Impacts of integrated pest management of Leafy Spurge (Euphorbia esula) following a 10-year sheep grazing study: A progress report

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The objective of the current study is to determine the most effective combination of grazing and herbicide treatments in combination of bio-control with insects for control of leafy spurge. This report highlights initial findings for an on-going study.

Introduction

Leafy spurge (*Euphorbia esula*) was first reported in North America in 1827 (Kaufman and Kaufman, 2007). Native to central and eastern Europe, leafy spurge was inadvertently introduced in cultivated crop seeds and as an ornamental in the United States. Worldwide introduction has brought leafy spurge to every continent except Australia (Lajeunesse et al., 1997). Leafy spurge is found in 35 states of the U.S. and throughout Canada, thriving in uncultivated areas (Kaufman and Kaufman, 2007). Within the North Great Plains (NGP) region, Liestritz et al. (2004) estimated the direct economic loss from leafy spurge at $37 million with secondary impacts of $83 million.

Biology and Ecology. Leafy spurge is a perennial forb, reaching a height of up to three feet and existing in a variety of habitats (Lajeunesse et al., 1997; Kaufman and Kaufman, 2007). Small, yellow-green flowers develop on like colored bracts (Lajeunesse et al., 1997). Growth begins in early spring with the first period of flower development occurring in late May and June. Additional periods of flowering can occur throughout the growing season.

Root structure plays a key role in successful colonization (Lajeunesse et al., 1997; Kaufman and Kaufman, 2007). Fibrous roots develop thick mats in the upper layer of soil, while taproots descend to 26 feet or more. Specialized root buds can produce a new plant if the top shoot is removed (Dersheid et al., 1985). Lym and Messersmith (1993) found leafy spurge root systems are most cold tolerant in the upper six inches of soil. Cultivation causes root fragmentation that increase root density in the subsequent year. However, but by the third year of cultivation leafy spurge density decreased to 0-30%. Laboratory experiments found leafy spurge root segments of one centimeter could regenerate six percent of the time (Lym and Messersmith, 1987). The diverse and massive root system aids leafy spurge in storing carbohydrates essential for surviving stressful environmental conditions (Lajeunesse et al., 1997) and early season growth (Dersheid et al., 1985).

Each flowering stem develops pod-like structures filled with seeds (Lajeunesse et al., 1997; Kaufman and Kaufman, 2007), potentially producing up to 140 seeds per stem. Once the pod has dried, it bursts open dispensing seeds up to 15 feet from the parent plant. Seeds can remain viable in the upper layers of the soil for eight years, while deeply buried seeds a longer potential life span. Selleck et al. (1962) found seeds remained viable for up to 13 years. Long distance dispersal relies on transfer of seeds embedded in fur, mud or feces (Lajeunesse et al. 1997).

Herbicide Control. Herbicides provide leafy spurge control at varying levels. Lym and Messersmith (1990) found picloram applied at a rate of two pounds/acre, applied twice, provided 90% control of leafy spurge, while dicamba applied at eight pounds/acre, applied twice, provided 70% control. For long-term control, an annual treatment using picloram and 2,4-D at a rate of 0.25 plus 1 pound/acre reduced leafy spurge density 85-93% after five years (Lym and Messersmith, 1987). Recent studies using picloram found fall was the preferred time of application (Lym and Messersmith, 2006). Annual applications are recommended until 90% control is reached.

Lym and Messersmith (2006) found 2,4-D reduced leafy spurge top growth during the season applied. Lym (2000) found 2,4-D did not translocate to leafy spurge roots, thus considered less effective in controlling or killing root growth. Application of 2,4-D is common in areas around water when picloram use is prohibited or when grazing animals may be sensitive to herbicides (Lym and Messersmith (2006).

The use of imazapic, methylated seed oil, and 28% nitrogen at a rate of two ounces plus two pints plus two pints/acre produced 98%, 78%, 94%, and 71% leafy spurge control for nine, 12, 21, and 24 months; respectively, after one treatment (Markle and Lym, 2001). Nitrogen aided in the absorption of imazapic with foliar applications. Markle and Lym (2001) found imazapic alone at a rate of two ounces/acre reduced leafy spurge by 75%, 33%, 74%, and 43% respectively for nine, 12, 21, and 24 months following the one treatment. Treatments were applied for two consecutive years.

