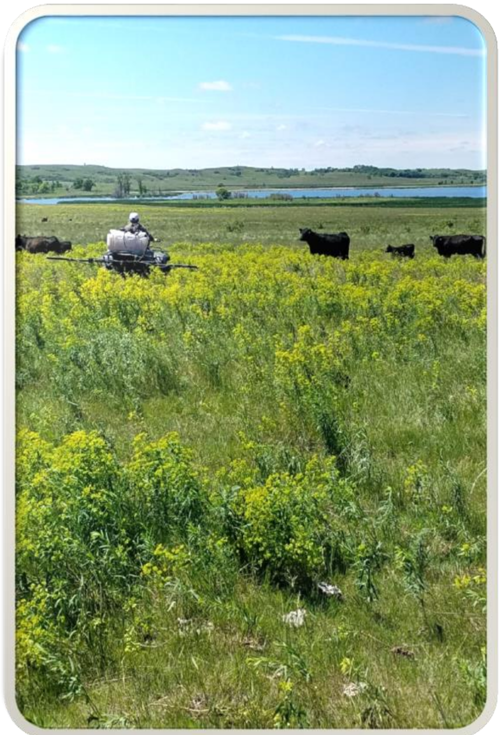

Figure 2.3. Raffinate being applied to the plots with the four wheel ATV.

Figure 2.4. Leafy Spurge plant with raffinate on the leaves.

Sampling Methods

Plant species composition was determined for graminoid composition (frequency) and forb (includes leafy spurge) density using a 0.25m^2 frame (forb density) with a nested 0.1 m^2 frame (graminoid frequency) every 5 m along a 60 m transect. Transects were placed at the center of the plots (5 m) and ran 60 m in length (n=12). Plant composition was collected pre-treatment in May and repeated post-treatment in mid-September. Degree of standing crop remaining at the end of the grazing season was determined by clipping 0.25 m^2 plots every 8 m along the same 60 m transects (n=7) at the end of the grazing season in mid-September, separating the plant material into graminoids, forbs, and leafy spurge.

Statistical Analysis

The study design for 2016 was a randomized block design with treatments of full raffinate, 50 percent raffinate and 50 percent water, and 10 salt blocks. The study design in 2017 was a randomized block design with the 100 percent raffinate and salt block treatments. The study consisted of three blocks; however, only two blocks were grazed in 2017 due to absence of cattle in the pasture (three were grazed in 2016). Data was analyzed using PROC GLM and LS means with an adjustment using the Tukey method in the SAS/STAT® software (Version [9.4] of the SAS System Copyright © 2002-2012 by SAS Institute Inc., Cary, NC, USA). When there was pre- and post-sampling the data were analyzed as a repeated measures analysis with time treated within an autoregressive covariance structure. The data were square root transformed before analysis.

Results

The treatment and study designs were different between the two years, with 2017 containing a second control (Control B). The two controls were not different ($p > 0.1$) in leafy spurge stem densities or biomass in 2017. There were no leafy spurge stem density differences (*p* > 0.1) between the 50 percent raffinate:50 percent water treatment and full rate of raffinate in 2016; however, the 100 percent raffinate treatment had a higher degree of disappearance ($p \leq 0.1$) of leafy spurge compared to the Control. The 50 percent raffinate:50 percent water treatment was not different ($p > 0.1$) from Control, thus we eliminated this treatment in 2017.

Precipitation may have been a factor in the end of the season standing crop when comparing the two study years. Standing crop in 2016 was greater than standing crop in 2017. In 2016, the growing season precipitation was greater than the 20-year average, but lower than 20-year average in 2017 (NDAWN 2016). Figure 2.5 shows the monthly growing season precipitation for 2016 and 2017.

