

EFFECTIVENESS OF CHEMICAL AND MECHANICAL MANAGEMENT ON *GYPHOPHILA*
PANICULATA L. IN CONSERVATION RESERVE PROGRAM, RANGELAND, PASTURE, AND
HAYLAND ACRES

by
Inga Rae Hawbaker

A professional paper submitted in partial fulfillment
of the requirements for the degree

of

Master of Science

in

Land Resources and Environmental Sciences

MONTANA STATE UNIVERSITY
Bozeman, Montana

December 2023

©COPYRIGHT

by

Inga Rae Hawbaker

2023

All Rights Reserved

DEDICATION AND ACKNOWLEDGEMENTS

This work is dedicated to my husband, Charley, who has provided me with unwavering support and encouragement over the last four years. The sacrifices made throughout this journey were not mine alone – I can't thank him enough.

I would also like to dedicate this work to my parents, Jack and Marian Larson, who taught me at a young age that education means opportunity – and it is one of life's most valuable gifts. Their constant encouragement and genuine faith in my abilities pushed me when I needed it the most.

I would like to express my sincere appreciation to Dr. Tim Seipel for generously sharing his time and expertise for the analysis of my project data and the writing of this paper. I would also like to express my appreciation to Dr. Jane Mangold for generously sharing her time over the course of this project and for providing valuable feedback regarding the paper.

I would like to thank my colleagues and mentors, Shelley Mills, Bobbie Roos, and Connie Wittak for being the driving force behind this project – their knowledge, patience, and tenacity was vital for its completion. I would like to recognize and thank the wonderful, skilled people that worked alongside me, setting up the plots, applying treatments, and gathering data in the field: Jim Wixon, Stan French, Cindy Fouhy, and Adam Christy.

John & Laura (Kasseth) King have my utmost appreciation for sharing their piece of Daniels County with me; a special thank you to Laura, for helping me find an appropriate location to place the research plots. The project would not have come to fruition without her genuine interest and support.

Lastly, I would like to thank the faculty and staff of the Land Resources and Environmental Sciences Department for their commitment to providing a challenging and rewarding master's degree program.

This work was supported by the Montana Noxious Weed Trust Fund (NWTF) Grant Program [MDA Grant No. 2019-063].

TABLE OF CONTENTS

1. INTRODUCTION	7
Origin and Distribution	7
Biology	9
Habitat and Invasive Potential	14
Impacts	16
Current Management	17
2. MATERIALS AND METHODS	23
Site description	23
Experimental design	25
Vegetation sampling	27
Statistical analysis	27
3. RESULTS	29
Density of <i>Gypsophila paniculata</i>	29
Perennial grass response	31
4. DISCUSSION	33
Effects of herbicide treatments	33
Effects of mowing	34
Effects on perennial grass cover	36
REFERENCES CITED	38

LIST OF TABLES

Table	Page
1. Dominant species present at the study site in Daniels County, Montana.	25
2. Treatments applied to <i>Gypsophila paniculata</i> ; 10 treatments with a control (non-sprayed) was applied to G. paniculata; three different herbicides were applied in the fall, spring, and fall and spring.....	26
3. Analysis of variance (ANOVA) for a linear mixed effects model of <i>Gypsophila paniculata</i> relative density in response to herbicide treatment (Herbic); mowing treatment (Mow); over years (Year), and their 2- and 3-way interactions.	29

LIST OF FIGURES

Figure	Page
1. Map of reported <i>Gypsophila paniculata</i> distribution in North America.....	8
2. <i>Gypsophila paniculata</i> (a) flowers and capsules, (b) mature plant in hayfield, (c) flower buds breaking, (d) fruit and seed(s), (e) mature plant late in the season, and (f) broken plants caught in fence along roadside.....	12
3. <i>Gypsophila paniculata</i> (a) shoots in early spring, (b) numerous shoots produced by a single mature plant, (c) the caudex and top 14" of taproots from two fused mature plants..	13
4. <i>Gypsophila paniculata</i> infestation in Conservation Reserve Program field in Daniels County, Montana.	17
5. <i>Gypsophila paniculata</i> in a wheat field in Daniels County, Montana.....	18
6. Map of the study site in Daniels County, Montana.	23
7. Effects of herbicide treatments on mean density of <i>Gypsophila paniculata</i> per m ² over a three-year period with 95% confidence intervals.	30
8. Perennial grass cover over three years according to herbicide treatment.....	32

ABSTRACT

Gypsophila paniculata L., commonly known as baby's breath, is a highly adaptive, perennial plant introduced to North America for ornamental purposes as early as 1887. While still used extensively in the floral industry, *G. paniculata* has high reproductive and dispersal potential, is considered a naturalized garden escape, and is listed as a noxious weed in some states and Canadian provinces. The invasion of *G. paniculata* in rangeland, pasture, Conservation Reserve Program (CRP) acres, and haylands throughout northeastern Montana has adverse ecological and economic implications. Precipitation events and the increase in CRP acres are believed to have advanced the spread of *G. paniculata*. This study investigates herbicide and mowing options in perennial acres north of Peerless, Montana, near the Canadian-U.S. border, using a split plot randomized complete block design with three replicates. Three different herbicides applied in the fall, spring, or fall and spring, and a non-sprayed control were applied for a total of 10 treatments. The herbicides tested included imazethapyr (Pursuit®); dicamba (Opti-DGA™); and metsulfuron methyl (Omni® Brand MSM 60 DF). The split plot included non-mowed or mowed to simulate dryland haying operations utilized by producers in the region. Herbicide treatments containing the active ingredient metsulfuron methyl significantly reduced the density of *G. paniculata* at the end of the study, strongly indicating that active ingredient is more important than timing. Mowing had no effect on density of *G. paniculata* and did not interact with herbicide treatment. Perennial grass cover was not affected by herbicide treatment. Perennial grass cover did not differ among herbicide treatments, indicating that there was no collateral damage of grass associated with herbicide applications. Based on the results of this study, I recommend the spring application of metsulfuron methyl used in this study to reduce the density of *G. paniculata* in rangeland, pasture, CRP acres, and haylands. I do not recommend mowing or haying as standalone treatments for *G. paniculata*, as mowing does not affect the density of *G. paniculata*. Furthermore, if admissible for the site, mowing or haying operations should take place before the flowering stage to effectively inhibit seed production.

CHAPTER ONE

INTRODUCTION

Gypsophila paniculata L., commonly known as baby's breath, is a highly adaptive, invasive perennial plant that prefers coarse textured soils, allowing it to thrive across the semi-arid landscape of northeastern Montana. The invasion of *G. paniculata* has adverse ecological and economic implications for producers in the region (Beck et al., 2008; USGS). *Gypsophila paniculata* causes shifts in plant community composition, displaces desirable native and forage species, and disrupts ecosystem function (Baskett et al., 2011; Darwent & Coupland, 1966; Brusati, 2016). Originally introduced as an ornamental for the floral industry, *G. paniculata* is now considered a naturalized garden escape, and has invaded rangeland, pasture, Conservation Reserve Program (CRP), waste areas, and hayland hectares. In Daniels County, Montana, *G. paniculata* has invaded an estimated 2700 ha.

Origin and Distribution

Gypsophila paniculata originated in Eurasia and occurs from Eastern Europe across Central Asia to as far east as China (Pringle, 2005, as cited in Olmstead, 2019). *Gypsophila paniculata* was first introduced to North America in 1887 as a garden ornamental in Manitoba, Canada (Darwent & Coupland, 1966; Macoun, 1888). Escaped plants have been reported throughout the Canadian provinces and territories, but the largest infestations occur in the most southern portions of Saskatchewan, Alberta, and British Columbia (Darwent, 1975). *Gypsophila paniculata* has reportedly formed sizeable populations in eastern, central, and western regions of North America (Figure 1).

In the U.S., *G. paniculata* is listed as a B-list noxious weed in California and a Class C noxious weed in Washington (DiTomaso et al., 2013; Invasive.org, 2018; Olmstead, 2019).

Although *G. paniculata* is not listed as a state noxious weed in Montana, the species has been reported in 22 of 56 counties since 1934, and it has been listed as a county noxious weed in the following 14 counties: Blaine, Broadwater, Chouteau, Daniels, Deer Lodge, Flathead, Jefferson, Ravalli, Richland, Roosevelt, Sanders, Sheridan, Silver Bow, and Valley (Montana Department of Agriculture, 2020; Montana State University Extension, 2015).

