EFFECTIVENESS OF THE PRE-EMERGENT HERBICIDE INDAZIFLAM ON THE RESTORATION OF CHEATGRASS (BROMUS TECTORUM L.) INFESTED RANGELANDS IN MONTANA

by

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ABSTRACT

Cheatgrass (*Bromus tectorum* L.) is an invasive annual grass that was introduced to North America in the 1850s and is very abundant over 210,000 km^2 in the western United States and is found in every Montana county. Cheatgrass encroachment negatively effects native vegetation in rangelands and results in losses of forage for livestock and wildlife, and its management is difficult. Therefore, the objective of this study was to determine if the use of indaziflam (Esplanade 200SC®) is an effective way to restore cheatgrass infested rangelands in Montana by decreasing cheatgrass abundance and increasing perennial grass abundance. The characteristics of indaziflam may provide an opportunity for rangeland managers to manage cheatgrass successfully. On ranches near Hall and Big Timber, Montana, I used a completely random design to compare vegetation in indaziflam treated plots and non-treated plots. Plots were sprayed in August 2018 with indaziflam using a CO_2 powered handheld boom sprayer at a rate of 350 g/ha. Canopy cover and biomass of cheatgrass was reduced in the indaziflam treated plots at both sites. Canopy cover was 32.7% and 50.5% in non-treated plots and 0.55% and 0.80% in indaziflam-treated plots, cheatgrass biomass was reduced from 53.4 g/m^2 and 82.2 g/m^2 to 1.67 g/m^2 and 2.8 g/m^2. Perennial grasses responded to indaziflam treatments by producing more biomass, 204 g/m^2 and 113.4 g/m^2 in indaziflam treated plots compared to 74.2 g/m^2 and 68.04 g/m^2 in non-treated plots. Canopy cover in indaziflam treated plots was not different compared to non-treated plots. Annual forb canopy cover and biomass was also reduced in the treated plots and were nearly absent following indaziflam applications. Perennial forb abundance was not different between plots that had been treated and the non-treated plots. Indaziflam effectively controlled cheatgrass at both sites. Increases in forage production indicate perennial grasses were more vigorous following the reduction of cheatgrass. Livestock producers would expect an increase in animal units per month (AUMs)/acre on rangelands treated with indaziflam, but grazing management and the cost of herbicide application indicate more long-term research is needed to determine if this would be an economically viable option for land managers.

CHAPTER ONE

INTRODUCTION

Cheatgrass (*Bromus tectorum* L.) is an annual invasive grass species that persists throughout the US (Mack 1981). It is very abundant over 210,000 km^2 in the western US (Bradley et al. 2018). Cheatgrass has overtaken rangelands that were previously covered by perennial species and areas that have been influenced by grazing and disturbance (Tueller 1989; Knapp 1996).

The invasion of cheatgrass into Montana's native rangelands has ecological and economic implications. Rangelands that become dominated by annual grass species produce less forage for livestock and wildlife (Young et al. 1987) and the forage base fluctuates greatly year to year (Murray et al. 1978). They also alter fire regimes (Whisenant 1990) and provide less soil organic matter than perennial species which can lead to more erosion (Norton et al. 2004).

Cheatgrass Origin and Distribution

Cheatgrass is native to the Mediterranean area of Europe and Asia. Cheatgrass was reported in New York and Pennsylvania in 1861 (Klemmedson and Smith 1964). The initial introduction has been linked to contaminated seed, contaminated ship ballast, and intentional seedings (Mack 1981; Novak and Mack 2001). Cheatgrass appeared in the western US in the 1880s and was reported in Washington, Utah, and Wyoming by 1900 (Klemmedson and Smith 1964). Encroachment into the western states was aided by overgrazing in open ranges in the 1850s and when homesteaders began farming following gold and silver mining strikes (Mack 1981). Both agricultural activities disturbed soils and reduced competitiveness of native plants. It is now found throughout the US (Figure 1) and has encroached into native rangelands and competes with perennial plant communities. The first report of cheatgrass in Montana was in 1898, and it had been reported in every Montana county by 1980 (Rice 2008).