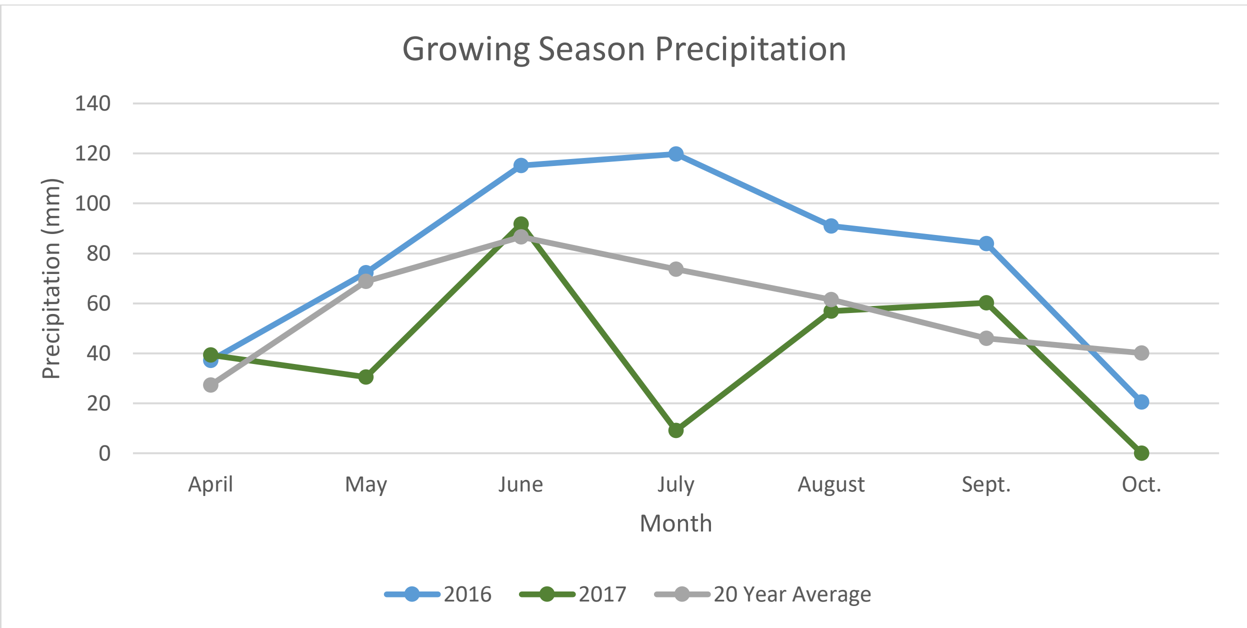

Figure 2.5. Growing season precipitation on the Gilbert C. Grafton Military Training facility – South Unit near McHenry, North Dakota, in 2016 and 2017.

2016 Results

There was no difference ($p > 0.1$) between the two raffinate treatments for leafy spurge stem density three and 15 months post-treatment. There was a reduction ($p \leq 0.1$) in leafy spurge stem density in the salt block treatment compared to the control three and 15 months post-treatment (Table 2.1). Part of the reduction in leafy spurge stem density in the salt block treatment is likely due to trampling from the cattle.

Table 2.1. Leafy spurge stem density pre- and post-treatment on leafy spurge invaded plant communities sprayed with different levels of raffinate and salt block placement on the Gilbert C. Grafton Military Training facility – South Unit near McHenry, North Dakota.

Treatment	**Leafy Spurge Density (# of stems/0.25m^2)**			
	Pre-treatment	Post-treatment 3 Months	Post-treatment 15 Months	Significance[1]
Control	8.7 ± 6.2	6.1 ± 2.8	7.9 ± 3.4	Not Significant
100% Raffinate	5.6 ± 4.7	3.4 ± 2.8	4.8 ± 2.5	Not Significant
50% Raffinate 50% Water	5.4 ± 4.5	4.2 ± 2.8	3.4 ± 1.8	Not Significant
Salt Block	10.3 ± 8.1	1.5 ± 2.1	1.9 ± 1.5	$p = 0.001$

[1]Significance applies to both post treatments compared to the pre-treatment.

There was a reduction ($p \leq 0.1$) in leafy spurge standing crop (kg/ha) remaining at the end of grazing season for the 100% raffinate and salt block treatments. The 50% raffinate: 50% water treatment was not different ($p > 0.1$) in standing crop reduction at the end of the grazing season ($p \geq 0.1$) compared to the control. The salt block treatment was the only treatment that had a reduction ($p \leq 0.1$) in graminoid standing crop at the end of the grazing season compared to the control. Table 2.2 shows the remaining standing crop at the end of the grazing season for leafy spurge and graminoids.

Table 2.2. Graminoid and leafy spurge standing crop remaining at the end of the grazing period (mid-September) on leafy spurge invaded plant communities sprayed with different levels of raffinate and salt block placement on the Gilbert C. Grafton Military Training facility – South Unit near McHenry, North Dakota.

Treatment	**Graminoid Standing Crop**[1]	**Leafy Spurge Standing Crop**[1]
	------------------------ Kg/ha	-----------------------
Control	1855[a]	399[c]
100% Raffinate	1916[a]	220[b]
50% Raffinate:50% Water	1992[a]	401[c]
Salt block	1048[b]	48[a]

[1] Treatments within standing crop category with the same letters are not different ($p \leq 0.1$).

2017 Results

There was no difference (p > 0.1) in leafy spurge stem density reduction between the raffinate treatment and Control A (Table 2.3). The salt block treatment had a leafy spurge stem density reduction ($p = 0.0338$) compared to the control (Control A). Leafy spurge stem density on the salt block treatment was 6.7 stems/0.25m^2 pre-treatment and 1.8 stems/0.25m^2 post treatment (Table 2.3).

Table 2.3. Leafy spurge stem density pre- and post-treatment on leafy spurge invaded plant communities sprayed with raffinate and salt block placement on the Gilbert C. Grafton Military Training facility – South Unit near McHenry, North Dakota. Controls located within the block (A) and 50-m (B) from the treatment blocks.

Treatment	**Leafy Spurge Density (# of stems/0.25 m^2)**		
	Pre-treatment	Post-treatment 3 months	Significance
Control A	4.5 ± 4.5	7.1 ± 3.4	Not Significant
Control B	3.3 ± 2.1	6.5 ± 3.3	Not Significant
Raffinate	4.9 ± 3.5	4.6 ± 2.4	Not significant
Salt Block	6.7 ± 5.2	1.8 ± 1.6	$p = 0.0338$

Leafy spurge standing crop at the end of grazing season was reduced ($p \leq 0.1$) on the salt block treatment (Table 2.4). The salt block treatment had a reduction ($p \leq 0.1$) in graminoid standing crop compared to both controls at the end of the grazing season. In contrast, the raffinate treatment had an increase ($p \leq 0.1$) in graminoid standing crop at the end of the growing season. Table 2.4 shows standing crop at the end of grazing season in 2017.

Table 2.4. Graminoid and leafy spurge standing crop at the end of the grazing period (mid-September) on leafy spurge invaded plant communities sprayed with raffinate and salt block treatment on the Gilbert C. Grafton Military Training facility – South Unit near McHenry, North Dakota. Control A is found within the block and Control B 50-m from treatment blocks.