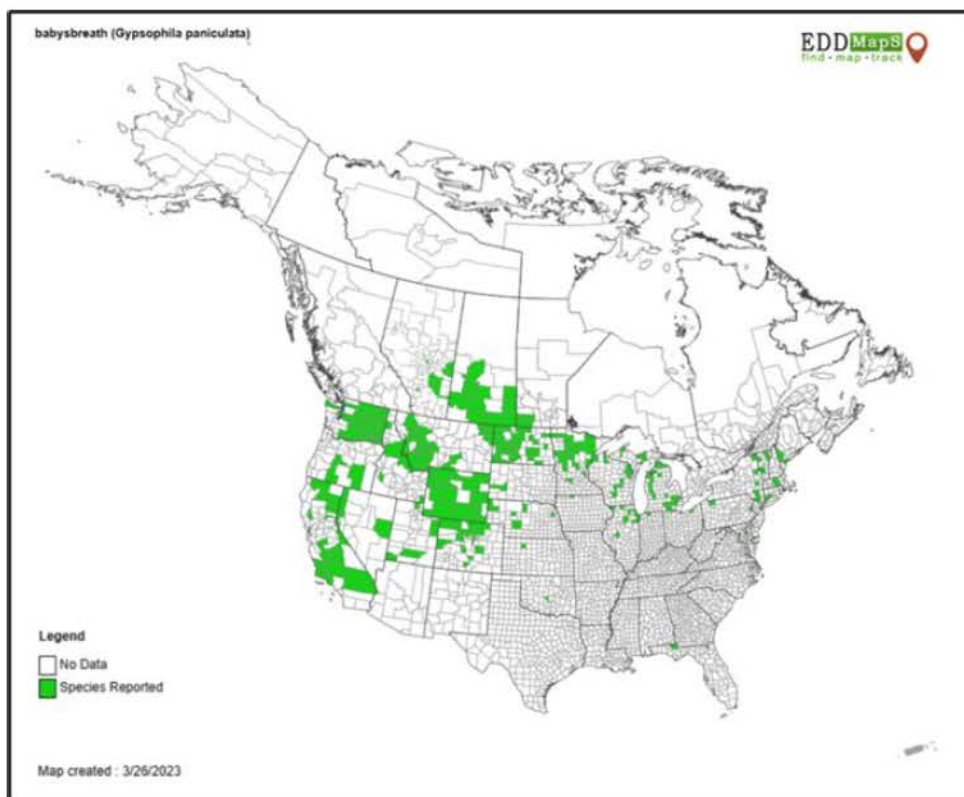


Figure 1: Map of reported *Gypsophila paniculata* distribution in North America. Image provided by EDDMapS, 2023.

Sharing their northern borders with Saskatchewan, landowners, and county agencies in northeastern Montana (Daniels, Sheridan, Richland, and Valley) have been trying to manage *G.*

paniculata infestations for the last two decades. Persons in Daniels County have been actively attempting to control *G. paniculata* for more than 20 years, where it has invaded about 2,700 ha of CRP, rangeland, pasture, and hayland. Conservation Reserve Program is a land conservation program administered by Farm Service Agency (FSA) that encourages eligible producers to remove environmentally sensitive land from crop production and convert it to valuable land cover (Daniels County Long Range Plan, 2019). Daniels County records indicate that *G. paniculata* has been present in the county for nearly 40 years. *Gypsophila paniculata* is believed to have been introduced to the area by homesteaders who brought the species with them for use as a hardy ornamental (Daniels County, Montana State University Extension Agent: Bobbie Roos (retired); Daniels County, Weed Coordinator: Connie Wittak, personal communication). *Gypsophila paniculata* seed can ripen in cut flower arrangements left in cemeteries and other locations, allowing the species to spread; the tumbling nature of mature *G. paniculata* facilitates dispersal (Washington State Noxious Weed, 2021). Invaded acres can be found adjacent or downwind of cemeteries and abandoned homesteads within Daniels County.

Biology

Gypsophila paniculata is a dicotyledonous, herbaceous perennial plant of the Caryophyllaceae family (Darwent & Coupland, 1966). Plants can reach approximately 1 m (3 ft) to 120 cm (4 ft) in height and width (DiTomaso et al., 2013; Olmstead, 2019). The leaves are linear-lanceolate, gradually tapering to a point, and are one-nerved; both sides are covered with dense, glandular hairs (Darwent, 1975; Lesica, 2022, p. 141). The leaves have an opposite arrangement, are 2.5 to 10 cm (1 to 4 in.) long, and are blue-green to grey-green (Saskatchewan Forage Council, 2018). The slender stems of the plant are similarly colored and are swollen at

the nodes (Darwent, 1975). The leaves on the top portion of the plant are smaller than those on the lower portion; as the plant develops flowers buds in early to mid-June, the plant foliage becomes sparse (Darwent & Coupland, 1966).

The inflorescence of *G. paniculata* is an open, panicle-like compound dichasium that is characterized by alternate branching and an abundance of small, 5-petaled flowers that range in color from white to purple, to grey bloom (Figure 2a.; Darwent & Coupland, 1966). Flowers measure 6 to 8 mm wide and pedicels measure 5 to 12 mm (DiTomaso, 2013; Darwent, 1975). Plants have a globe-like growth form and a cloud-like appearance (Figure 2b.; Montana State University Extension, 2015; Saskatchewan Forage Council, 2018). Under normal field conditions, *G. paniculata* does not become reproductive until the third year; observations indicate that intermediate aged plants do not flower every year (Darwent and Copeland, 1966). Flower buds break mid-June through August in northeastern Montana (Figure 2c.). Insects seem to affect pollination but cross and self-pollination are also likely (Darwent & Coupland, 1966; Saskatchewan Forage Council, 2018). *Gypsophila paniculata* increases the diversity and abundance of pollinators in an area along with an increase in arthropod predators resulting in an overall reduction in pollinator visits to native plants, impacting reproduction and overall native plant-pollinator interactions (Baskett et al., 2011; Emery & Doran, 2013).

The fruit of *G. paniculata* is a globose capsule comprised of 4 valves in which as many as 4 seeds develop. The fruit reaches maturity 4 to 5 weeks after the first buds open. Mature plants tend to have a multitude of flowers at various stages of development (Darwent & Coupland, 1966). Bean-shaped seeds are red-brown to black and 1 to 2 mm long (Figure 2d.; Olmstead, 2019; Darwent & Coupland, 1966; Darwent, 1975). As a polycarpic species, reproduction is

dependent on seed production, with a single mature plant annually producing nearly 14,000 seeds (Darwent, 1975). Under normal field conditions, wind is the most important agent of seed dispersal. Turning reddish-brown later in the season (mid-August through September), the hollow plant stems become dry and brittle; strong winds cause the entirety of the interwoven stems to break off at the base and tumble across the landscape (Figure 2e.). Although most seeds are dropped near the parent plant, seed that is still contained in capsules can be carried for distances of 1 km or greater. This species-specific behavior likens *G. paniculata* to tumbleweed, resulting in infestations commonly found along roadsides, ditches, and fence lines (Figure 2f.). Seeds may be viable in the soil for 1 to 2 years (DiTomaso et al., 2013).

Soil texture, air temperature, and seed depth greatly affect germination and seedling development. Although *G. paniculata* can grow in all soil textures, germination is significantly higher in sandy loam soil (Darwent & Coupland, 1966). Fine-textured soils are noted to retard root development in *G. paniculata* (Tucakov, 1958, as cited in Darwent, 1975). Seeds exhibit little to no dormancy, prompting high rates of germination when temperature and moisture conditions allow (Darwent & Coupland, 1966). Darwent and Coupland (1966) reported total maximum germination to be greatest at 20 °C with 97% germination; total emergence of seedlings was highest with 95% in sandy loam soil at a buried depth of 0.25 cm (0.10 in; Darwent & Coupland, 1966). Increased seeding depth resulted in reduced seedling emergence, and light availability did not affect germination (Darwent, 1975). Under normal field conditions, seeds germinate in May to early June.

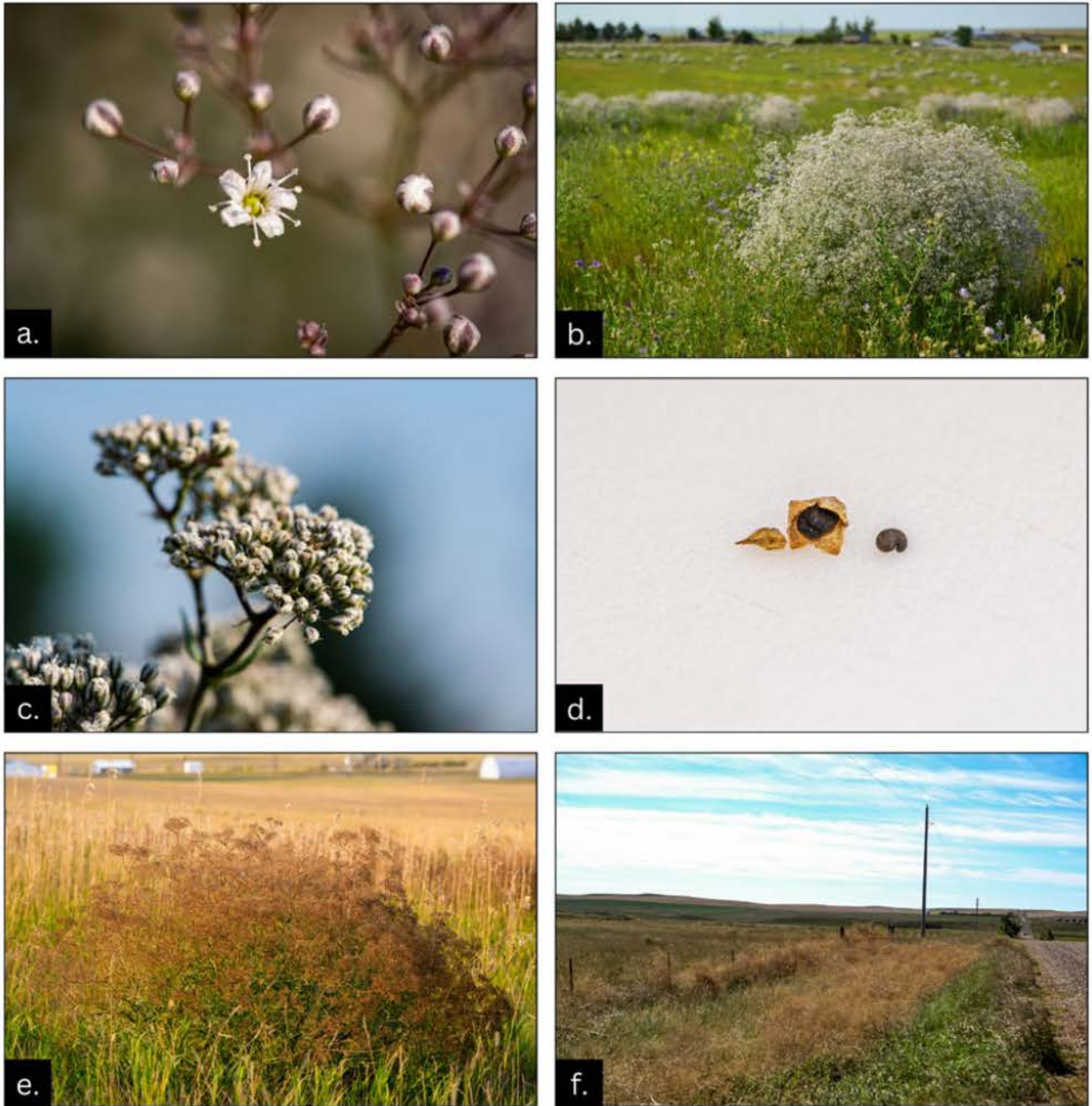


Figure 2: *Gypsophila paniculata* (a) flowers and capsules, (b) mature plant in hayfield, (c) flower buds breaking, (d) fruit and seed(s), (e) mature plant late in the season, and (f) broken plants caught in fence along roadside. Photos: Inga Hawbaker