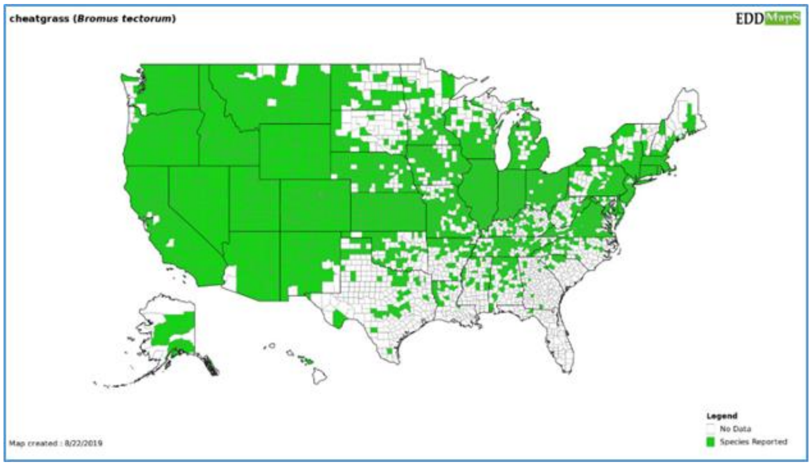

Figure 1: Map of reported cheatgrass distribution in the United States. Image provided by EDDMapS, 2019

Cheatgrass Biology

Cheatgrass is a winter annual that germinates in the fall, overwinters as a seedling, and resumes growth the following spring. The roots of cheatgrass will grow at cooler temperatures when compared to perennial grasses (Aguirre and Johnson 1991). This earlier root elongation allows cheatgrass access to moisture and nutrients in the soil before other cool-season species. Its fibrous root system captures moisture in the top 0.5 m of the soil profile (Cline et al. 1977). Cheatgrass's shallow root system gives it a competitive advantage for moisture and nutrients compared to slower establishing native species especially in disturbed areas leading to the failure of revegetating native rangelands (Monsen 1994; Rafferty and Young 2002).

Cheatgrass seed production can vary depending on growing conditions. Each plant may produce 5,000-15,000 seeds/m^2 when competition is low (Young et al. 1987; Young and Evans 1975). Cheatgrass seed is very viable; Hull and Hansen (1974) found that seed collected at maturity can reach 99% germination, and seed that overwintered in the panicle averaged 96% germination. Seeds from cheatgrass will germinate when there is adequate moisture but only remain viable between 2 to 3 years in the soil (Young et al. 1987; Pyke and Novak 1994).

Cheatgrass Impacts on Native Rangeland

Impacts associated with cheatgrass include increased wildfire risk, degradation of wildlife habitat, loss of livestock forage, and increased soil erosion (Whisenant 1990; Ostoja and Schupp 2009; Young and Clements 2007; Norton et al. 2004). As rangelands become more dominated by cheatgrass they are more susceptible to fire and erosion. Cheatgrass is a very fine fuel and areas dominated by annual grasses can alter fire regimes where they will occur at a higher frequency. Cheatgrass creates a continuous fine fuel load that carries fires easily, in contrast to perennial grasses which are spaced further apart and do not create the same fuel continuity, thus leading to a larger and more frequent fires (Whisenant 1990). Each successive fire enhances the ability of the cheatgrass to invade further across the landscape and replace perennial plant species (Billings 1994). Increased fire frequency can also alter wildlife habitat. Cheatgrass monocultures lead to a less diverse small mammal population as well (Ostoja and Schupp 2009). This loss of small mammal abundance and diversity can also adversely affect primary producers and predators that rely on small rodents as a food source (Freeman et al. 2014).

Cheatgrass is very competitive for soil water and nutrients and will reduce growth rates of perennial grasses. On native pastures that are grazed by livestock, cheatgrass competition with perennials can reduce both the quantity and quality of forage available. Cheatgrass grows quickly in the spring but matures much earlier than perennials. The grazing window of green cheatgrass is very short and livestock will avoid it at maturity. The awns on seed heads can lead to lump jaw and injuries to the eyes of livestock. This leads to a low-quality forage source during most of the grazing season for livestock producers (Murray et al. 1978) and production is highly variable year to year (Young and Clements 2007), making planning grazing strategies difficult. The competitiveness of cheatgrass can lead to the failure of perennial grass establishment (Hull 1963; Mazzola et al. 2008) making rangeland seeding a difficult restoration option.