Treatment	**Graminoid Standing Crop**[1]	**Leafy Spurge Standing Crop**[1]
	-------------------Kg/ha------------------	
Control A	561.5^{ab}	446.5^{a}
Control B	416.5^{ab}	664^{a}
Raffinate	907.5^{a}	320.5^{a}
Salt Block	365.5^{b}	26^{b}

[1]Treatments within standing crop category with the same letters are not different ($p \leq 0.1$).

Discussion

Leafy spurge has been invading and degrading range and pasture land for decades, with range managers achieving low success of control (North Dakota Department of Agriculture, 2017). Our study looked at an alternative management strategy to reduce leafy spurge by grazing cattle and verify if cattle grazing behavior can be altered to consume this noxious weed. The only treatment with success over both years at reducing leafy spurge stem density and end of the year standing crop was the salt block treatment. The salt block treatment achieved a 75 percent stem density reduction when compared to the control 15 months post treatment. The end of the year leafy spurge standing crop also had an 88% reduction on the salt block treatment three months post-treatment. Similarly, Martin and Ward (1973) found a trend that placement of salt on lightly grazed areas away from the water source increased utilization of all plant species within the area.

The 100 percent raffinate treatment reduced leafy spurge standing crop at the end of the grazing season by 55 percent compared to the control three months post-treatment. However, the 100 percent raffinate treatment did not differ in leafy spurge standing crop compared to the control 15 months post-treatment, thus suggesting an uneven response. A few papers suggest that using molasses as a sweetener may increase palatability or acceptance of an unfamiliar plant (Olson, 1999; Launchbaugh and Walker, 2006)

Summary

The use of salt blocks was the most effective treatment at attracting cattle to a leafy spurge infestation area over the two years of the study, followed by the 100 percent raffinate treatment. There are two potential reasons for the decreased leafy spurge stem density and end of the year standing crop using these treatments. Because the cattle had a strong attraction to the salt blocks, the sites were visited more often and could have increased a trampling effect, thus decreasing stem density. The second potential reason for the effectiveness of the raffinate treatment was that the leafy spurge was presumably more palatable, and the cattle actually consumed the plant (Figure 2.6.

Figure 2.6. Defoliated leafy spurge plant.

Salt blocks and raffinate are environmentally friendly and relatively safe to use when compared to other management strategies such as herbicides. While one may not want to place salt blocks in the same location in consecutive years due to creating spots that have saline or sodic soil conditions, the raffinate is a natural product. The salt block and raffinate treatments are inexpensive when compared to other management practices such as herbicides. This may also be a feasible solution for spot treating leafy spurge or for small scale management areas. A land manager or owner should take all management strategies into consideration and find the best solution that is suited for their operation and infestation level.

There is probable evidence to support using targeted or prescribed grazing to reduce leafy spurge density. Leafy spurge has forage quality that meets dietary needs of cows at all life stages. By placing salt blocks in heavily infested leafy spurge patches and potentially spraying raffinate in the surrounding area, a rancher or land manager could turn a weed into a usable forage while at the same time improving pasture or land quality.

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CHAPTER 3: EFFECTS OF A PRESCRIBED BURN FOLLOWED BY A FULL AND HALF RATE OF SELECTED HERBICIDES TO LEAFY SPURGE INVADED RANGELANDS

Introduction

Rangelands and biodiversity on these rangelands continue to decline, creating a need to improve management and preserve native species on rangelands (Randall, 1996). Many exotic species have become common throughout much of North America, threatening rangeland (Keeley, 2006). Leafy spurge is one of these exotic weeds that infests mostly uncultivated land, especially in the Northern Great Plains of the United State and Canada. It is listed as a noxious weed with many management strategies limited in success.

When managing weeds, herbicides are the most common used strategy. Unfortunately, leafy spurge is fairly resilient to many herbicides and only a few herbicides have shown success in reducing leafy spurge populations (Lym and Messersmith, 1983). The herbicides that have shown success in controlling leafy spurge are generally expensive (Bangsund et al., 1996). A few of these herbicides are dicamba, glyphosate, quinclorac, imazapic, aminocyclopyrachlor and chlorsulfuron, and picloram alone or in combination with 2,4-D (Lym and Messersmith, 1985; Masters et al., 1994; Kuehl and Lym, 1997).

Combining two or more types of management tools has been a strategy to controlling leafy spurge. Studies have been conducted focusing on leafy spurge control using fire and biological control (Fellows and Newton, 1999), biological control and herbicides (Lym and Nelson, 2002), and herbicides and grazing (Lym et al., 1997). However, there is a knowledge gap when comparing prescribed fire with herbicides on controlling leafy spurge.

Advantages to incorporating prescribed fire with herbicides is the potential enhanced control of an exotic weed. Prescribed burning has been shown to successfully control yellow starthistle (*Centaurea solstitialis* L.), an exotic weed found in the western United States that originated from Europe (Keeley, 2006). This study evaluated the effects of a spring burn followed by six herbicide treatments applied in the fall. The study objectives were:

1. Determine if a late spring burn followed by fall applied herbicide treatments will have a greater effect on controlling leafy spurge density using a half-recommended rate versus the full recommended rate of selected herbicides.

Materials and Methods

Study Site

The study was conducted in east-central North Dakota on the Gilbert C. Grafton Army National Guard Training Base, South Unit (CGS). The study location is approximately 64.4 km southeast of Devils Lake, ND (Barker et al., 2001). Camp Grafton South is comprised of 3764 ha of mostly uncultivated rangeland (Barker et al., 2001). This study was located at two locations (blocks; 47˚42’07.30”N, 98˚40’01.74”W; 47˚42’51.90”N, 98˚39’58.80”W), approximately 150 and 100 ha, respectively. The pastures were rotationally grazed with cow calf pairs stocked at full use grazing rate, or 40% to 50% degree of disappearance.