Stems are ascending at the base and vary in number depending on plant maturity (Darwent & Coupland, 1966). Shoots usually appear above ground in late April, elongate rapidly, and develop lateral branches through late May (Figure 3a.; Darwent & Coupland, 1966). As plants mature, a thick, woody caudex, or crown, forms with the upper portion of the taproot, comprising of single to several stem bases from which shoots develop. Plants in their second year of growth usually produce a minimum of two shoots and often exceed 30 in mature plants (Figure 3b.; Darwent & Coupland, 1966). If a stem breaks off at the base before reaching maturity, the stem will resprout from the caudex. A strong variation in rainfall does not significantly affect the number of stems nor the height of mature *G. paniculata* plants (Darwent & Coupland, 1966). The growth of additional shoots is the only observed type of vegetative reproduction which results in the expanding diameter of the caudex; the caudex can reach 25 cm (10 in) in diameter (Darwent & Coupland, 1966).

A mature root system is characterized by a thick tap root below the caudex. In its entirety, the

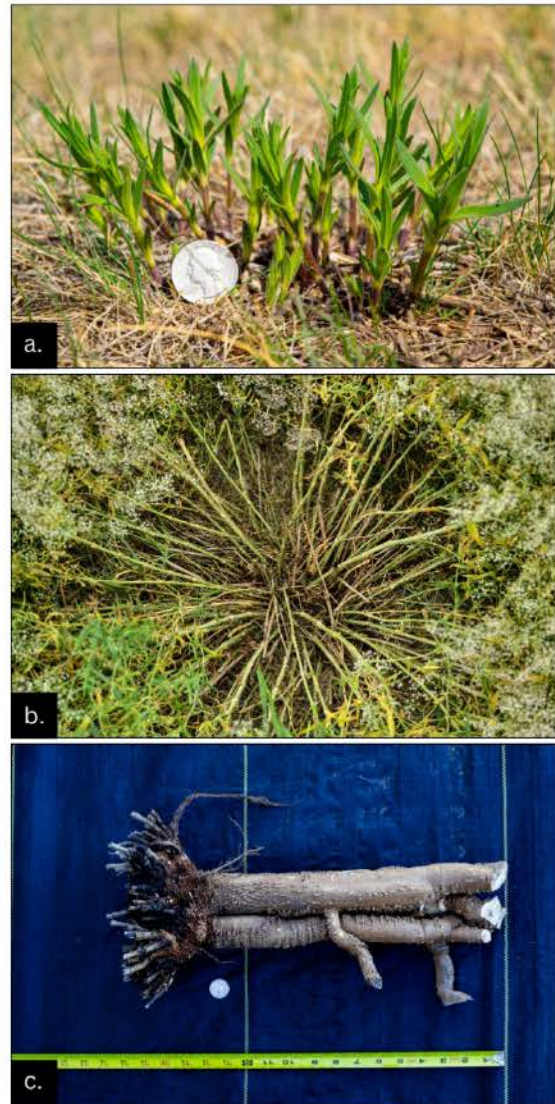


Figure 3: (a) *Gypsophila paniculata* shoots in early spring, (b) numerous shoots produced by a single mature plant, (c) the caudex and top 14" of taproots from two fused mature plants. Photos: Inga Hawbaker

rapid growing root system reaches approximately 4 meters (13 ft) in depth, allowing access to moisture and other resources at depths below other plants (Figure 3c.; Darwent & Coupland, 1966). A rapid rate of root penetration is exhibited by seedlings in the first two years of growth (Darwent & Coupland, 1967). The root system is especially advantageous during periods of drought, allowing *G. paniculata* to withstand considerable variation in both temperature and moisture (Darwent & Coupland, 1966; Olmstead, 2019). *Gypsophila paniculata* produces saponin in its roots; saponin is a highly glycosylated triterpenoid compound that has antimicrobial properties that may protect *G. paniculata* from disease and herbivory (Fons et al., 2003; Korkmaz & Ozcelik, 2013) Saponin from *G. paniculata* is allelopathic, influencing soil processes stemming from changes in soil microbial composition; this trait likely plays an indirect role in the displacement of interspecific forage and native plants (Fons et al., 2003; Wolfe & Klironomos, 2005).

Habitat and Invasive Potential

Gypsophila paniculata most aggressively colonizes areas with coarse textured soils and can withstand considerable variation in both moisture and temperature (Darwent, 1975). *Gypsophila paniculata* occurs in areas above 5.56 °C where mean annual precipitation ranges between 0.25 to 1 m and the mean number of degree days range between 832 and 2,220 (Darwent, 1975). The species' natural range in Eurasia is characterized by dry climates with stony, sandy, and often calcareous soil (Olmstead, 2019). *Gypsophila paniculata* does not tolerate acidic soils and is one of the few perennial ornamentals that is recommended for gardens located on permafrost (Nau, 1996, as cited in Alaska Natural Heritage; Darwent, 1975).

Although *G. paniculata* is highly adapted to semiarid climates, specific seasonal conditions can accelerate invasion. Daniels County records indicate that deep, heavy snow may increase the invasion potential of *G. paniculata*. High snowfall can facilitate invasion, with *G. paniculata* responding more strongly than native species (Blumenthal et al., 2008). High snow fall may favor *G. paniculata* by increasing the availability of deep relative to shallow soil moisture; the deep taproot of *G. paniculata* can access water not available to shallow rooted species (Blumenthal et al., 2008). *Gypsophila paniculata* is often not found until the species is in bloom, confirming that it has already been growing for at least two seasons. Throughout its vegetative stages, *G. paniculata* can easily be confused with alfalfa and other broadleaves.

Gypsophila paniculata has been studied extensively in the sandy soils of southern Saskatchewan, where invaded habitats include roadsides, railroad ballasts, vacant lots, and prairie slopes dominated by native grasses. Populations are also found in protected slopes and ravines where tumbling stems become trapped (Darwent et al., 1967). Escaped plants from home gardens are considered a likely route of introduction (Darwent, 1975; Olmstead, 2019). Serious infestations are confined to habitats where heavy, continual grazing, or regular, intense cultivation are not practiced (Darwent et al., 1967). The introduction and increase in CRP acres in Daniels County have led to an increase in invaded acres. While some CRP acres are grazed or hayed in accordance with contract requirements, thousands of acres throughout the county that were once used as farmland, now sit idle in CRP; as a result, *G. paniculata* invaded acres have exponentially increased. Absentee landowners present a challenge in Daniels County as their land is either enrolled in CRP or was enrolled in CRP and is now utilized for dryland forage production (USDA, 2019). The USDA Natural Resources Conservation Service (NRCS) Scobey

Field Office states that “We are getting into the third-generation land managers that have never nor have any desire to ever physically see the land in their control. This poses a larger issue with noxious weed control and land stewardship accountability” (USDA, 2019). Daniels County was ranked third in the state in 2014 for total number of acres enrolled in CRP (USDA, 2019).

Impacts

Gypsophila paniculata has been associated with shifts in plant community composition and structure and displacement of desirable native and forage species thus disrupting ecosystem function (Baskett et al., 2011; Darwent, & Coupland, 1966; Brusati, 2016). The presence of *G. paniculata* reduces protein of desirable grass hay species (Darwent et al., 1967; Emery & Doran, 2013; Alaska Natural Heritage Program, 2011). Native plants contain higher crude protein than *G. paniculata* but are outcompeted (Darwent et al., 1967). *Gypsophila paniculata* also reduces the nutrients and other resources available to native plants and co-occurring grass species (Robson 2004; Wisconsin DNR 2004, as cited in Alaska Natural Heritage Program; Darwent, 1975). Cattle tend not to graze on *G. paniculata* beyond its vegetative stage, so it is of little forage value (Darwent, 1975).

Gypsophila paniculata can negatively impact soil morphology. At maturity stems break off at the base and tumble in the wind, often resulting in off-site accumulation of plant litter. Plant litter is a major source of carbon; therefore, this behavior adversely affects soil cover and soil organic matter. Low soil cover increases the susceptibility of soil loss to wind and water erosion, impacting water holding capacity, cation exchange capacity, and other soil processes (DiTomaso et al., 2013; Chapin et al., 2012; Wolfe & Klironomos, 2005). Low soil cover also affects habitat quality for wildlife (Masters & Sheley, 2001). The phloem of *G. paniculata*

synthesize the allelopathic saponins (Hérolde & Henry, 2001). After synthesis, the compounds move throughout the plant and are present in root exudates, leachates, and litter, eventually affecting the chemical composition of soil organic matter (Henry et al., 1990; Korkmaz & Ozcelik, 2011; Weidenhamer and Callaway, 2009).