Cheatgrass can have a negative impact on soil morphology. Cheatgrass litter and roots are much finer than perennial plant species (Klemmedson and Smith 1964; Hull 1963) and competition from cheatgrass will reduce perennial root length and density (Graciela Melgoza and Nowak 1991). When a plant community is primarily cheatgrass, there is an increased likelihood for erosion. Cheatgrass also more quickly cycles organic matter in the soil which depletes overall soil organic matter (Norton et al. 2004). This leaves the soil depleted of nutrients and can lower plant community diversity (Wilson et al. 1966).

Current Cheatgrass Management

The abundance of cheatgrass in the western states has led to multiple strategies and resources to control cheatgrass and prevent new infestations. The proper management method is dependent on the site, land use, and existing plant community (DiTomaso et al. 2010).

Mechanical control of cheatgrass is limited on large rangeland landscapes. Burying the existing seed bank under 5 to 15 cm of soil using a plow or disc can reduce cheatgrass densities (Clements et al. 2017) and also can kill the current year's growth of cheatgrass. However, revegetation and establishment of desirable species is needed so that the disturbed soil will not be re-infested with undesirable plants. On a small scale, cheatgrass can be easily pulled by hand. Its shallow annual root system allows for easy removal of the plant. This method does not control the seed bank, though, so plants need to be pulled repeatedly over multiple years to deplete the existing seed bank.

Biological control for cheatgrass is limited to targeted grazing with livestock and can be successful. Although livestock grazing has been considered a factor for the encroachment and spread of cheatgrass (Mack 1981), livestock has also been used as a control method (Vallentine and Stevens 1994). In early spring cheatgrass is very nutritious to grazing animals but loses total protein and becomes less palatable as the plant matures (Cook and Harris 1952). Defoliation of cheatgrass during early phenological stages can greatly reduce seed production (Hempy-Mayer and Pyke 2008), and intensive early livestock grazing can reduce plant height. This type of grazing management can lower the competitiveness on native rangelands (Stewart and Hull 1949). Grazing can be implemented with other strategies such as seeding and potentially chemical control (Lehnhoff et al. 2019).

A rhizobacterium *Pseudomonas fluoresc*ens D7, that inhibits cheatgrass root elongation negatively affected cheatgrass plants in a climate-controlled bench study

(Kennedy et al. 2001). *Pseudomonas fluorescens* is a naturally occurring bacterium in the soil that is active at cooler temperatures and has only negatively affected a few non-target species (Kennedy et al. 2001). However, field experiments have suggested that *P. fluorescens* alone was not effective at controlling cheatgrass (Reinhart et al. 2019).

Herbicides are often used to control invasive plants because they are cost effective and require less labor than other control methods (Radosevich et al. 2007). Herbicide options for grass species in rangelands are limited to a few modes of action, and those used for cheatgrass control in Montana are limited and vary in their effectiveness. However, selective herbicides have been used in perennial grass stands to target annual grasses and improve perennial grass yields (Currie et al. 1987).

Herbicide active ingredients that are recommended for cheatgrass control include glyphosate, imazapic, propoxycarbazone-sodium, rimsulfuron, and sulfometuron methyl + chlorsulfuron. All of these herbicides, with the exception of glyphosate, have the same mode of action. Imazapic, propoxycarbazone-sodium, rimsulfuron, and sulfometuron methyl + chlorsulfuron s are acetolacetate synthase (ALS) inhibitors, and glyphosate is an aromatic amino acid inhibitor that targets EPSP synthase (Menalled et al. 2017). Glyphosate is one of the most widely used chemicals in the US (Benbrook 2016). It is a non-selective herbicide and can be used to effectively control cheatgrass by applying it in early spring before seed production. This controls the current year’s growth but does not reduce the existing seed bank. Four to five years of repeated glyphosate applications have been shown to deplete cheatgrass seedbanks enough to increase perennial grass biomass (Sebastian et al. 2017). Since glyphosate is non-selective, to avoid non-target injury glyphosate must be applied before perennial plants break dormancy.