Livestock grazing. Grazing with sheep and goats has proven to be successful in controlling leafy spurge. Cattle have an aversion to toxins contained in leafy spurge and can develop scours if enough spurge is consumed (Heemstra et al., 1999). Sheep and goats, however, readily forage on leafy spurge (Walker et al., 1994). Differences in internal organs allow each species to consume different types of forage than cattle (Frost and Launchbaugh, 2003). Sheep are able to consume more forbs due to a large rumen, while a large liver allows goats to more efficiently process toxic compounds.

A reduction in sheep grazing occurs when pastures reach a high-density of leafy spurge. Walker et al. (1994) showed sheep consumed only 51% of the available leafy spurge in a pasture per season. Dahl et al. (2003) found sheep remove only leave and flowering portions of the plant. Grazing by sheep over a four-year period can reduce leafy spurge stem density by 99% (Schauer et al., 2006). Cattle and sheep combined require 5 years of grazing to achieve the same level of control with sheep only when sheep consumed 100% of the carrying capacity. Dahl et al. (2000) found six years of grazing by cattle and sheep is required to reach a 98% level of control. The use of sheep with cattle did not decrease cattle or sheep performance, or change grass and grass-like species production.

In contrast, goats readily graze leafy spurge consuming up to 66% in a single pasture per season (Walker et al., 1994). Goats tend to defoliate leafy spurge rather than consume just flower and leaf parts. Angora goats used at Camp Grafton, ND reduced leafy spurge stem densities by 84.2% and shrubs 91.6% in a four-year period (Sedivec et al., 1995). Sedivec and Maine (1993) found a 57.2% increase in grass and a

44.1% decrease in leafy spurge after two years of grazing with angora goats. Sedivec et al. (1995) found that grass species production increased significantly after three years of grazing.

Biological Controls. Four genera of biological control agents were released in the United States to combat leafy spurge (Hansen et al., 1997). Root boring moths (*Chamaesphecia hungarica*) lay eggs on leafy spurge stems with larvae move downward, burrowing into the roots and killing the plant (Gassman and Tosevski, 1994). Female root-boring beetles (*Oberea erythrocephala*) girdle leafy spurge stems and lay eggs in a cavity. The larvae tunnel downward through the stem to the root area (Schroeder, 1980). Gall midge (*Spurgia esulae*) laid eggs near buds and once the eggs hatch the instars feed on the buds (Pecora et al., 1991). Flea beetle (*Apthona* spp.) adults consume foliage and flowers. The female lay eggs at the base of the stem and once hatched, feed on the shallow, fine roots of leafy spurge (Gassman et al., 1996). Of the four agents released, the flea beetle has had the greatest success with established populations in 18 states (Hansen et al., 1997).

Flea beetles slowly decrease leafy spurge density (Lym and Nelson, 2000). Several subspecies of the leafy spurge flea beetle (*Apthona* spp.) were released in the NGP region. *Apthona nigriscutis* decreased leafy spurge densities by 65% within 53 feet of its release. The reduction in leafy spurge took three to five years. *A. czwalinae* and *A. lacertosa* took four years to reduce leafy spurge densities by 95%. *A. nigriscutis* required a beetle density of 4-8 beetles/yd^2 and *A. czwalinae* and *A. lacertosa* a beetle density of 22.5 beetles/yd^2. *A. czwalinae* was more prolific and dispersed faster from the release site. Hansen et al. (1997) found flea beetles are not suited for release in high-density leafy spurge areas. Lym and Olson (1999) found densities of 60-90 stems/yd^2 were the limit for flea beetle introduction. Soil type also influences flea beetle establishment. Sandy soils reduced flea beetle establishment (Larson et al., 2008), while silt loam, silty clay loam, clay loam, and clay soils with 6-9.5% organic matter had the highest establishment rates (Lym and Olson, 1999). South facing slopes had the highest establishment success.

Combining different control methods can be an effective management tool (Lym, 2005). Integrated pest management systems use site assessment to select the most appropriate control methods based on landowner's budget and site conditions. Multiple control methods can target different parts of the leafy spurge plant and life stages, thus providing better overall control of leafy spurge (Lajeunesse et al., 1997).