Figure 4: *Gypsophila paniculata* infestation in Conservation Reserve Program field in Daniels County, Montana. Photos: Inga Hawbaker

Current Management

Mechanical, cultural, and chemical control methods are utilized in managing *G. paniculata*, often delivering varied results. No form of biological control is available for the species (DiTomaso et al., 2013).

Mechanical. *Gypsophila paniculata* has been known to tolerate shallow and infrequent tillage; however, frequent, deep tillage in annual cropping systems tends to stave off establishment and survival of *G. paniculata* (Darwent et al., 1967; DiTomaso et al., 2013). Land comprised of sandy, coarse textured soils is usually tilled less intensively, and many producers in

northeastern Montana have adopted conservation tillage practices, therefore *G. paniculata* occasionally survives (Figure 5; Darwent et al., 1967). In perennial landscapes, deep cultivation controls *G. paniculata*, although it is critical that the plant is severed 15-30 cm (6-12 in) below the crown to decrease the likelihood of plant regeneration (DiTomaso et al., 2013). Although cultivation effectively controls *G. paniculata*, it negatively impacts the soil by causing compaction, reduced hydraulic conductivity, nutrient depletion, increased runoff, and erosion (Kasper et al., 2009; Seitz et al., 2019).



Figure 5: *Gypsophila paniculata* in a wheat field in Daniels County, Montana; field was in the second year of annual crop production.
Photo: Inga Hawbaker

On a small scale, hand pulling can control young plants but becomes difficult as plants mature. Severing the taproot below the caudex with a sharp tool will kill the plant (DiTomaso et al., 2013; Emery & Doran, 2013). Below the caudex, there are no buds to reestablish the plant if tilled or severed (Agriculture Knowledge Centre, 2023). Spot-burning has been advocated as an effective control method by flaming the crown of the plant; initial treatments are often sufficient

to remove most seedlings and young plants, but repeated treatments are necessary to stress resprouting plants (Agriculture Knowledge Centre, 2023; McGowan-Stinski, J. & Gostomski, T.; Emery & Doran, 2013).

Mowing is another mechanical control method and can be used to decrease annual seed set and to increase the availability of light and resources for desirable plant species (DiTomaso et al., 2013; Sheley et al., 2017). The timing of mowing is critical as research indicates that *G. paniculata* seeds continue to ripen when discarded in cut floral bouquets, suggesting mowing before flowering is required (Washington State Noxious Weed, 2021). While mowing depletes root reserves, reduce seed production, and the subsequent spread of the plant, it does not have a noticeable effect on the vigor or abundance of existing *G. paniculata* plants (DiTomaso et al., 2013; Agriculture Knowledge Centre, 2023; Sheley et al., 2017). Mowing can be most effective when used with other management methods (Flint, 2012). Integrating mowing with herbicides enhances control of perennial weeds (Sheley et al., 2017). Mowing or haying operations on invaded CRP acres are prohibited May 15 to July 15 to allow for the primary bird nesting period, thus limiting the feasibility of mowing as a management tool.

Cultural. Research suggests that heavy, continuous grazing can be used to control *G. paniculata* in perennial landscapes when plants are in vegetative stages, inhibiting plant vigor, seed production, and seedling development. Light or inconsistent grazing has little effect on plant growth or seedling development and has even increased populations (Darwent et al., 1967; DiTomaso et al., 2013). As the plant nears flowering, nutritional value, and palatability of the plant decrease; the shoots become brittle and fibrous and are no longer of vegetative value to livestock (Darwent et al., 1967).

Chemical. Herbicides with varying modes of action have been used to manage *G. paniculata* (DiTomaso, 2013). The foliage of *G. paniculata* becomes sparse as plants mature, reducing herbicide effectiveness as there are fewer leaves for droplets to adhere to. The herbicide active ingredients, application timing, application rate, and integration of other control methods are factors that affect treatment results. Most herbicide treatments are recommended when *G. paniculata* is post-emergent, during the bolt to pre-flower stages (DiTomaso, 2013; Montana State University Extension, 2015).

Growth regulators, which are systemic, synthetic auxin herbicides selective for broadleaf species, are often used for chemical control of *G. paniculata*. These herbicides mimic auxin, a plant growth hormone, resulting in many growth-related effects in the plant (Orloff et al., 2020b). The following growth regulator herbicides or tank mixed products containing a growth regulator herbicide are recommended for *G. paniculata*: (1) 2,4-D at 2242 to 4483 g ha⁻¹ (32 to 64 oz ac⁻¹); (2) aminopyralid + metsulfuron at 175 to 210 g ha⁻¹ (2.5 to 3 oz ac⁻¹; Opensight®); and (3) dicamba at 3363 to 6725 g ha⁻¹ (48 to 96 oz product ac⁻¹; Banvel®; DiTomaso, 2013; Prather & Peachey, 2022). Research indicates that 2,4-D only provides suppression, therefore adding chlorsulfuron to the tank mix results in improved control. Aminopyralid and metsulfuron methyl are recommended at preemergence in the fall or postemergence in the spring when plants are at the seedling or rosette stage; metsulfuron is an amino acid inhibitor and is effective in the tank mix given its soil residual activity. Dicamba is most effective at higher rates, is broadleaf-selective, and is safe on most grasses (DiTomaso, 2013; Prather & Peachey, 2022).

Amino acid synthesis inhibitors are another type of chemical mode of action that are often used to control *G. paniculata*. When applied to young actively growing plants, amino acid

synthesis inhibitors bind to enzymes and prevent the development of key amino acids essential to protein development and plant growth (Orloff et al., 2020a). Recommendations include: (1) glyphosate at 4483 g ha⁻¹ (64 oz product ac⁻¹; Roundup Pro Max®); (2) chlorsulfuron at 7 to 182 g ha⁻¹ (1 to 3 oz product ac⁻¹; Telar®); (3) imazapic at 560 to 841 g ha⁻¹ (8 to 12 oz product ac⁻¹; Plateau®); and (4) metsulfuron methyl at 70 to 140 g ha⁻¹ (1 to 2 oz product ac⁻¹; Escort®; DiTomaso, 2013; Prather & Peachey, 2022). All herbicides are recommended as post emergent treatments when plants are rosettes or are bolting (DiTomaso, 2013; Prather & Peachey, 2022). Glyphosate is often used when reseeding is to closely follow treatment as glyphosate has no soil activity and will not injure seedlings emerging after application (DiTomaso, 2013). However, glyphosate is non-selective and will injure non-target plants. Imazapic is selective, has soil residual, and can be used in combination with glyphosate, or 2,4-D, to aid in burndown. A non-ionic surfactant improves metsulfuron methyl applications (DiTomaso, 2013). Peer reviewed research is limited regarding effectiveness or long-term results of these treatments. Like mowing or haying operations, landowners with *G. paniculata* invaded CRP acres must consider the primary nesting period (May 15 to July 15) when implementing herbicide control methods. According to the document “Montana Implementation Requirement Sheet, Conservation Reserve Program (CRP), Cover Establishment and Maintenance Requirements” (MT-IR-14A), herbicide control methods are often confined to spot spraying and timing outside of the primary bird nesting period to reduce the impacts to wildlife habitat.

Our understanding of the invasive potential of *G. paniculata* and the ecological and economic consequences stemming from *G. paniculata* infested environments has progressed in recent years. However, there is a continued lack of information concerning management of the

invasive species using chemical control in CRP acres, rangelands, pasture, and haylands. The objective of this study was to improve *G. paniculata* management by addressing the following: 1) identify a treatment regime that provided effective control of *G. paniculata*; 2) determine whether herbicide application timing, or mowing as a treatment, lends value to an herbicide management program; and 3) identify a treatment regime with minimal injury to desirable vegetation, specifically perennial grasses. The herbicides selected as treatments in this project included imazethapyr (Pursuit®), metsulfuron methyl (Omni® Brand MSM 60 DF), and dicamba (Opti-DGA™). The use of brand names in the description of the herbicides is only for clarification and a broader understanding. Like metsulfuron methyl and imazapic, imazethapyr is a group 2 amino acid synthesis inhibitor and can be used in managing broadleaf weeds in alfalfa (Orloff et al., 2020a). Herbicides were chosen based on previous literature, product label requirements, and alignment with overall project objectives to obtain effective control of *G. paniculata* with minimal damage to desirable vegetation. I hypothesized that the spring metsulfuron methyl treatments would result in the greatest reduction in density of *G. paniculata* compared to other herbicides and herbicides would not affect the density of *G. paniculata*. I also predicted that mowing would not affect the density of *G. paniculata*.

CHAPTER TWO

The experiment was conducted on sandy-loam soil in the frigid Typic Argiustolls class, containing very deep, well drained soils that formed in alluvium and have very gravelly, loamy coarse sand at a depth of 50.8 to 101.6 cm (20 to 40 in; National Cooperative Soil Survey). Soils in the area are primarily of the Turner series, a series found primarily on the plains of central and eastern Montana and used for dryland and irrigated crops and as rangeland (National Cooperative Soil Survey; Soil Survey Staff). Cation exchange capacity for these soils is 11.3 milliequivalents per 100 g with 3% organic matter; the soils are comprised of 17.5% clay, 64.2% sand, and 18.3% silt (Soil Survey Staff).