The herbicide imazapic, sold as Plateau® or Panoramic 2SL®, has also shown good control of cheatgrass. When applied early post-emergent (cheatgrass at 1 to 2 leaf growth stage), control between 70-95% can be achieved in Montana (Mangold et al. 2013). It is less effective pre-emergent and late post-emergent. However, applications of imazapic have resulted in the decline of native forbs and grasses (Baker et al. 2009; Wallace and Prather 2016). Rimusulfuron, sold as Matrix®, is a pre-emergent herbicide used to control cheatgrass. Applications of rimsulfuron alone have mixed results in the level of control of cheatgrass. In some cases, seedling emergence and biomass was reduced (Hirsch et al. 2012), and alternatively single applications have resulted in a reduction in canopy cover but not cheatgrass biomass (Lehnhoff et al. 2019). Long-term cheatgrass control with imazapic and rimsulfuron is inconsistent (Kyser et al. 2012), and applications must be timed effectively. The short-term control from these herbicides has not been an effective way to increase native plant abundance (Elsroad and Rudd 2011; Lehnhoff et al. 2019).

Propoxycarbazone-sodium and sulfosulfuron, sold as Canter® and Outrider®, are not as widely used to control cheatgrass, and peer reviewed research is limited. Studies of propoxycarbazone-sodium and sulfosulfuron used as pre-emergent or early post-emergent herbicides on another annual invasive grass, ventenata (*Ventenata dubia* (Leers) Coss.), showed initial control of greater than 90% for sulfosulfuron and between 58-88% for propoxycarbazone-sodium. However, the invasive grass increased the following season and there was perennial grass injury as well (Wallace and Prather 2016).

Indaziflam, a New Herbicide for Cheatgrass

Developed as a bareground herbicide, indaziflam, sold as Esplanade 200SC®, is a pre-emergent herbicide that inhibits cellulose biosynthesis in seedlings (Brabham et al. 2014) offering an alternative mode of action for cheatgrass control. Indaziflam integrates into the soil profile following a precipitation event due to its high water solubility characteristics. Desorption of indaziflam is very low, so it may persist in the soil and shows very little mobility (Alonso et al. 2011). Indaziflam has been shown to provide multiple years of control for annual species (Sebastian et al. 2016) without impacting established perennial plant species (Clark et al. 2019). Sebastian et al. (2016) found that indaziflam provided 89-100% control of cheatgrass two years after treatment and 83-100% control three years after treatment. Reduced competition from cheatgrass and an increase in perennial plant cover following indaziflam applications can shift plant communities from being dominated by annual species to a rejuvenated perennial plant community (Sebastian et al. 2019).

Therefore, the objective of my study was to determine if indaziflam treatment is an effective way to restore cheatgrass infested rangelands in Montana by decreasing cheatgrass abundance and increasing perennial grass abundance. I hypothesized that indaziflam would result in a decrease in cheatgrass canopy cover and biomass compared to a non-treated control while increasing canopy cover and biomass of perennial grasses. Annual forb canopy cover and biomass would also be decreased with indaziflam, but perennial forb canopy cover and biomass would increase. The characteristics of indaziflam may provide an opportunity for rangeland managers to control cheatgrass successfully. Since indaziflam provides extended control of the cheatgrass seedbank

(Sebastian et al. 2016) and does not target established perennial species (Clark et al. 2019), it could be a tool to control invasive grasses and benefit perennial grasses on rangelands, which are critical for livestock production.

CHAPTER TWO

MATERIALS AND METHODS

Two cheatgrass infested sites in Montana were selected that had similar land use. Both sites are on active cattle ranches (Figure 2). Site 1 is in Sweet Grass County approximately 21 km north of Big Timber, Montana. Elevation at Site 1 is 1,500 m and the average annual precipitation is 41 cm. Soils are comprised of Yawdim-Rentsac-Cabbart complex that have clay loam properties (USDA NRCS Web Soil Survey, 2020). Commonly found plant species at this site include cheatgrass (*Bromus tectorum* L.), Kentucky bluegrass (*Poa pratensis* L.), western wheatgrass (*Pascopyrum smithii* Rydb.), smooth brome (*Bromus inermis* Leyss.)*,* field cudweed (*Filago arvensis* L.), *w*estern salsify (*Tragopogon dubius* Scop.), yellow alyssum (*Alyssum alyssoides* L.), common dandelion (*Taraxacum officinale* F.H. Wigg), curlycup gumweed (*Grindelia squarrosa* Pursh Dunal), and yellow sweetclover (*Melilotus officinalis* L.).

Site 2 is in Granite County approximately 11 km south of Hall, Montana. Elevation at Site 2 is 1,427 m and average annual precipitation is 32 cm. Soils are Danvers-Roy complex that are clay loam in the top soil horizon and cobbly loam deeper into the soil horizon (USDA NRCS Web Soil Survey, 2020). Commonly found plant species at this site include cheatgrass, Kentucky bluegrass, western wheatgrass, field cudweed, *w*estern salsify, yellow alyssum and common dandelion.