Camp Grafton South is part of the Transitional Grasslands Prairie located in the Northern Great Plains (Barker and Whitman, 1989). The Transitional Grasslands Prairie is an interface of the Mixed- and Tall -Grass Prairies (Whitman and Wali, 1975; Barker and Whitman, 1989). The study sites consisted of many cool and warm season grasses with both native and exotic species present. The most abundant grasses found were Kentucky bluegrass (*Poa pratensis* L.), smooth bromegrass (*Bromus inermus* L.), quackgrass (*Elymus repens* (L.) Gould), green needlegrass

(*Nassella viridula* (Trin.) Barkworth), little bluestem (*Schizachyrium scoparium* (Michx.) Nash), needle and thread (*Hesperostipa comate* (Trin. & Rupr.) Barkworth), porcupinegrass (*Hesperostipa spartea* (Trin.) Barkworth), prairie sandreed (*Calamovilfa longifolia* (Hook) Schribn), and western wheatgrass (*Pascopyrum smithii* (Rydb.) Á. Löve) (USDA-NRCS, 2018a). The north study sites were a Kentucky bluegrass/needlegrass plant community and the south study site a smooth bromegrass/Kentucky bluegrass/needlegrass plant community.

Several native and exotic forb species were found on CGS. Leafy spurge (*Euphorbia esula* L.) was the primary forb present on our study sites. White sagewort (*Artemisia ludoviciana* Nutt.), common ragweed (*Ambrosia psilostachya* DC.), oval-leaf milkweed (*Asclepias ovalifolia* Decne.), common dandelion (*Taraxacum officinale* F.H. Wigg.), and smooth horsetail (*Equisetum laevigatum* A. Braun) were common forbs present on the study sites. Western snowberry (*Symphoricarpos occidentalis* Hook.) (USDA-NRCS, 2018a) was the most common shrub species.

Camp Grafton South is located in Major Land Resource Area 55B, the Central Black Glaciated Plains (USDA, 2006) The dominant soil order found on the study area is Mollisols. Dominant soil textures found at CGS are fine sandy loams and loamy fine sands (USDA-NRCS, 2018b). The soil series found on the north study site was a Heimdal-Esmond-Sisseton loamy complex and on the south study site a Maddock-Serden loamy fine sands complex. The topography is generally rolling hills in the glaciated till plain (USDA, 2006).

The climate is sub-humid continental. This is characterized by cold winters with warm summers. Most of the precipitation comes in the form of rainfall during the growing season late April through October (NDAWN 2018). Weather data was collected throughout the study period (NDAWN, 2018, NOAA, 2018). North Dakota Agricultural Weather Network (NDAWN, 2018) does not record precipitation in the form of snow, so the Nation Oceanic Atmospheric Administration (NOAA2018) was used as a second weather source to collect nearby winter precipitation data. The 30-year average annual precipitation for CGS was 485 mm per year (NDAWN 2018). In 2016, CGS received 540 mm of annual precipitation and 289 mm (60 percent of average) in 2017. The mean annual air temperature for CGS was 6 and 5 Cº in 2016 and 2017, respectively (NDAWN 2018).

There were three herbicide combinations used in this study: 1) quinclorac, 2) picloram + imazapic + 2, 4-D, and 3) aminocyclopyrachlor + chlorsulfuron. Each herbicide was applied at the recommended rate according to the herbicide label and at half the recommended rate, creating six treatments and a control.

Quinclorac is a BASF product used to control broadleaf weeds and annual grasses found mainly in rice fields (Kuehl and Lym, 1997). "Quinclorac is a systemic herbicide which is readily absorbed by germinating seeds, roots, and leaves; translocated into the plant both acropetally and basipetally" (Grossmann and Kwiatkowski, 2000). Methylated seed oil of soybean (MSO) is an adjuvant that is added to herbicides to increase the effectiveness of the herbicide (Thompson et al., 1996). MSO was added to the Quinclorac treatment for this study (Sterling et al., 2000; Woznica et al., 2003).

Aminocyclopyrachlor + chlorsulfuron is a Bayer product. Aminocyclopyrachlor is used to control broadleaf weeds on rangelands and can be paired with chlorsulfuron (Greet et al., 2016). Non-ionic surfactant (NIS) is a wetting agent that is added to herbicides to increase coverage, penetration and effectiveness (Hess and Foy, 2000). NIS was added to the aminocyclopyrachlor + chlorsulfuron treatment for this study (Bukun et al., 2009, 2010).

Picloram + imazapic + 2, 4-D is manufactured by Dow AgroSciences. Picloram is generally the most effective herbicide for the control of leafy spurge and often paired with 2,4-D for better control (Lym and Messersmith, 1987). MSO was added to the Picloram + imazapic + 2, 4-D treatment for this study (Thompson et al., 1996; Markle and Lym, 2000).