Procedures

Study Sites. This study was developed to test different management practices on leafy spurge re-establishment following a long-term sheep grazing study near Mandan, North Dakota at two locations. The first location is owned by the North Dakota State Correctional Center (NDSCC) two miles southwest of Mandan in Morton County on Section 32, T139N, R81W. The second location is operated by the USDA-ARS Northern Great Plains Research Laboratory and three miles south of Mandan in Morton County on the north half of Section 9, T138N, R81W. The NDSCC location contains two replicate blocks and the USDA-ARS one replicate block. Each replicate consists of a 20-acre block subdivided into four 5-acre plots. The treatments were incorporated using a randomized complete block design in each 5-acre plot. Each of the four 5-acre plots represented one of four treatments from a previous study (see Previous Study section for description). Barker and Whitman (1989) classified the vegetation as northern mixed grass prairie comprised of wheatgrass-grama-needlegrass (*Elymus, Bouteloua, Heterostipa*; Shiftlet, 1994).

Previous Study. The current study was designed to study leafy spurge stem density change following different sheep and cattle grazing treatments using a maintenance type program. The study locations were part of a long-term research project studying three different grazing treatments on leafy spurge control, plant community impacts, and livestock performance. The grazing treatments included cattle only (**CO**), sheep only (**SO**) and cattle and sheep (**CS**); with a non-use treatment as the control (**Ctrl**; Schauer et al., 2006). Grazing occurred from approximately June 1 through October 1 each year or until 50 to 60% disappearance. Leafy spurge stem densities in the **SO** and **CS** grazing treatments were reduced by 99% from the beginning of the trial (1996) to the end (2006) compared to the **Ctrl**. The **SO** treatment required four years and **CS** five years to achieve 99% reduction in leafy spurge. As a note, flea beetles (*Apthona* species) infested all three replicates in 2001, resulting in leafy spurge stem density reduction on the **CO** and **Ctrl** that had not occurred in the first five years, with leafy spurge stem densities reduced by 91% and 89% on the **CO** and **Ctrl**; respectively.

Current Study. The current maintenance study focuses on integrated pest management using grazing, herbicides, and leafy spurge flea beetles. Based on the results from the previous trial, sheep were selected as the control, since they had effectively decreased leafy spurge in a short period and maintained control throughout the duration of the trial. The cattle only treatment was the least effective method of control in the previous trial. Therefore, additional research using a combination of treatments is necessary to determine potential methods of controlling leafy spurge in conjunction with cattle only grazing.

In May 2006, Admire Pro, an insecticide, was applied at 8 ounces/acre to remove spurge beetles from each of the sites. Core samples were taken in July 2006 to confirm the insecticide treatment was successful. All three replicate sites used in the current trial contained two grazing treatments in the four 5-acre pastures and included one sheep only (**SO**) pasture (considered the control and was previously the **SO** pasture) and three cattle only (**CO**) pastures. The three **CO** pastures comprised the previous study's **CO**, **CS**, and **Ctrl** pastures and labeled as such.

Stocking rates were 1.6 AUM/acre for cattle on the **CO**, **CS**, and **Ctrl** treatments, and 1.4 AUM/acre for **SO**. Although stocking rates were design to be the same between treatments, animal equivalent conversions created slightly different rates. Ten ewes were placed on the **SO** treatment on 20 May and removed by 9 October. Two steers were placed on the cattle only **CO, CS**, and **Ctrl** treatments 1 June and removed by 1 October. The target grazing disappearance rate is 50 to 60% of grass and grass-like species. Grazing occurred at all sites in 2007, 2008, and 2009. Sheep depredation by coyotes occurred at the second NDSCC site in June 2009. Sheep were not replaced at that site due to losses.

Each of the **CO**, **CS**, and **CTRL** 5-acre pastures was further divided into 32 - 12 ft by 50 ft sections (192 ft by 100 ft area). The **SO** contained a total eight 12 ft by 50 ft sections.

Eight treatments were studied and included a non-use control (**NU**); insect only **(I)**; 2.4-D only **(2,4D)**; Plateau only **(P)**; 2,4-D and Tordon **(2,4DT)**; 2,4-D and insect **(2,4DI)**; 2,4-D, Tordon, and insect **(2,4DTI)**; and Plateau and insect **(PI)**. The **CO, CS,** and **Ctrl** pastures contained four replicates the eight treatments, while the **SO** one replicate.

Leafy spurge stem density was determined for each treatment prior to livestock grazing each season. Stem counts were obtained by averaging five 2.7 ft^2 quadrats from each treatment replicate.