Some of the dominant plant species at the study site were *G. paniculata* (baby's breath), *Agropyron cristatum* (L.) Gaertn. (crested wheatgrass), *Bromus inermis* Leyss. (smooth brome), *Medicago sativa* L. (alfalfa), *Andropogon gerardii* Vitman (big bluestem), *Elymus smithii* Rydb. (western wheatgrass), *Koeleria macrantha* Ledeb. (prairie June grass), *Dalea purpurea* Vent. (purple prairie clover), and *Artemisia frigida* Willd. (fringed sage) (Table 1). The average annual precipitation for the area is 320 mm (12.6 in) with the majority falling in May, June, and July (Western Regional Climate Center, 2023).

Table 1: Dominant plant species present at the study site in Daniels County, Montana.

Plant functional group	Scientific Name	Common Name	Origin
Perennial forbs	<i>Gypsophila paniculata</i> L.	Baby's breath	Non-native
	<i>Medicago sativa</i> L.	Alfalfa	Non-native
	<i>Melilotus officinalis</i>	Yellow sweetclover	Non-native
	<i>Solidago canadensis</i> L.	Canada goldenrod	Native
	<i>Dalea purpurea</i> Vent.	Purple prairie clover	Native
	<i>Linum lewisii</i> Parsh var. <i>lewisii</i>	Prairie flax	Native
	<i>Gaura coccinea</i> (<i>Oenothera suffrutescens</i> (Ser.) W.L.	Scarlet gaura	Native
	<i>Pedimelum argophyllum</i> (Pursh) J.W. Grimes	Silvery scurfpea	Native
	<i>Artemisia frigida</i> Willd.	Fringed sage	Native
	<i>Antennaria neglecta</i> Greene	Field pussytoes	Native
	<i>Heterotheca villosa</i> var. <i>minor</i>	Hairy goldenaster	Native
	<i>Achillea millefolium</i> L.	Western yarrow	Native
	<i>Sphaeralcea coccinea</i> (Nutt.) Rydb.	Scarlet globemallow	Native
	<i>Vicia americana</i> Muhl. Ex Willd.	American purple vetch	Native
	<i>Thermopsis rhombifolia</i> (Nutt. ex Pursh) Nutt. ex	Roundleaf thermopsis	Native
	<i>Potentilla pensylvanica</i> L.	Pennsylvania cinquefoil	Native
	<i>Penstemon gracilis</i> Nutt.	Slender beardtongue	Native
	<i>Selaginella densa</i> Rydb.	Clubmoss	Native
Perennial grass	<i>Agropyron cristatum</i> (L.) Gaertn.	Crested wheatgrass	Non-native
	<i>Bromus inermis</i> Leyss.	Smooth brome	Non-native
	<i>Bouteloua gracilis</i> Willd.	Blue grama	Native
	<i>Koeleria macrantha</i> Ledeb.	Prairie Junegrass	Native
	<i>Stipa comata</i> Trin. & Rupr.	Needle and thread grass	Native
	<i>Andropogon gerardii</i> Vitman	Big bluestem	Native
	<i>Schizachyrium scoparium</i> (Michx) Nash	Little bluestem	Native
	<i>Oryzopsis hymenoides</i>	Indian ricegrass	Native
	<i>Elymus smithii</i> Rydb.	Western wheatgrass	Native
Annual forb	<i>Crepis tectorum</i>	Narrowleaf Hawksbeard	Non-native
	<i>Conyza canadensis</i> (L.) Cronquist	Canada horseweed	Native

Experimental Design

The field trial used a split-plot randomized complete block design with three blocks (replicates). Blocks were positioned at the study site based on availability of contiguous *G. paniculata* plants. Each block was divided in half and one side was determined at random to receive a mowing treatment (split-plot). Each whole plot measured 3 m by 9 m and each split plot measured 3 m by 4.5 m.

Three different herbicides applied in the fall, spring, or fall and spring, and a non-sprayed control were applied for a total of 10 treatments. The split plot included non-mowed or mowed to simulate dryland haying operations used by producers in the region (Table 2).

Herbicide applications were made using a handheld CO₂-powered boom sprayer with flat fan nozzles, and included the following: 1) imazethapyr (Pursuit®) at 210.2 g ha⁻¹ (3 oz ac⁻¹); 2) metsulfuron methyl (Omni® Brand MSM 60 DF) at 46.9 g ha⁻¹ (0.67 oz ac⁻¹); and 3) dicamba (Opti-DGA™) at 280.2 g ha⁻¹ (4 oz ac⁻¹). All herbicides were applied with a nonionic surfactant at 0.25% v/v herbicide solution. Fall herbicide treatments were applied on 16 September 2020, 16 September 2021, and 29 September 2022. Spring herbicide treatments were applied 15 May 2021, 2 June 2022, and 17 June 2023. Split-plots were mowed to 8 cm (3 in.) with an 18hp DR® (DR Power Equipment Vergennes, Vermont) field and brush mower on 5 August 2020, 13 August 2021, and 31 August 2022.

Table 1: Ten treatments, including a control (non-sprayed), were applied to *Gypsophila paniculata*; three different herbicide timings were tested including fall, spring, and fall and spring.

Herbicide treatments	Season	Year	Spray rate
1. Imazethapyr (Pursuit®)	Spring	2021, 2022, 2023	210.2 g ha ⁻¹ (3 oz ac ⁻¹)
2. Metsulfuron methyl (Omni® Brand MSM 60 DF)	Spring	2021, 2022, 2023	46.9 g ha ⁻¹ (0.67 oz ac ⁻¹)
3. Dicamba (Opti-DGA™)	Spring	2021, 2022, 2023	280.2 g ha ⁻¹ (4 oz ac ⁻¹)
4. Control – Non-sprayed	-	-	-
5. Imazethapyr (Pursuit®)	Fall	2020, 2021, 2022	210.2 g ha ⁻¹ (3 oz ac ⁻¹)
6. Metsulfuron methyl (Omni® Brand MSM 60 DF)	Fall	2020, 2021, 2022	46.9 g ha ⁻¹ (0.67 oz ac ⁻¹)
7. Dicamba (Opti-DGA™)	Fall	2020, 2021, 2022	280.2 g ha ⁻¹ (4 oz ac ⁻¹)
8. Imazethapyr (Pursuit®)	Fall, Spring	2020, 2021, 2022, 2023	210.2 g ha ⁻¹ (3 oz ac ⁻¹)
9. Metsulfuron methyl (Omni® Brand MSM 60 DF)	Fall, Spring	2020, 2021, 2022, 2023	46.9 g ha ⁻¹ (0.67 oz ac ⁻¹)
10. Dicamba (Opti-DGA™)	Fall, Spring	2020, 2021, 2022, 2023	280.2 g ha ⁻¹ (4 oz ac ⁻¹)

Vegetation Sampling

Data collection occurred on 28 July 2021, 17 August 2022, and 28 August 2023. To limit subjectivity, field teams consisted of two experienced persons that made measurements, and two recorders. In the field we: (1) counted the number of individual *G. paniculata* plants per split plot; (2) measured plant height from the base to tallest point of canopy; (3) counted the number of stems (shoots) per plant; (4) measured diameter of plants (across top of canopy); and (5) noted if plant was flowering/not flowering.

Canopy cover was evaluated based on the following functional groups: (1) perennial forbs; (2) perennial grasses; (3) annual forbs; (4) annual grasses; (5) litter; and (6) bare ground. A 20 cm x 50 cm Daubenmire (1959) frame was used to estimate cover; three frames were randomly placed in the center of each split-plot and cover to the nearest 1% of each functional group was recorded. A 0.61-m (2-ft) buffer between adjacent plots within whole blocks was excluded to avoid edge effects.

Statistical Analysis

We assessed changes in *G. paniculata* plant density and perennial grass cover annually over a three-year period following herbicide treatments, starting with data collection at the end of the 2021 field season and culminating with data collection at the end of the 2023 field season. Density of *G. paniculata* was analyzed using a linear mixed effects model ('lmer' in R package 'lme4'; Bates et al., 2015). The random effect was plot identity, which was used to account for repeated measures of the same plots over the three-year period. To assess the impact of herbicide treatment and mowing, backwards model selection was used starting with the full model and removing the interactive terms first. The full model had fixed effects of mowing, year, and

herbicide, the 3-way interaction between the 3 effects, and the 2-way comparisons of the effects. To simplify models a criterion of $\alpha=0.05$ derived from an F-test ratio was used to justify removal of terms, and type-III analysis of variance (ANOVA) using the Satterthwaite's method was used to estimate degrees of freedom. Using the most parsimonious model, estimated marginal means of *G. paniculata* density was calculated and compared using the Tukey *post-hoc* ('emmeans' in R package 'emmeans'; Lenth, 2021). Perennial grass cover was also analyzed using the same backward analysis of variance (ANOVA) procedure. All statistical analyses and graphics were performed and produced using R, version 4.3.2 (2023-10-31 ucrt). Differences between all explanatory and response variables for the models were analyzed at the $P < 0.05$ level.

CHAPTER THREE

RESULTS

Density of *Gypsophila paniculata*

The density of *G. paniculata* was significantly affected by herbicide treatments ($P=0.001$; Table 3), and year ($P=0.0043$; Table 3), but not by mowing ($P=0.3930$, Table 3). Mowing did not interact with herbicide to affect the density of *G. paniculata* ($P=0.3067$; Table 3). Also, mowing did not affect the density of *G. paniculata* in the non-sprayed control ($P=0.3930$; Table 3). After model selection, the main effect from herbicide treatments and the main effect from the year affected the density of *G. paniculata*. Year significantly affected *G. paniculata* density ($P=0.0043$). However, herbicide and year did not interact to affect *G. paniculata* density ($P=0.4018$).