The herbicide treatment rate for the half rate of quinclorac with MSO was 420 g/ha and 2.2 L/ha, and the quinclorac recommended rate with MSO 840 g/ha and 2.2 L/ha. The half rate of picloram + imazapic + 2, 4-D and MSO was 280 + 35 + 560 g/ha and 2.2 L/ha and the recommended rate of picloram + imazapic + 2, 4-D and MSO 560 + 70 + 1120 g/ha and 2.2 L/ha. The half rate of aminocyclopyrachlor + chlorsulfuron with NIS was 116.2 g/ha and 0.25 V/V, and aminocyclopyrachlor + chlorsulfuron recommended rate with NIS 232.4 g/ha and 0.25 V/V. A non-herbicide control was added as shown in Figure 3.1.

Herbicide Treatment	**Rep 1**	**Rep 2**	**Rep 3**
Recommended rate quinclorac + MSO	3	11	19
Half rate quinclorac + MSO	5	8	21
Recommended rate picloram, imazapic & 2,4-D + MSO	6	9	20
Half rate Picloram, imazapic & 2,4-D + MSO	1	14	17
Recommended rate aminocyclopyrachlor & chlorsulfuron + NIS	7	12	16
Half rate aminocyclopyrachlor & chlorsulfuron + NIS	2	13	15
Control	4	10	18

Figure 3.1. Experimental layout of the treatments for each replicate.

Experimental Design

The experimental study design was a split plot randomized block design with a between factor of burned or unburned and a within factor herbicide and rate combination. Each herbicide treatment was applied to each split (burn and unburned) treatment with three replicates. The study was conducted at two different locations. Each of the six herbicide treatments and control were randomly assigned to seven subplots for each replicate for a total 21 subplots per split plot (Figure 3.2). Each split plot was 32 m x 48 m. Each subplot was 10 m x 6 m with a 1-meter buffer zone between each subplot. Each herbicide treatment was applied with a hand held CO_2 pressurized broadcast sprayer with 8002 nozzles at 35 psi delivering 159.017 liter/ha on 20 September 2016.

Unburned

Rep 3	15	16	17	18	19	20	21
Rep 2	8	9	10	11	12	13	14
Rep 1	1	2	3	4	5	6	7

Burned

Rep 3	15	16	17	18	19	20	21
Rep 2	8	9	10	11	12	13	14
Rep 1	1	2	3	4	5	6	7

Figure 3.2. Experimental layout of six treatments and control, and three replicates showing the 21 subplots by prescribed burn and unburned splits.

The burned plots were burned using a strip head type fire. The strip fire was started with a head fire (fire that starts on the most upwind side and burns with the wind) to create a blackened, burned control area on the downwind side. The perimeter was then burned starting at each side of the head fire, moving into the wind until the two igniting sources met. Two igniting personal were used to ignite the fire at the same time on each side (NWCG, 2018). The two study locations were burned on 9 June 2016.

Sampling Methods

Changes in graminoid frequency were determined by recording presence and absence of graminoids using a nested 0.1 m^2 frame. Changes in forb, including leafy spurge, density were collected using a 0.25 m^2 frame that contained the nested 0.1 m^2 frame. Each subplot had two transects 10 m long, one located at two meters and the second located at four meters from the plot edge. Five frames were sampled on each transect every two meters for a total of 10 frames in each subplot. Pre-burn data was collected in 2 June 2016. Post-data for graminoid frequency, forb density, and leafy spurge density was collected on 5 June 2017 and 20 September 2017.

Statistical Analysis

The analysis design was a nested randomized block design with a between factor (burning) and a within factor (herbicide and rate combination). The two sites had different environmental conditions such as topography, plant community, soil type, and drainage. They were therefore analyzed separately. The analysis utilized PROC MIXED with a Tukey test for means comparison in the SAS/STAT® software (Version [9.4] of the SAS System Copyright © 2002-2012 by SAS Institute Inc., Cary, NC, USA). There was no difference ($p > 0.05$) in leafy spurge stem densities between plots for either block pre-treatment. The data was square root transformed before the analysis.

Results

There was an increase ($p \leq 0.05$) in leafy spurge stem density due to burning in the spring and nine months after treatment (MAT) at both study locations. Table 3.1 shows stem densities for both locations on the burned and unburned plots. There was a difference ($p \leq 0.05$) in leafy spurge stem density among herbicide treatments for both locations and time periods. There was no interaction ($p > 0.05$) between burning and herbicide treatments for either location and time period.

Table 3.1. Leafy spurge stem densities by location (1 and 2) nine months after treatment on the Gilbert C. Grafton Military Training facility – South Unit near McHenry, North Dakota. Treatments (burned vs unburned) within a location with the same letters were not different ($p \leq 0.1$).

Study Location	**Stems per 0.25 m^2**
1 (Burned)	3.1[a]
1 (Unburned)	2.0[b]
2 (Burned)	4.2[a]
2 (Unburned)	1.8[b]

All herbicide treatments had a reduction ($p \leq 0.05$) in leafy spurge stem densities when compared to the control nine MAT on location 1 (Figure 3.3). Within treatments, quinclorac and aminocyclopyrachlor & chlorsulfuron were not different ($p > 0.05$) between the full rate and half rates nine MAT. The full rate of picloram, imazapic & 2,4-D had a reduction ($p \leq 0.05$) in leafy spurge stem density when compared to the half rate nine MAT.