Tordon (picloram), Plateau (impazapic), and 2,4-D were applied to the treatment plots in 2008. The 2,4-D treatment was applied at 2 quarts/acre in mid-July and the 2,4-D and Tordon treatment applied at rates of 1 quart and 1 pint/acre; respectively, in mid-July. Plateau was applied at the rate of 7 ounces/acre in late September. Herbicide was applied by a hand sprayer. Flea beetles reinvaded all three sites by 2007 and not manually applied with the combination treatments in 2008.

Treatment effect for leafy spurge stem density between treatments was analyzed using SAS (SAS Inst. Inc., Cary, NY) GLM statistical model to compare between treatments and across years. A SAS analysis using a split plot design was used to compare year, block, and grazing treatment affects. When significant differences occurred ($P \leq 0.05$), Tukey's Honesty Significant Difference was performed to separate differences.

Results

Insects were removed as a treatment from the study due to reinfestation of flea beetles at all three sites. The study was modified to four treatments (three herbicides and one control) with a eight replication pasture in **CO, CS**, and **Ctrl** and two replicated within the **SO** pasture.

Significant changes ($P \leq 0.05$) in leafy spurge stems density occurred between treatments in each of the three cattle grazing treatments (**CO, CS,** and **Ctrl**) in 2009 (Figure 1). The **P** treatment was more effective when compared to the **NU** and **2,4DT** treatments in the **CO** pasture. The **P** treatment reduced ($P \leq 0.05$) leafy spurge density 56.6% and 38.7% greater than the **NU** and **2,4DT**; respectively. Within the **CS** treatments, **P** reduced ($P \leq 0.05$) leafy spurge density by 56.5% and 60.7% compared to the **NU** and **2,4D**; respectively. Leafy spurge density was also best controlled by **P** in the **Ctrl** pasture. The **P** treatment reduced ($P < 0.05$) leafy spurge by 51.5% and 37.2% compared to **2,4D** and **NU**; respectively.

The only other herbicide to show difference in leafy spurge density changes was **2,4D** in the **CO** pasture. Leafy spurge was reduced by 46.2% by **2,4D** compared to the **NU** (Figure 1). Leafy spurge stem density was at 99% control in the **SO** pasture, similar to pre-levels found in the previous study.

Levels of leafy spurge varied between the grazing treatments pastures. Pre-treatment levels of spurge in 2007 were 29.4 times greater in the **Ctrl**, 5.2 times greater in the **CS**, and 29.4 times greater in the **CO** compared to the **SO**. Leafy spurge presence in **SO** was maintained at levels below 1.3%. Comparisons of grazing treatments within 2008 showed **CO** had a higher level ($P = 0.01$) of leafy spurge compared to the **SO** treatments (Figure 1). A difference in leafy spurge stem density levels was found between **Ctrl** and **SO** ($P = 0.007$), **CO** and **CS** ($P = 0.037$), and **CO** and **SO** ($P = 0.047$) in 2009.

Discussion

Plateau at a rate of 7 oz/acre applied in late summer consistently reduced leafy spurge in all three of cattle grazing pastures. Plateau targets the root system and is drawn down into the plant's roots when fall applied (Markle and Lym, 2001). At this time of the growing season in North Dakota, plants draw down available nutrients to aid in over wintering. Markle and Lym (2001) found Imazapic (Plateau) alone reduced leafy spurge by 75% nine months after the first application (mid September), with a decrease in effectiveness to 33% twelve months after the first treatment. The results of this study showed an overall effectiveness rate nine months after the first application of 50.1% compared to **NU** (Figure 2). The level of control was not as high in our study, which may be attributed to the higher number of replications. The Markle and Lym study had four field replicates for each of their herbicide treatments. This study used three blocks with 24 replications contained in each of the blocks among the **CO, CS,** and **Ctrl** pastures, totaling 72 replications for each of the herbicide treatments. The higher number of replications may show a truer level of herbicide effectiveness in field settings.

The 2,4-D treatment applied at 2 qt/ac during the flower growth stage reduced leafy spurge only in the **CO** grazing treatment (Figure 2). Leafy spurge levels increased in the nine months following the first treatment in the **Ctrl** and **CS** treatments. Averaged across all three grazing treatments, a 2.4% decrease in leafy spurge stem density occurred. Lym and Messersmith (2006) found a 20% reduction in leafy spurge using 2,4-D applied at a rate of 1 qt/ac and a reapplication of 1pt/acre twelve months following the initial application. Their timing for herbicide application was June when flowering of leafy spurge was at maximum. Our application timing was in mid-July during a later period of flowering. The lower control levels of 2,4-D compared to Plateau may reflect a lower 2,4-D control due to application time (Lym, 2000).