Table 2: Analysis of variance (ANOVA) for a linear mixed effects model of *Gypsophila paniculata* relative density in response to herbicide treatment (Herbic); mowing treatment (Mow); over years (Year), and their 2- and 3-way interactions. Significant P-values are in bold type ($\alpha = 0.05$).

Predictor	Sum Sq.	Mean Sq.	NumDF	DenDF	F-value	Pr(>F)
Herbic	192.5	21.4	9	165	65.3	<0.001
Mow	0.2	0.2	1	164	0.7	0.3930
Year	3.7	1.8	2	165	5.6	0.0043
Herbic: Mow	3.5	0.4	9	155	1.2	0.3067
Herbic: Year	6.1	0.3	18	137	1.1	0.4018
Mow: Year	0.2	0.1	2	135	0.2	0.7965
Herbic: Mow: Year	3.8	0.2	18	117	0.6	0.8786

ANOVA table using type III analysis of variance with Satterthwaite's method.

Herbicide active ingredient was more important than timing of the application.

Metsulfuron methyl treatments resulted in the lowest density of *G. paniculata* (Fig. 7) after three years. All herbicides reduced *G. paniculata* density compared to the non-sprayed control (4.8 plants/13.5 m²), but the imazethapyr and dicamba treatments had a higher density of *G. paniculata* than treatments that contained metsulfuron methyl (Fig. 7).

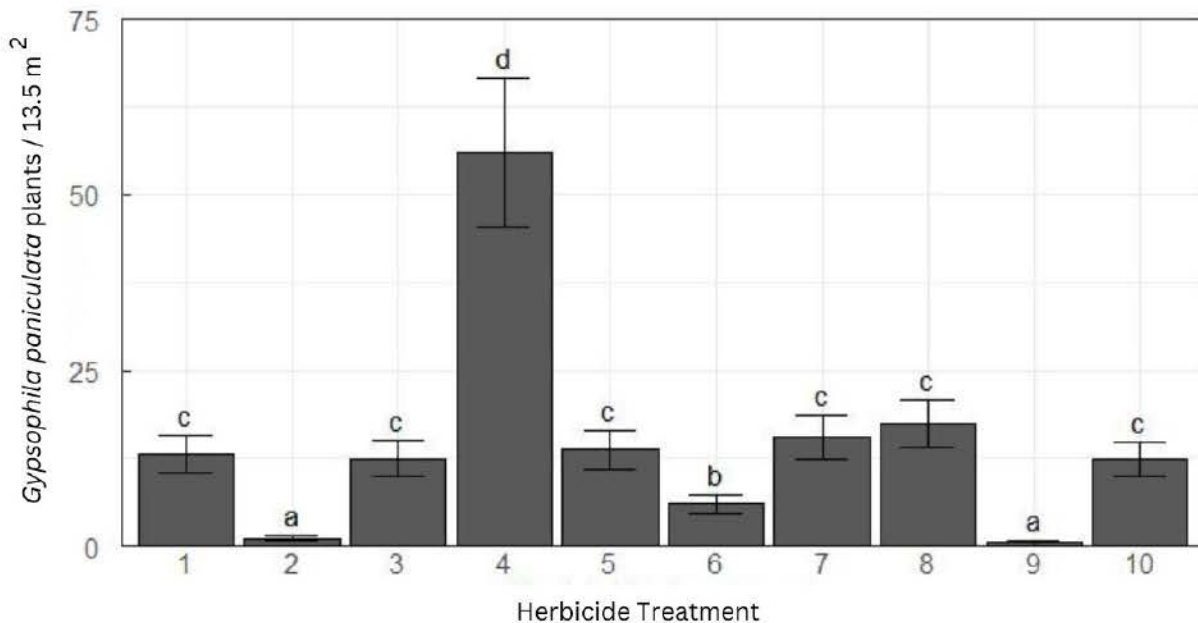


Figure 7: Effects of herbicide treatments on mean density of *Gypsophila paniculata* per sample unit over a three-year period with 95% confidence intervals. Different grouping letters indicate differing means among the 10 herbicide treatments; identical grouping letters indicate similar means. The herbicide treatments included the following: 1: imazethapyr at 210.2 g ha⁻¹, spring application; 2: metsulfuron methyl at 46.9 g ha⁻¹, spring application; 3: dicamba at 280.2 g ha⁻¹, spring application; 4: non-sprayed control; 5: imazethapyr at 210.2 g ha⁻¹, fall application; 6: metsulfuron methyl at 46.9 g ha⁻¹, fall application; 7: dicamba at 280.2 g ha⁻¹, fall application; 8: imazethapyr at 210.2 g ha⁻¹, spring and fall application; 9: metsulfuron methyl at 46.9 g ha⁻¹, spring and fall application; 10: dicamba at 280.2 g ha⁻¹, spring and fall application.

Timing of metsulfuron methyl treatments affected *G. paniculata* density, with combined spring and fall application (0.1 plants/13.5 m²) and spring-only application (1.4 plants/13.5 m²) being significantly lower than the fall-only application (2.7 plants/13.5 m²; Fig. 7). Timing of dicamba and imazethapyr treatments did not matter.

Perennial Grass Response

Perennial grass cover was not affected by the interaction between year and herbicide treatment ($P=0.9695$). Perennial grass cover was not affected by year ($P=0.1138$), nor was it affected over the three years by herbicide treatment ($P=0.6101$).

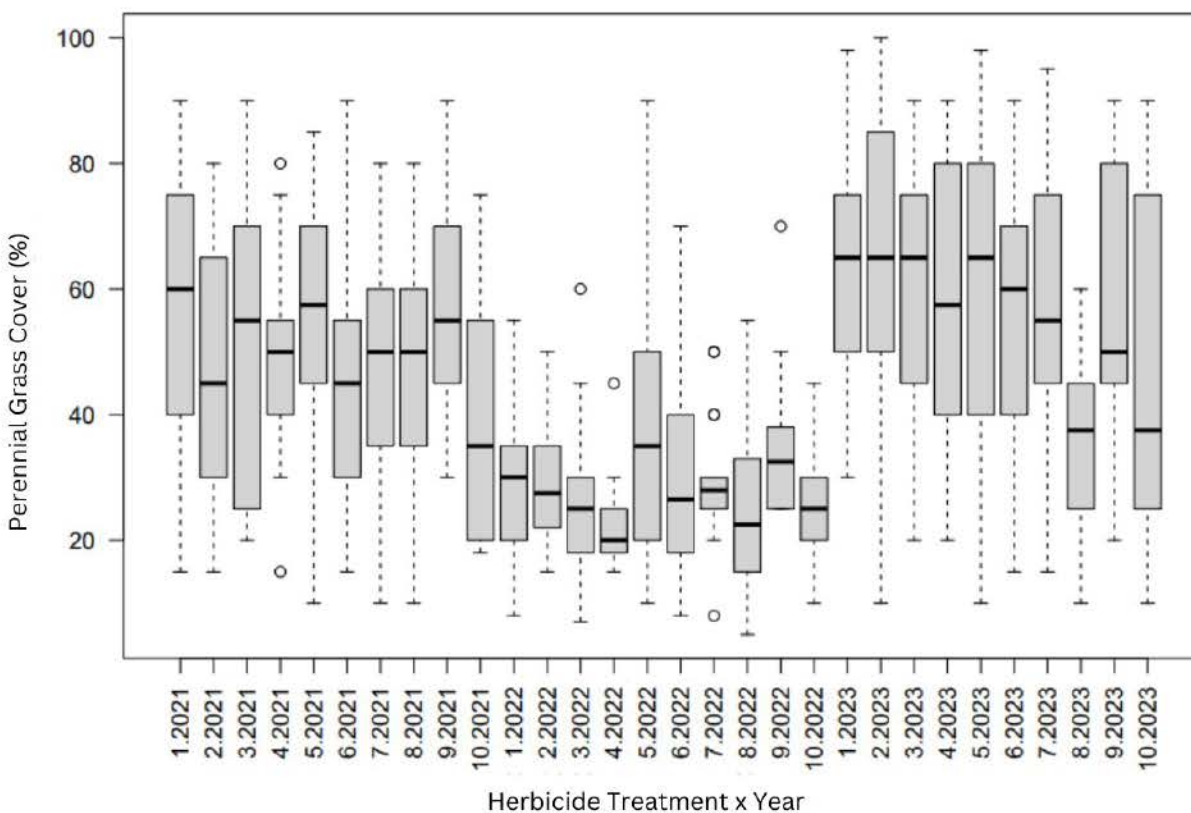


Figure 8: Perennial grass cover over three years according to herbicide treatment. Perennial grass cover was not affected by the interaction between year and herbicide treatment ($P=0.9695$). The herbicide treatments included the following: 1: imazethapyr at 210.2 g ha^{-1} , spring application; 2: metsulfuron methyl at 46.9 g ha^{-1} , spring application; 3: dicamba at 280.2 g ha^{-1} , spring application; 4: non-sprayed control; 5: imazethapyr at 210.2 g ha^{-1} , fall application; 6: metsulfuron methyl at 46.9 g ha^{-1} , fall application; 7: dicamba at 280.2 g ha^{-1} , fall application; 8: imazethapyr at 210.2 g ha^{-1} , spring and fall application; 9: metsulfuron methyl at 46.9 g ha^{-1} , spring and fall application; 10: dicamba at 280.2 g ha^{-1} , spring and fall application.