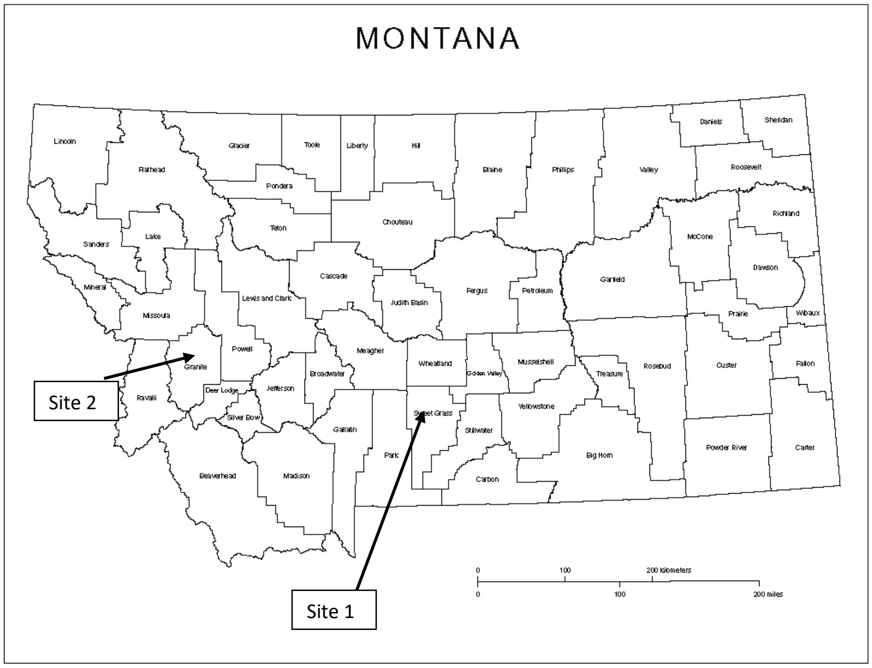

Figure 2: Map of study sites in Stillwater (Site 1) and Granite (Site 2) Counties (Map from Yellow Maps World Atlas from http://www.yellowmaps.com/map/montana-blank-map-117.htm)

Study Design

A completely randomized design was used to test two treatments, an herbicide application of indaziflam (Esplanade 200 SC®) and a non-treated control. Treated and non-treated plots were randomly assigned. Each treatment was replicated three times at each site. Plots measured 3 x 9 m and were placed side by side with a 0.5 m buffer between plots. The plots in Site 1 were located in a 63 hectare pasture and Site 2 plots were located in a 40 hectare pasture. Sites were selected on cooperating ranches due to the locations having similar levels of cheatgrass infestation and similar vegetation in the functional groups.

Indaziflam was applied at Site 1 on 22 August 2018 and on 23 August 2018 at Site 2. Indaziflam was applied with a CO_2 powered handheld boom sprayer with flat fan nozzles at a rate of 350 g/ha (5 oz/A). Weather conditions at Site 1 were clear during applications and overcast during applications at Site 2. Cheatgrass was pre-emergent at the time of the indaziflam applications. Livestock grazing was excluded from Site 1. At Site 2, grazing continued in the spring of 2019 during April and early May.

Vegetation Sampling

Pre-treatment sampling occurred 20 July 2018 at Site 1 and 25 July at Site 2. Three 20 x 50 cm Daubenmire frames (Daubenmire 1959) were randomly located in each replication of treated and non-treated plots. Canopy cover by plant species was collected. Biomass from each frame was clipped and bagged by functional group. Biomass samples were dried and weighed to the nearest 0.1 g. Functional groups were deemed to be cheatgrass, perennial grasses, perennial forbs, and annual grasses.

After applications of indaziflam in 2018, vegetation sampling was done again in the summer of 2019. Sampling occurred at Site 1 on 18 July 2019 and at Site 2 on 21 July 2019. Canopy cover was estimated with Daubenmire frames and biomass was clipped, dried, and weighed in the same fashion as in 2018.