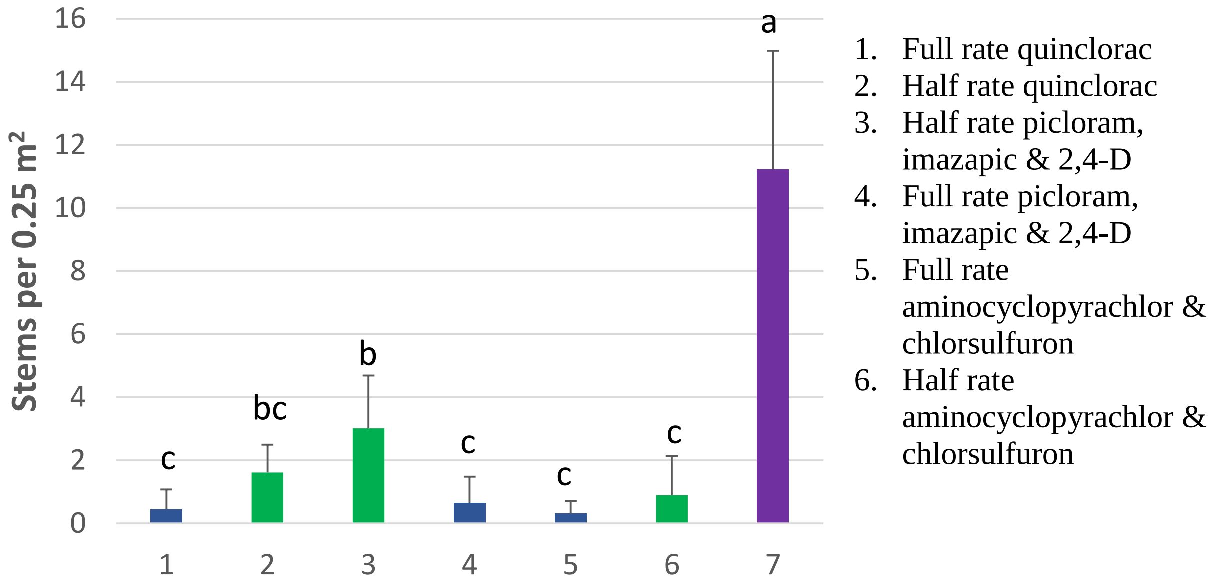

Figure 3.3. Leafy spurge stem density per $0.25m^2$ nine months after treatment on study location 1. Treatments with the same letters are not different ($p > 0.05$).

Leafy spurge stem density was not different ($p > 0.05$) between the half and full rate of picloram, imazapic & 2,4-D when compared to the control twelve MAT on location 1 (Figure 3.4). However, the full and half rates of quinclorac and aminocyclopyrachlor & chlorsulfuron reduced leafy spurge stem density ($p \leq 0.05$) when compared to the control twelve MAT. There was no difference ($p > 0.05$) in leafy spurge stem density between the full and half rates of quinclorac, picloram, imazapic & 2,4-D, and aminocyclopyrachlor & chlorsulfuron twelve MAT (Figure 3.4).

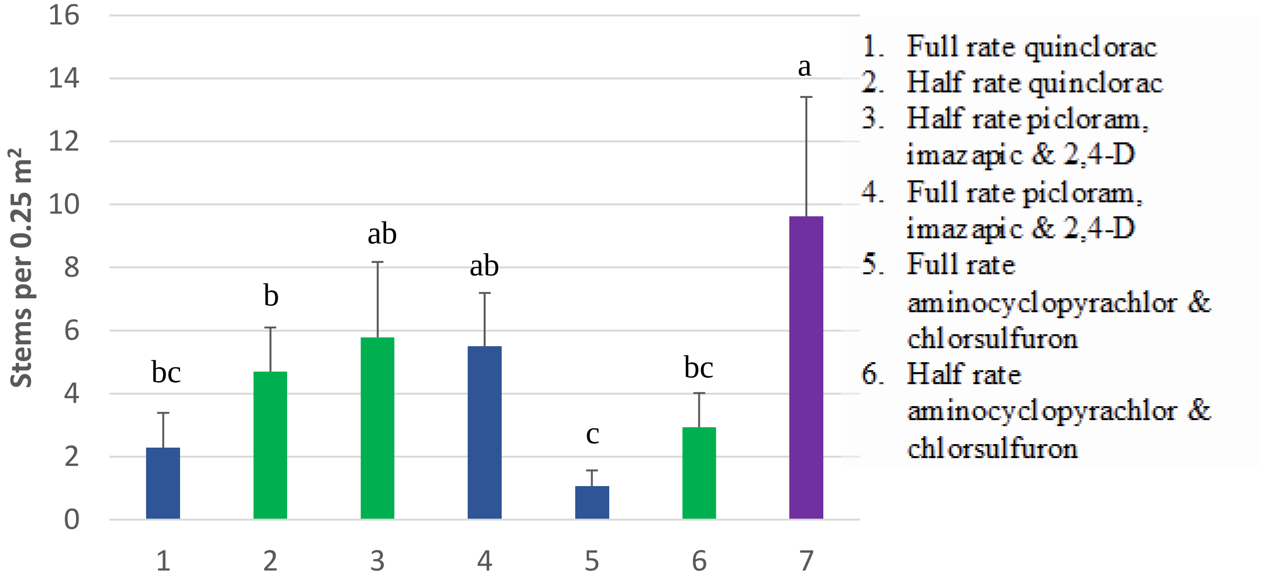

Figure 3.4. Leafy spurge stem density per 0.25 m^2 twelve months after treatment on location 1. Treatments with the same letters were not different (p > 0.05).

All herbicide treatments reduced leafy spurge stem density ($p \leq 0.05$) twelve MAT when compared to the control on location 2 (Figure 3.5). Leafy spurge stem density had a greater reduction ($p \leq 0.05$) with the full rate of picloram, imazapic & 2,4-D compared to the half rates. Quinclorac and aminocyclopyrachlor & chlorsulfuron herbicide treatments applied at the full and half rates were not different ($p > 0.05$) twelve MAT on location 2 (Figure 3.5).