CHAPTER FOUR

DISCUSSION

In this study, we compared methods of management of *G. paniculata*, a highly adaptive and problematic perennial weed in rangeland, pasture, Conservation Reserve Program (CRP) acres, and haylands. Certain herbicide treatments reduced *G. paniculata* after initial treatment compared to the control and other herbicide treatments. Mowing had no effect on *G. paniculata* and did not interact with the herbicide treatment. Perennial grass cover was not affected by herbicide treatment. Herbicide treatments containing the active ingredient metsulfuron methyl had the lowest amount of *G. paniculata* and application conducted in spring or in spring and fall had the lowest amount of *G. paniculata* at the end of the study. Perennial grass cover did not differ among treatments, indicating that there was no collateral damage of grass associated with herbicide applications.

Effects of herbicide treatments

Metsulfuron methyl treatment which was applied in the spring and fall were the most effective in reducing the density of *G. paniculata*. The effect of spring and fall treatments of metsulfuron methyl (Omni® Brand MSM 60 DF) applied at 46.9 g ha⁻¹ was closely followed by the spring-only treatment of metsulfuron methyl (Omni® Brand MSM 60 DF) applied at 46.9 g ha⁻¹ and were different from the fall-applied metsulfuron methyl treatment. However, the fall-applied metsulfuron methyl treatment was significantly more effective than the spring-applied imazethapyr and dicamba treatments, which strongly indicates that herbicide active ingredient is more important than timing. It also indicates that carryover of fall-applied metsulfuron methyl inhibits *G. paniculata* spring growth. Herbicide carryover occurs when the active ingredient in a

formulated product remains in the soil for a period depending on the persistence of the active ingredient (Orloff et al., 2020c). According to the Omni® Brand 60 DF product label, under certain conditions, metsulfuron methyl can remain active in the soil for up to 34 months.

Nonetheless, the results from the metsulfuron treatments strongly suggest that spring applications are the catalyst for effective control of the species. The success of these findings aligns with previous work conducted on managing *G. paniculata* (DiTomaso, 2013; Montana State University Extension, 2015). From an economic perspective, the similar efficacy of the spring metsulfuron methyl treatments indicates that producers can put less chemical into the environment and spend less money by applying the spring-only treatment.

Like metsulfuron methyl, imazethapyr is a group 2 amino acid inhibitor, but imazethapyr treatments did not perform as well as metsulfuron methyl treatments even though they did reduce *G. paniculata* compared to the non-sprayed control. The timing of imazethapyr treatments did not matter. Dicamba, a group 4 synthetic auxin growth regulator, had a mean density of *G. paniculata* that was similar to the imazethapyr treatments, reducing *G. paniculata* density below that of the non-sprayed control regardless of timing of application. Nonetheless, dicamba treatments did not reduce the density of *G. paniculata* as low as metsulfuron methyl treatments.

Effects of Mowing

Mowing did not affect the density of *G. paniculata* in the non-sprayed control which aligned with previous work (DiTomaso et al., 2013; Agriculture Knowledge Centre, 2023). The results of this study did not confirm this, but some evidence suggests that combining mowing with herbicides can enhance perennial weed control (Sheley et al., 2017). However, the results suggest that mowing or haying during the tested period does not lend value to a management

program as a stand-alone treatment, especially if applied when plants are beyond the early flowering stages (Sheley et al., 2017; Flint, 2012). Proper timing of mowing is critical and should be tailored depending on the growth and flowering pattern of the weed present (Flint, 2012). If properly timed, mowing undesired plants will decrease reproductive potential and competitive abilities and favor desired plants (Sheley et al., 2017).

Over the three-year study, *G. paniculata* was in the intermediate to late stages of flowering when mowing was applied at the study site (August 5, 2020; August 13, 2021; and August 31, 2022, respectively) and it is possible the mowing treatment was applied too late in the season to effectively inhibit seed production. Mature plants tend to have a multitude of flowers at various stages of development (Darwent & Coupland, 1966). In northeastern Montana, *G. paniculata* develops flowers buds in early to mid-June; flower buds break starting in mid-June; starting in mid-August through September, plants stems become dry and brittle, break off at the base and tumble across the landscape (Darwent & Coupland, 1966).

Gypsophila paniculata seeds continue to ripen when discarded in floral arrangements, implying that *G. paniculata* plants in infested acres will do the same if mowed or harvested when plants are in full bloom or beyond (Washington State Noxious Weed, 2021). Therefore, whether *G. paniculata* is harvested as forage and moved off-site, if conditions allow, seeds will reach viability and germinate in subsequent years (Darwent & Coupland, 1966; Washington State Noxious Weed, 2021). Currently, the benefit for land managers and producers in haying infested acres when *G. paniculata* is in flower can be viewed as a reduction in seeds deposited on site; however, mowing or haying operations may spread *G. paniculata* seed by blowing seeds from the site or transporting them on equipment (Hooks & Joseph, 2022). Mowing or haying

operations on invaded CRP acres are prohibited until July 15 to allow for the primary nesting period, thus limiting the feasibility of mowing as a management tool.

Effects on perennial grass cover

Perennial grass cover was not affected by the interaction between year and herbicide treatment. Overt collateral damage to perennial grasses was not observed, despite cautionary statements on the metsulfuron methyl (Omni® Brand MSM 60 DF) and imazethapyr (Pursuit®) product labels stating that injury to perennial grasses may occur. Surprisingly, overt collateral damage to non-target perennial forbs and *Medicago sativa* (alfalfa), was also not observed. Metsulfuron methyl (Omni® Brand MSM 60 DF) and dicamba (Omni®-DGA) herbicide labels both referred to the sensitivity of alfalfa, clover, and other legumes, and noted that the species may be severely stunted or injured by the products. Perennial forb cover data were convoluted as it included *G. paniculata*, therefore they were not statistically evaluated. Given the effectiveness of metsulfuron methyl in reducing *G. paniculata* density, the herbicide deserves further research to determine if it provides long-term control of *G. paniculata* without sacrificing perennial forbs.

Recommending spring herbicide treatments to reduce *G. paniculata* density in infested areas could potentially conflict with agronomic activities in the region; historically, it has been common for herbicide treatment not to occur until after spring farming activities have subsided, often when *G. paniculata* was in bloom (Daniels County, Weed Coordinator, Connie Wittak, personal conversation). *Gypsophila paniculata* is also easier to locate and identify when plants are flowering. Furthermore, landowners with *G. paniculata* invaded CRP acres must consider the primary nesting period (May 15-July 15) when implementing herbicide control methods. Herbicide control methods are often confined to spot spraying and timing outside of the primary

bird nesting period to reduce the impacts to wildlife habitat. Whether spraying is allowed within the primary nesting period is to be evaluated on a case-by-case basis by Farm Service Agency (FSA) and Natural Resources Conservation Service (NRCS), with timing and scope of the infestation being contributing factors (District Conservationist, USDA-NRCS, Garrett Larson, personal communication).

Overall, *G. paniculata* invaded acres pose a significant problem for land managers and producers in northeastern Montana. My paper presents results from nine different herbicide treatment regimens evaluated over a three-year period. Metsulfuron methyl treatments applied in the spring were the most effective in reducing the density of *G. paniculata*. Prior research conducted regarding long-term control of *G. paniculata* in Montana is limited, therefore additional years of monitoring will occur to determine the long-term effects of the herbicide treatments. Long term impacts will be studied to refine management decisions.

Based on the results of this study, I recommend the spring application of metsulfuron methyl used in this study to reduce the density of *G. paniculata* in rangeland, pasture, CRP acres, and haylands throughout northeastern Montana. Perennial grass cover was not affected by herbicide treatment, and overt collateral damage to perennial grasses and perennial forbs was not observed. Metsulfuron methyl deserves further research to determine if the herbicide provides long-term control of *G. paniculata* without sacrificing perennial forbs. I do not recommend mowing or haying as standalone treatments for *G. paniculata*, as mowing does not affect the density of *G. paniculata*. Furthermore, if admissible for the site, mowing or haying operations should take place before the flowering stage to effectively inhibit seed production.

REFERENCES CITED

- Agriculture Knowledge Centre. (2023). Problem Weeds – A Cattlemen’s Guide: Baby’s Breath (*Gypsophila paniculata* L.). Government of Saskatchewan. Accessed 8 September 2023. Available at: <https://www.saskatchewan.ca/business/agriculture-natural-resources-and-industry/agribusiness-farmers-and-ranchers/livestock/pastures-grazing-hay-silage/problem-weeds---a-cattlemens-guide/babys-breath>
- Alaska Natural Heritage Program. (2011). Baby’s breath, *Gypsophila paniculata* L. University of Alaska Anchorage (UAA). Available at: https://accs.uaa.alaska.edu/wp-content/uploads/Gypsophila_paniculata_BIO_GYPA.pdf
- Baskett, C., Emery, S., and Rudgers, J. (2011). Pollinator Visits to Threatened Species are Restored Following Invasive Plant Removal. *International Journal of Plant Sciences*, 172(3), 411-422. doi: 10.1086/658182
- Bates, D., Mächler, M., Bolker, B., and Walker, S. (2015). Fitting linear mixed-effects models using lme4. *J. Stat. Softw* 67, 1-48. doi: 10.48550/arXiv.1406.5823
- Beck, K., Zimmerman, K., Schardt, J., Stone, J., Lukens, R., Reichard, S., . . . Thompson, J. (2008). Invasive Species Defined in a Policy Context: Recommendations from the Federal Invasive Species Advisory Committee. *Invasive Plant Science and Management*, 1(4), 414-421. doi:10.1614/IPSM-08-089.1
- Blumenthal, D., Chimner, R. A., Welker, J. M., and Morgan, J. A. (2008). Increased Snow Facilitates Plant Invasion in Mixedgrass Prairie. *New Phytologist*, 179(2), 440–448.
- Brusati, E. D. (2016). *Gypsophila paniculata* Risk Assessment. *California Invasive Plant Council*. Retrieved February 19, 2023, from <https://www.cal-ipc.org/plants/risk/gypsophila-paniculata-risk/>
- Darwent, A. L. (1975). The biology of Canadian Weeds. *Gypsophila paniculata* L. *Canadian Journal of Plant Science*, 55(4), 1049-1058. doi:10.4141/cjps75-164
- Darwent, A. L., and Coupland, R. T. (1966). Life History of *Gypsophila paniculata*. *Weeds*, 14(4), 313–318. doi:10.2307/4040974
- Darwent, A. L., and Coupland, R. T. (1967). The potential of *Gypsophila paniculata* as a weed in Saskatchewan. *Canadian Journal of Plant Science*, 47(2), 125-134. Available at: <https://doi.org/10.4141/cjps67-022>. Accessed 5 December 2022.
- DiTomaso, J. M., G.B. Kyser et al. (2013). *Weed Control in Natural Areas in the Western United States*. Weed Research & Information Center, University of California. Available at: https://wric.ucdavis.edu/information/natural%20areas/wr_G/Gypsophila.pdf