Statistical Analysis

Data were analyzed using two sample t-tests at $\alpha = 0.05$ to compare means of canopy cover and biomass for indaziflam-treated plots and non-treated plots for each functional group. The result of Levene's test for homogeneity of variances indicated that the variances between means were equal and the data was not transformed. Analysis were performed using RStudio version 3.3.1, 2016. Error was reported as one standard deviation above and below the mean for all analyses.

CHAPTER THREE

RESULTS

T-tests were used to compare non-treated plots to the indaziflam-treated plots before herbicide applications and there were no statistically significant differences between the plots' biomass and canopy cover for cheatgrass and the functional groups at Site 1 (Table 1). At Site 2, there were no differences in canopy cover for cheatgrass and the functional groups (Table 1). At Site 2, biomass was different between cheatgrass plots ($P=0.0300$ at $\alpha = 0.05$, Table 1) 2018 biomass sampling resulted in a mean of 160.6 g/m^2 in the non-treated plots and a mean of 73.7 g/m^2 in indaziflam-treatment plots before herbicide application. Biomass t-tests for the remaining functional groups at Site 2 were not different (perennial grass P=0.0850, perennial forb P=0.9043, annual forb P=0.2999, Table 1).

Table 1: P-values at $\alpha = 0.05$ of cheatgrass and functional groups evaluating difference between non-treated plots and treatment plots before herbicide applications.

	Site 1		Site 2	
	Canopy Cover	Biomass	Canopy Cover	Biomass
Cheatgrass	0.2429	0.4828	0.0850	0.0300
Perennial Grass	0.8070	0.5492	0.5533	0.0850
Perennial Forb	0.1185	0.4396	0.6271	0.9043
Annual Forb	0.7703	0.1380	0.6451	0.2999

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Cheatgrass

Cheatgrass canopy cover (P= 0.0074 at Site 1 and P= 0.0196 at Site 2, Table 2), and biomass (P=0.0058 at Site 1 and P= 0.0254 at Site 2, Table 2) were reduced by the indaziflam treatment at both Site 1 and Site 2. At Site 1, cheatgrass canopy cover in the non-treated plots was 32.7 ± 4.8% and 0.55 ± 0.5% in the indaziflam-treated plots (Table 3). Biomass was 53.4 ± 6.6 g/m^2 in non-treated plots and 1.6 ± 3.3 g/m^2 in the indaziflam-treated plots (Table 4).

At Site 2 cheatgrass canopy cover in the non-treated plots was 50.5 ± 12.2% and 0.8 ± 0.8% in the indaziflam-treated plots (Table 3). Biomass in the non-treated plots was 82.2 ± 22.1 g/m^2 and was reduced to 2.8 ± 2.8 g/m^2 in the indaziflam-treated plots (Table 4).

Table 2: P-values at $\alpha = 0.05$ of cheatgrass and functional groups evaluating difference between non-treated plots and treatment plots after indaziflam herbicide applications, 11 months after treatment.

	Site 1		Site 2	
	Canopy Cover	Biomass	Canopy Cover	Biomass
Cheatgrass	0.0074	0.0058	0.0196	0.0254
Perennial Grass	0.1370	0.0046	0.0870	0.0254
Perennial Forb	0.5029	0.6328	0.6638	0.3910
Annual Forb	0.0919	0.1972	0.0877	0.5185

Perennial Grass

Perennial grass canopy cover was not different in the indaziflam-treated plots compared to the non-treated plots at Site 1 (P=0.1370, Table 2). Canopy cover in the indaziflam-treated plots was 26.9 ± 11.9% and 9.5 ± 3.8% in the non-treated plots (Table 3). However, perennial grass biomass at Site 1was different between indaziflam treated plots and non-treated (P=0.0046, Table 2). Biomass in the indaziflam-treated plots was 204 ± 3.3 g/m^2 and 74.2 ± 14.8 g/m^2 in the non-treated plots (Table 4).

At Site 2 perennial grass canopy cover was no different between indaziflam-treated and non-treated plots (P=0.087, Table 2). Canopy cover in indaziflam-treated plots was 33.7 ± 10.6% and 16.1 ± 5.9% (Table 3) in the non-treated plots. Biomass was different between indaziflam-treated plots and non-treated plots (P=0.0254, Table 2). Perennial grass biomass was 113.4 ± 14.1 g/m^2 in the indaziflam-treated plots and 68 ± 18.6 g/m^2 (Table 4) in the non-treated plots.