The 2,4-D plus Tordon treatment reduced leafy spurge from

8.2% to 29.2% with an average reduction between all grazing treatments 17.9% (Figure 2). Lym and Messersmith (2006) found leafy spurge reduction rates of 50% 12 months following the first application. Their application rate was also 1 qt/ac plus 1 pt/acre of 2,4-D and Tordon; respectively. Their application of the 2,4-D plus Tordon mix occurred in June, which they determined was the optimal treatment timing for this herbicide combination. Our application of the 2,4-D plus Tordon was mid-July. Earlier spraying of herbicides such as 2,4-D and Tordon appear to weaken leafy spurge at a time when a large portion of its nutrients and energy are used for seed production and plant growth (Lym and Messersmith, 1985). Later in the season, when leafy spurge has attained maturity, it is less vulnerable to these herbicide applications.

Flea beetles may have aided in controlling leafy spurge to a certain extent. Flea beetle presence was noted in 2007, 2008, and 2009; however, counts were not collected to determine beetle density. As noted by Lym and Nelson (2000) effective flea beetle densities range from 4-22.5 beetles/yd^2, and once introduced, individuals may take 3-5 years to control leafy spurge. Once established, the combination of flea beetles and herbicides may compliment each by weakening both the reproductive cycle and root systems of leafy spurge.

The previous study's grazing treatments appear to have an ongoing impact on leafy spurge levels. The 2007 levels of leafy spurge were lower in the **CS** grazing treatment compared to the **CO** and **Ctrl.** Stem count comparisons in 2008 showed a continued trend with higher levels of leafy spurge in **CO** treatments compared to **SO**. Leafy spurge counts in 2009 (Figure 1) continue the trend of higher levels of spurge in the **CO** treatments compared to the **SO** and lower levels of leafy spurge within the **CS** pastures compared to the **CO** and **Ctrl** treatments. In the previous study the **CO** treatment was least responsive to leafy spurge control by grazing (Schauer et al. 2006), while the **CS** treatment was second in effectively controlling leafy spurge. The **SO** pastures have consistently shown very low spurge numbers in both studies, confirming sheep are an effective method to control leafy spurge and maintain infestations.

Additional research is required to determine if herbicides will control leafy spurge within the cattle grazing treatments at levels comparable to sheep grazing.