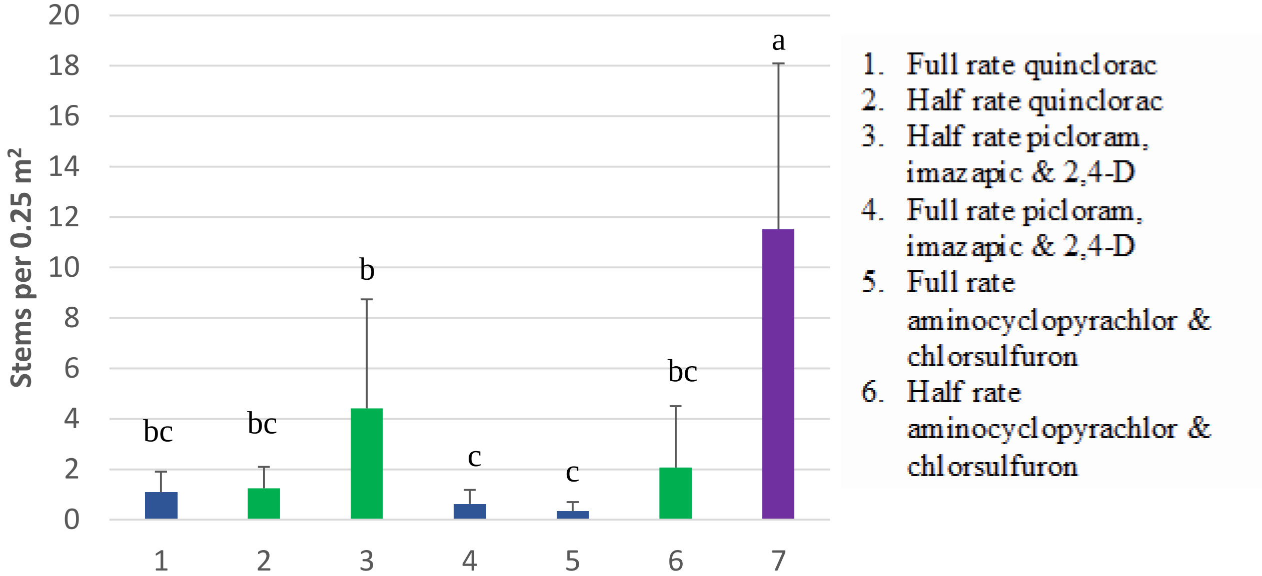

Figure 3.5. Leafy spurge stem density per 0.25 m^2 nine months after treatment on location 2. Treatments with the same letters were not different ($p > 0.05$).

Leafy spurge stem density was not reduced ($p > 0.05$) on the half rates of quinclorac and picloram, imazapic & 2,4-D twelve MAT compared to the control on location 2 (Figure 3.6). The full rate of aminocyclopyrachlor & chlorsulfuron had a greater reduction ($p \leq 0.05$) of leafy spurge stem density compared to the half rate on location 2 (Figure 3.6).

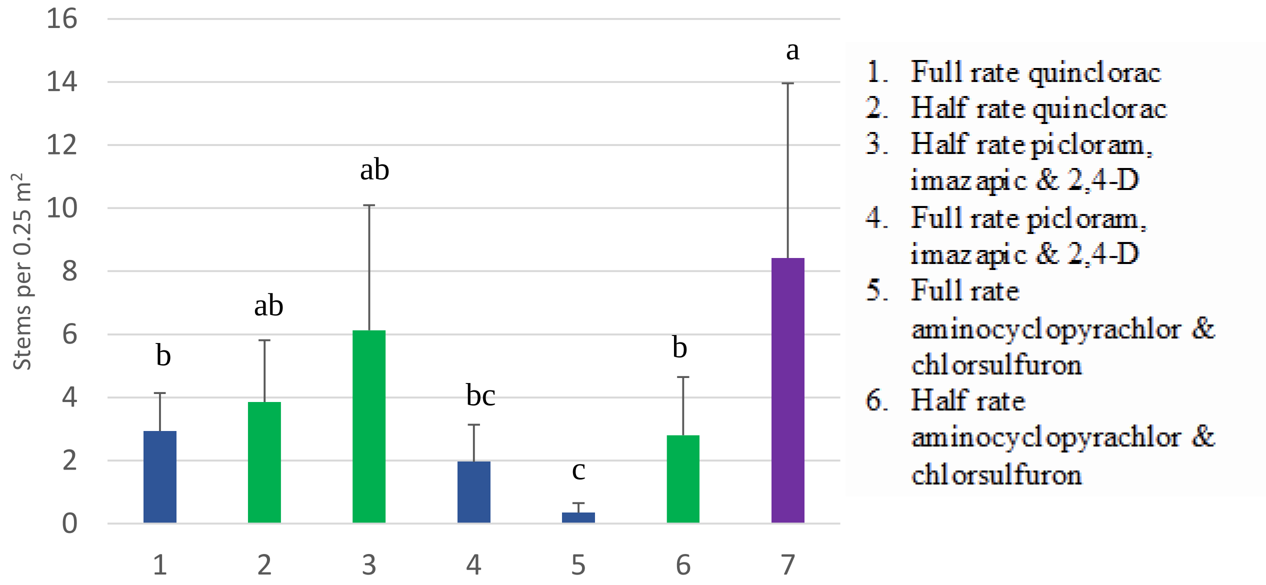

Figure 3.6. Leafy spurge stem density per 0.25 m^2 twelve months after treatment on location 2. Treatments with the same letters were not different ($p > 0.05$).