Table 3: Percent canopy cover (%) ± 1 standard deviation of functional groups in non-treated plots and plots sprayed with indaziflam 11 months after treatment (n=3). Different letters in parentheses following a mean indicate a difference in means between the two treatments and within a function group and within a site.

	Site 1		Site 2	
	non-treated	indaziflam	non- treated	indaziflam
Cheatgrass	32.7 ± 4.8 (a)	0.55 ± 0.5 (b)	50.5 ± 12.2 (a)	0.8 ± 0.8 (b)
Perennial Grass	9.5 ± 3.8 (a)	26.9 ± 11.9 (a)	16.1± 5.9 (a)	33.7 ± 10.6 (a)
Perennial Forb	3.8 ± 1.2 (a)	5.2 ± 2.7 (a)	1.3 ± 1.2 (a)	1.6 ± 0.8 (a)
Annual Forb	5.5 ± 3.1 (a)	0 (a)	1.7 ± 0.8 (a)	0.3 ± 0.5 (a)

Table 4: Biomass (g/m^2) ± 1 standard deviation of functional groups in non-treated plots and plots sprayed with indaziflam 11 months after treatment (n=3). Different letters in parentheses following a mean indicate a difference in means between the two treatments and within a function group and within a site.

	Site 1		Site 2	
	non-treated	indaziflam	non- treated	indaziflam
Cheatgrass	53.4 ± 6.6 (a)	1.67 ± 3.3 (b)	82.2 ± 22.1 (a)	2.8 ± 2.8 (b)
Perennial Grass	74.2 ± 14.8 (a)	204 ± 3.3 (b)	68.04 ± 18.6 (a)	113.4 ± 14.1 (b)
Perennial Forb	21.6 ± 10.6 (a)	30.2 ± 25.8 (a)	0.9 ± 1.6 (a)	2.8 ± 2.8 (a)
Annual Forb	12.5 ± 11.4 (a)	0 (a)	1.9 ± 1.6 (a)	0.9 ± 1.6 (a)

Perennial Forbs

Perennial forb canopy cover was not different between indaziflam-treated and non-treated plots at Site 1 (P=0.5029) and Site 2 (P=0.6638, Table 2). Canopy cover for perennial forbs at Site 1 was 5.2 ± 2.7% for indaziflam-treated plots and 3.8 ± 1.2% in non-treated plots (Table 3). At Site 2 canopy cover was 1.6 ± 0.8% in indaziflam-treated plots and 1.3 ± 1.2% in non-treated plots (Table 3).

Perennial forb biomass was not different between indaziflam-treated and non-treated plots at Site 1 (P=0.6328) and Site 2 (P=0.3910, Table 2). Biomass at Site 1 was 30.2 ± 25.8 g/m^2 in indaziflam-treated plots and 21.6 ± 10.6 g/m^2 in non-treated plots (Table 4). At Site 2 biomass was 2.8 ± 2.8 g/m^2 in indaziflam-treated plots and 0.9 ± 1.6 g/m^2 in non-treated plots (Table 4).

Annual Forbs

Treatment had no effect on annual forb abundance at Site1 (P=0.0919) and Site 2 (P=0.0877, Table 2). Canopy cover at Site 1 was 0% for indaziflam-treated plots and 5.5 ± 3.1% for non-treated plots (Table 4). At Site 2 canopy cover was 0.3 ± 0.5% for indaziflam-treated plots and 1.7 ± 0.8% for non-treated plots (Table 4).

Annual forb biomass was not different between indaziflam-treated and non-treated plots at Site 1 and Site 2 (P=0.1972 for Site 1 and P=0.5185 for Site 2, Table 2). At Site 1 there was 0 g/m^2 in indaziflam-treated plots and biomass in non-treated plots was 12.5 ± 11.4 g/m^2 (Table 3). At Site 2 annual forb biomass was 0.9 ± 1.6 g m^2 in indaziflam-treated plots and 1.9 ± 1.6 g/m^2 (Table 3) in non-treated plots.

CHAPTER FOUR

DISCUSSION

This study hypothesized that applications of indaziflam in rangelands would decrease canopy cover and biomass of cheatgrass while increasing canopy cover and biomass of perennial grasses thus restoring rangelands to being more productive for livestock grazing. At both study sites, indaziflam resulted in effective control of cheatgrass and lowered canopy cover to less than 1% at both sites. Cheatgrass biomass was also reduced to 1.67 g/m^2 and 2.83 g/m^2 at Site 1 and 2, respectively. Perennial grass response to reduced competition from cheatgrass was positive.