- EDDMapS. 2023. Early Detection & Distribution Mapping System. The University of Georgia - Center for Invasive Species and Ecosystem Health. Available at: <http://www.eddmaps.org/>
- Emery, S. E., and Doran, P. J. (2013). Presence and management of the invasive plant *Gypsophila paniculata* (baby's breath) on sand dunes alters arthropod abundance and community structure, *Biological Conservation*, Volume 161, Pages 174-181. Available at: <https://doi.org/10.1016/j.biocon.2013.03.015>.
- Flint, M. L. (2012). *IPM in Practice: Principles and Methods of Integrated Pest Management*, 2nd Edition. University of California Agriculture and Natural Resources.
- Fons, F., Henry, M., and Leyval, C. (2003). Effects of *Gypsophila* saponins on bacterial growth kinetics and on selection of subterranean clover rhizosphere bacteria. *Canadian Journal of Microbiology*, 49(6):367-73. doi: 10.1139/W03-052
- Hooks, C. & Joseph, D. (2022). Mowing: A casually thought of integrated weed management tool. Maryland Agronomy News. The University of Maryland, College of Agriculture and Natural Resources. Available at: <https://blog.umd.edu/agronomynews/2022/03/23/mowing-a-casually-thought-of-integrated-weed-management-tool/>
- Invasive.org, University of Georgia - Center for Invasive Species and Ecosystem Health. (2018). Babysbreath, *Gypsophila paniculata* L. Available at: <https://www.invasive.org/browse/subinfo.cfm?sub=5682>
- Kasper, M., Buchan, G.D., Mentler, A., and Blum, W.E.H. (2009). Influence of soil tillage systems on aggregate stability and the distribution of C and N in different aggregate fractions. *Soil and Tillage Research*. 105(2), 192-199. doi: 10.1016/j.still.2009.08.002.
- Korkmaz, M. & Ozcelik, H. (2013). Soil-plant relations in the annual *Gypsophila* (Caryophyllaceae) taxa of Turkey. *Turkish Journal of Botany*. 37:85-98. doi:10.3906/bot-1201-3
- Lenth, R. (2021). *Emmeans: estimated marginal means, aka least-squares means. r package version 1.8.9*. Available at <https://CRAN.R-project.org/package=emmeans>.
- Lesica, P. (2022). *Manual of Montana Vascular Plants: Gypsophila paniculata* L., Second Edition. BRIT Press, Fort Worth Botanic Garden, Botanical Research Institute of Texas, U.S.A.
- Macoun, J. (1988). *Catalogue of Canadian Plants: Part IV. Emdogens*. Dawson Bros., Montreal, Quebec. Available at: <https://archive.org/details/cataloguecanadi00canagoog/page/n10/mode/2up?q=paniculata>
- Masters R. A., and Sheley, R. L. (2001). Principles and Practices for Managing Rangeland Invasive Plants. *Journal of Range Management*, 54(5), 502–517. doi: 10.2307/4003579

McGowan-Stinski, J. and Gostomski, T. Recommended removal methods for baby's breath (*Gypsophila paniculata*). The Nature Conservancy, Michigan Chapter. Accessed 8 September 2023. Available at: <https://www.invasive.org/gist/moredocs/gyppan01.pdf>

Montana Department of Agriculture. (2020). County Listed Noxious Weeds 2018-19. Montana.gov. Available at: https://agr.mt.gov/_docs/weeds-docs/County-Listed-Noxious-Weeds-2019.pdf

Montana State University Extension. (2015, May). Monthly Weed Post: Baby's breath (*Gypsophila paniculata*). Available at: http://www.sarc.montana.edu/documents/weedposts/May_babys_breath.pdf

National Cooperative Soil Survey, United States Department of Agriculture. (2014). Official Soil Survey Description: Turner Series. Available at: https://soilseries.sc.gov.usda.gov/OSD_Docs/T/TURNER.html

Olmstead, K. (2019). California Pest Rating for *Gypsophila paniculata* (Baby's breath). California Department of Food & Agriculture. Available at: <https://blogs.cdfa.ca.gov/Section3162/?p=6101>

Orloff, N., Mangold, J., and Seipel, T. (2020a). Amino Acid Synthesis Inhibitors. *Diagnosing Non-Target Herbicide Injury on Plants*. Montana State University Extension. Available at: <https://www.montana.edu/extension/pubs/herbicideinjuryguide/>

Orloff, N., Mangold, J., and Seipel, T. (2020b). Synthetic Auxins. *Diagnosing Non-Target Herbicide Injury on Plants*. Montana State University Extension. Available at: <https://www.montana.edu/extension/pubs/herbicideinjuryguide/>

Orloff, N., Mangold, J., and Seipel, T. (2020c). Causes of non-target injury: herbicide carryover. *Diagnosing Non-Target Herbicide Injury on Plants*. Montana State University Extension. Available at: <https://www.montana.edu/extension/pubs/herbicideinjuryguide/>

Prather, T. and Peachey, E. (2022). Pacific Northwest Weed Management Handbook. Control of problem weeds. Available at: <https://pnwhandbooks.org/sites/pnwhandbooks/files/weed/chapterpdf/control-problem-weeds.pdf>

Ross, M., and Childs, D. (1996). Herbicide mode of action summary. Cooperative Extension Work. Department of Botany and Plant Pathology, Purdue University. Available at: <https://www.extension.purdue.edu/extmedia/ws/ws-23-w.html>

Saskatchewan Forage Council. (2018). Baby's Breath – *Gypsophila paniculata*. *Saskatchewan Invasive Species Guide, Second Edition*. Available at: <http://www.beefresearch.ca/files/pdf/Invasive-Plant-Guide-Sask-Forage.pdf>

Seitz, S., Goebes, P., Puerta, V. L., Perira, E. I. P., Wittwer, R., Six, J., et al. (2019). Conservation tillage and organic farming reduce soil erosion. *Agronomy for Sustainable Development*. 39(4). doi: 10.1007/s13593-018-0545-z

Sheley, R., Goodwin, K., and Rinella, M. (2017). Mowing to manage noxious weeds. *Montana State University Montguide*. MT200104AG reviewed 2017.

Soil Survey Staff, Natural Resources Conservation Service, United States Department of Agriculture. Web Soil Survey. Available at: <https://websoilsurvey.nrcs.usda.gov/app/WebSoilSurvey.aspx>. Accessed September 3, 2023.

United States. (2020) U.S. National Agriculture Statistics Service. 2020 North Dakota Custom Rates, Part I – Early Season Operations. North Dakota State University Extension Service. Available at: <https://www.ndsu.edu/agriculture/sites/default/files/2021-08/custearly20.pdf>

USDA Natural Resources Conservation Service. (2023, March). Montana Implementation Requirement Sheet, Conservation Reserve Program (CRP), Cover Establishment and Maintenance Requirements (MT-IR-14A).

United States Department of Agriculture, Natural Resources Conservation Service, Plant Database. Available at: <https://plants.usda.gov/home/plantProfile?symbol=AIAL>. Accessed 30 September 2023.

United States Department of Agriculture, NRCS Scobey Field Office. (2019, December). Daniels County Long Range Plan. *Natural Resources Conservation Service Montana*. Available at: <https://www.nrcs.usda.gov/wps/portal/nrcs/mt/technical/cp/0d04faec-0fde-45f9-8d8e-6a19cf047317/>

USGS. What is an invasive species and why are they the problem? *U.S. Department of the Interior*. Available at: <https://www.usgs.gov/faqs/what-invasive-species-and-why-are-they-problem>

Washington State Noxious Weed Control Board. (2021). Garden wise: Non-invasive plants for your garden. Eastern Washington Guide. Available at: <https://www.nwcb.wa.gov/pdfs/Eastern-GW-2021.pdf>. Accessed 3 September 2023.

Western Regional Climate Center. (2023). Total of Precipitation (Inches) (Scobey 4 NW, MT)., Available at: <https://wrcc.dri.edu/cgi-bin/cliMAIN.pl?mt7425>. Accessed 23 September 2023.

Wolfe, B. and Klironomos, J. (2005). Breaking New Ground: Soil Communities and Exotic Plant Invasions. *BioScience*. 55(6), 477-487. doi:153.90.6.16