The cost of herbicides used in this study range from $23.66 - $62.86 per hectare (Table 3.2). The picloram, impazapic & 2,4-D with MSO was the least expensive of the three herbicide combinations with the full rate at $33.24/ha and half rate at $23.66/ha. The quinclorac with MSO treatments was in the middle of the treatments in terms of cost. The full rate of quinclorac with MSO was $44.20/ha and half rate was $29.14/ha. The aminocylopyrachlor and chlorulfuron with NIS was the most expensive of the herbicide combinations. The full rate was $62.86/ha and half rate $38.50/ha (The Board of Regents of the University of Nebraska–Lincoln, 2017).

Table 3.2. Calculated cost per hectare of the herbicide and adjuvant used by treatments at Gilbert C. Grafton Military Training facility – South Unit near McHenry, North Dakota in 2017.

picloram, imazapic & 2,4-D + MSO	
Full Rate	$33.24
Half Rate	$23.66
quinclorac + MSO	
Full Rate	$44.20
Half Rate	$29.14
aminocyclopyrachlor & chlorsulfuron + NIS	
Full Rate	$62.86
Half Rate	$38.50

Discussion

Burning in the late spring increased emergence of leafy spurge stems when compared to the unburned site. However, there was no interaction between the treatments and the burn, therefore burning before herbicide application did not have an effect on the leafy spurge stem density. There was an herbicide treatment effect in leafy spurge stem density at both study locations.

All herbicide treatments, irrelevant of rate, reduced leafy spurge stem density when compared to the control nine MAT. Lym and Messersmith (1985) found similar results using 2,4-D and picloram, as well as the herbicides dicamba and glyphosate. When compared to our study, at similar full and half rates, leafy spurge stem density was reduced by as much as 70 percent nine MAT using 2,4-D and picloram. Markle and Lym (2001) showed similar leafy spurge control compared with our full rate using imazapic. They concluded that nine MAT, imazapic applied alone obtained 50% leafy spurge control and with the addition of MSO obtained 94% control. This is comparable with the full rate picloram, imazapic and 2,4-D treatment obtaining at least 90% control nine MAT. Similar half and full rates of quinclorac obtained 72% and 86% leafy spurge control; respectively, nine MAT (Kuehl and Lym, 1997). In our study quinclorac leafy spurge control was 82% and 91% control for half and full rates; respectively, nine MAT.

The only herbicide that was different between the recommended and half rate was the picloram, imazapic and 2,4-D treatment, with the full rate providing greater control of leafy spurge stem densities compared to the half rate. This is similar to findings by Lym and Messersmith (1985) using picloram and 2,4-D at different rates, where they found the highest rate provided 20% to 30% better leafy spurge control compared to lowest rate.

The picloram, imazapic, & 2,4-D treatment was the least effective treatment in this study. Neither the full nor half rates reduced leafy spurge stem density compared to the control twelve MAT at study location 1. The half rate of the picloram, imazapic, & 2,4-D treatment was not different from the control at study location 2. These findings are similar to what Lym and Messersmith (1985) reported, where piclorma & 2,4-D at the full rate provided control of leafy spurge twelve MAT. Lym and Messwersmith (1985) also showed reduced control of leafy spurge after twelve months without retreatment.

Quinclorac provided greater than 90% control of leafy spurge stem density nine MAT on both the full and half rate at both study locations. However, only the full rate maintained this reduction at location 2 twelve MAT. In a similar study, Kuehl and Lym (1997) stated that “Quinclorac controlled leafy spurge similar to or better than picloram plus 2,4-D.” Findings by Kuehl and Lym (1997) were similar to our findings with leafy spurge control declining from the nine MAT and twelve MAT, and Quinclorac having better control than the picloram, imazapic, & 2,4-D treatment.

Aminocyclopyrachlor & chlorsulfuron reduced leafy spurge stem density on both study sites by as much as 95% nine and twelve MAT when compared to the control. The full rate of aminocyclopyrachlor & chlorsulfuron gave the overall best leafy spurge control out of the six treatments. The half rate of aminocyclopyrachlor & chlorsulfuron was similar to the full rate nine MAT; however, effectiveness was lower twelve MAT. Greet et al., (2016) conducted a study looking at Duncecap larkspur (*Delphinium occidentale*) response to aminocyclopyrachlor. They found that aminocyclopyrachlor in combination with chlorsulfuron reduced stalks by over 80% twelve MAT with similar rates that were used in our study.

Leafy spurge has an extensive underground root system and bud below the soil surface, allowing it to have an advantage in surviving a burn. Leafy spurge stem density increased in the burned sites when compared to the unburned sites, which indicates that fire increases seedling emergence. Since we only had two study locations, it was difficult to show completely address the prescribed fire impacts, or lack of impacts.

Summary

The herbicide combination that performed the best to control leafy spurge was aminocylopyrachlor & chlorsulfuron. It obtained the greatest reduction at both study locations nine and twelve MAT. The half and full rates were similar in leafy spurge control for the aminocylopyrachlor & chlorsulfuron treatment. However, this herbicide combination was the most expensive treatment.

The full rate of quinclorac provided similar control to the aminocyclopyrachlor & chlorsulfuron. However, the half rate of aminocyclopyrachlor & chlorsulfuron was still more economical than the full rate of quinclorac.

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