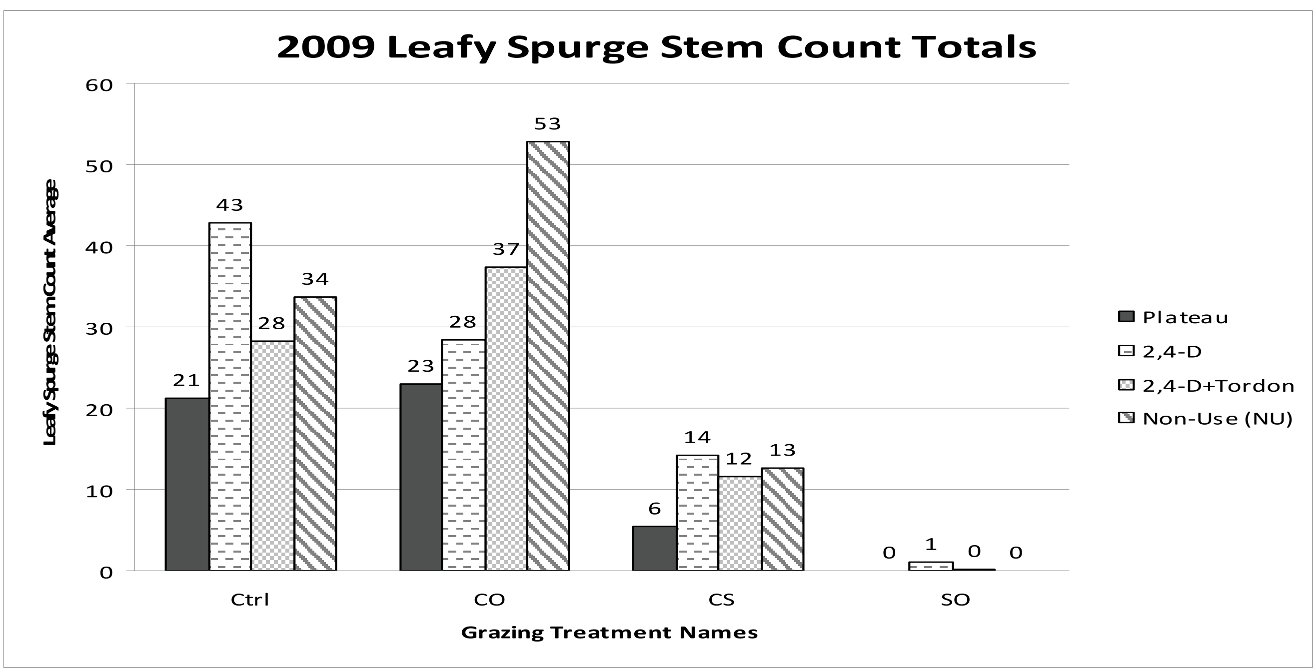

Figure 1. Average leafy spurge stem count within the treatments for 2009. Averages based on the total of five 2.7 ft^2 quadrats per herbicide treatment. **CO**, **CS**, and **Ctrl** are the three cattle only treatments for the current study with two steers per 5 acre pasture. The **SO** treatment has ten ewes per pasture and is the control for the study. **SO** (sheep only) shows the best overall control of leafy spurge.

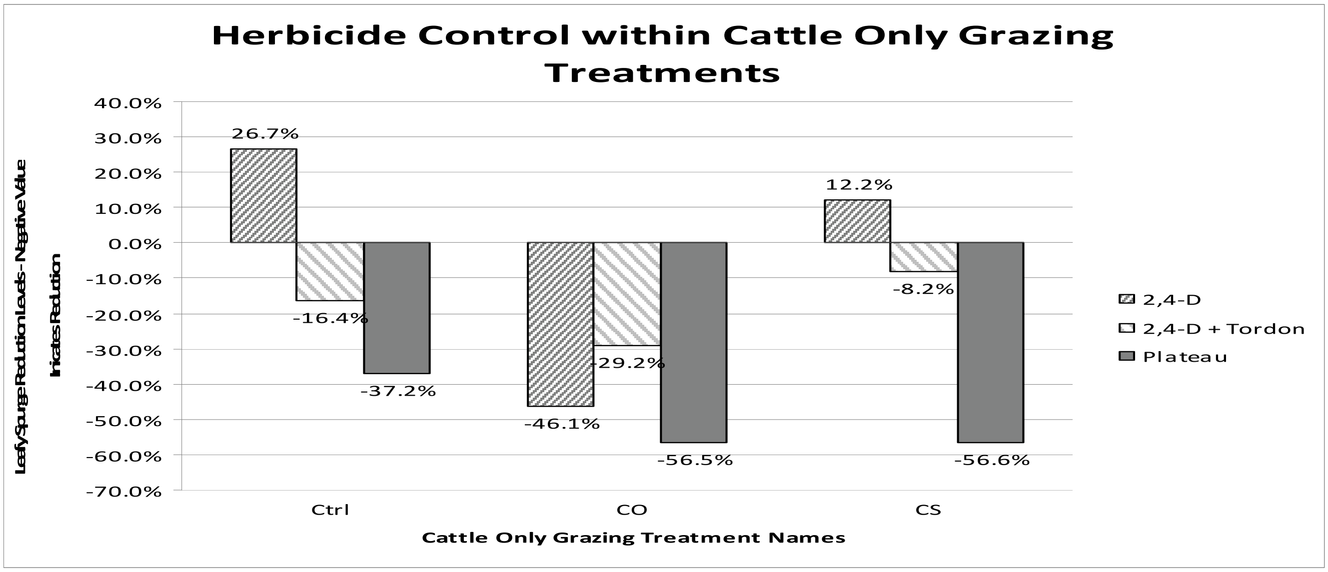

Figure 2. Effectiveness of herbicides nine months follwing the first application. Negative values indicate a reduction in leafy spurge. The three cattle only treatments are shown above as **Ctnl**, **CO**, and **CS**. Overall herbicide control was most effective within the **CO** treatments.

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