Although there was no difference in canopy cover between treated and non-treated plots at either site, biomass, i.e. forage production, increased substantially. For example, perennial grass biomass was nearly three times higher in treated plots compared to non-treated plots at Site 1. The existing plants would be more vigorous without the cheatgrass there to compete for resources and result in an increase in biomass. This was most evident at Site 1 where grazing was prevented. Site 2 perennial grasses also had a positive response to indaziflam but would have likely been higher if the plants had a full growing season of rest from grazing. Cattle grazing had occurred in the very early spring at Site 2 which shortened the recovery time by 6 weeks. Perennial grass biomass was 68.04 g/m^2 in non-treated plots compared to 113.4 g/m^2 in plots that had been sprayed with indaziflam, which was still nearly a doubling of biomass in response to spraying.

Annual forbs showed a negative response to the indaziflam treatments and were nearly totally absent from both Sites 1 and 2 after indaziflam applications. This is an expected outcome since annual forbs, like the annual grass cheatgrass, require seed germination to maintain a population. Perennial forbs did not respond to the indaziflam treatment. This is likely due to the perennial forb component in each site being very low overall. Therefore, increases in cover and biomass when cheatgrass was removed were minimal. Plant diversity at each site will likely consist of the perennial grasses and perennial forbs that existed before indaziflam treatments. Clark et al. (2019) showed that multiple years of cheatgrass control provided by indaziflam maintained the existing perennial species abundance.

My paper presents results from the first year after treatment with indaziflam. Additional years of monitoring will occur to determine long-term effects of indaziflam in terms of controlling cheatgrass and annual forbs and the resulting perennial vegetation's response. Long-term impacts need to be studied to refine management decisions. Other research suggests controlling the cheatgrass seedbank can provide long-term management of cheatgrass (Sebastian et al. 2017). Indaziflam has effectively controlled cheatgrass for multiple years after application (Sebastian et al. 2016) without a reduction in perennial abundance and richness (Clark et al. 2019).

Applying indaziflam at the recommended rate of 5 oz/A Esplanade 200SC (the rate applied in this study) costs $46.45/A for the herbicide alone. If commercially applied, the cost per acre will be significantly higher. An average custom application rate could cost $7.37/A putting the total expense of the application at $53.82/A. The benefit for livestock producers could be calculated in additional forage gained by an increase in perennial grass forage base. In 2019, the average grazing lease rate on an animal unit per month (AUM) was $24.50 (USDA NASS). At Site 1 the non-treated plots provided 1,444 lb of forage per acre and plots treated with indaziflam provided 2,096 lb of forage per acre. To find the economic gain offered to a cattle rancher who might treat cheatgrass with indaziflam, the difference in AUMs per acre can be used. A use rate of 25% would allow for a conservative grazing plan and adjust for forage that is trampled, bedded down on, covered by waste, or grazed by wildlife. Cow intake of 30 lb of dried forage per day for a 1,000 lb cow with a calf under three months is used to equal one animal unit for this calculation. With these considerations, the non-treated plot provides 0.4 AUMs/acre and the indaziflam-treated plot provides 0.6 AUMs/acre. A difference in 0.2 AUMs/acre equates to an increase of $4.90/acre in value based on the grazing lease rate of $24.50/AUM. This conservative calculation would see a return on investment 11 years after application. This economic analysis for Site 1 is very reliant on the assumptions of use and underscores the need to evaluate each case closely. For example, if a producer assumed that their take half leave half grazing plan would use 50% of the standing forage crop (Ritten et al. 2010), the return on investment would happen after only five and a half years. In addition, indaziflam would likely need to be re-applied after three years (Sebastian et al. 2016), thus extending the period needed to see a return on investment if the management of the land is not changed to prevent a reinvasion of cheatgrass.

Integrating this information into professional extension teaching will allow me to work with land managers and livestock producers who attempt to manage cheatgrass infested rangelands. Other future considerations managers will include in their decision making is if the site is suitable enough to have a positive response to justify the high cost of an indaziflam application. Managers should also understand the underlying reasons for the initial cheatgrass infestation. Thought should be put into determining if there can be an adequate change in management to avoid further infestations once indaziflam is no longer present in the soil.

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