Cattle as Grazing Management and Seed Dispersal Tools for Increasing Native Species Diversity on Great Basin Rangelands

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CATTLE AS GRAZING MANAGEMENT AND SEED DISPERSAL TOOLS FOR INCREASING NATIVE SPECIES DIVERSITY ON GREAT BASIN RANGELANDS

by

Marina K Whitacre

A thesis submitted in partial fulfillment of the requirements for the degree of

MASTER OF SCIENCE in Range Science

Approved:

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ABSTRACT

Cattle as Grazing Management and Seed Dispersal Tools for Increasing Native Species Diversity on Great Basin Rangelands

by

Marina K Whitacre, Master of Science

Utah State University, 2004

Major Professor: Dr. Christopher A. Call
Department: Forest, Range, and Wildlife Sciences

A series of experiments evaluated: 1) the influence of seed intake and gut retention time on seed passage, recovery, and germinability; 2) fecal seeding and broadcast/trampling as techniques to incorporate seeds into a well-established Agropyron desertorum (Fisch.) Schult. stand in Skull Valley, Utah; 3) intensive grazing as a means to reduce Agropyron biomass and increase establishment and survival of seeded species; and 4) the recovery and germinability of seed extracted from dung collected from the field. Two shrubs (Artemisia tridentata Nutt. ssp. wyomingensis Beetle & Young and Atriplex confertifolia Torr. & Frem.), a grass (Elymus elymoides (Raf.) Swezey), and a forb (Sphaeralcea grossulariaefolia (H. & A.) Rydb.) were selected as representative native species. Holstein heifers were fed 15,000, 30,000, and 60,000 seeds of Artemisia, Sphaeralcea, and Elymus. Elymus recovery was negatively correlated to seed intake. Sphaeralcea had the highest
percentage of recovered, undamaged seed, followed by *Elymus* and *Artemisia*. *Sphaeralcea* and *Artemisia* seed passage was highest on Day 1 then dropped sharply. *Elymus* passage and recovery were more consistent through time. Post-passage germinability was highest for *Elymus* and *Sphaeralcea* on Day 1. *Artemisia* germination was negligible.

In the fall seeding, *Sphaeralcea* emerged in 6% of the subplots (half were volunteers). Overall seedling mortality was 93%. *Elymus* emerged in 63% of the dung pats, with 86% mortality. No *Artemisia* emerged. Drought and *Anabrus simplex* herbivory contributed to low seedling emergence and survival. In April 2003, similar treatments were applied, except *Atriplex* seed was substituted for *Artemisia*, and a third treatment was added (broadcast seeding/raking). No emergence was observed. *Sphaeralcea* had the highest seed recovery from dung collected in the field trials, followed by *Elymus*, *Atriplex*, and *Artemisia*. *Sphaeralcea* germinability was similar for seeds collected from both trials (11%) and *Elymus* germination was highest in the fall seeding (13%).

These studies indicate that: 1) physical seed properties (size, shape, density, seed coat) influence seed passage, recovery, and germination; 2) intensive grazing can reduce *Agropyron* biomass by 50% for 2 years; 3) broadcast/trampling may be effective for *Sphaeralcea*; and 4) an average-sized dung pat (714 g) may have ample germinable *Sphaeralcea* and *Elymus* seeds for plant establishment.

(127 pages)
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Marina K Whitacre
# CONTENTS

| ABSTRACT | ii |
| ACKNOWLEDGMENTS | iv |
| LIST OF TABLES | x |
| LIST OF FIGURES | xiii |

## CHAPTER

### I. INTRODUCTION

LITERATURE REVIEW ................................................................. 5

- Crested Wheatgrass ................................................................. 5
- Rangeland Rehabilitation Following Fire .................................... 7
- Grazing as a Vegetation Manipulation Tool ............................... 9
- Trampling as a Method of Seed Incorporation .......................... 11
- Broadcast Seeding ................................................................. 13
- Fecal Seeding ......................................................................... 14

LITERATURE CITED ..................................................................... 16

### II. RECOVERY AND GERMINABILITY OF NATIVE SEED FED TO CATTLE

ABSTRACT ............................................................................... 25

INTRODUCTION ....................................................................... 26

MATERIALS AND METHODS ...................................................... 28

RESULTS .................................................................................. 32

- Fecal Output .......................................................................... 32
- Seed Recovery ....................................................................... 33
- Seed Germinability ............................................................... 34

DISCUSSION ............................................................................ 36

LITERATURE CITED .................................................................. 41
IV. SYNTHESIS ................................................................. 91

LITERATURE CITED ...................................................... 97

APPENDIX ......................................................................... 100
# LIST OF TABLES

<table>
<thead>
<tr>
<th>Table</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Physical characteristics (± SE) of sagebrush, globemallow, and squirreltail seed fed to heifers</td>
</tr>
<tr>
<td>2</td>
<td>Mean (± SE) seed recovery (% of seed ingested) of sagebrush, globemallow and squirreltail collected from dung 1, 2, 3, and 4 days after seed ingestion (n = 9)</td>
</tr>
<tr>
<td>3</td>
<td>Mean (± SE) squirreltail seed recovery (% of seed ingested) from dung 1, 2, 3, and 4 days after seed ingestion. Heifers were fed 3 quantities of seed (15,000, 30,000, 60,000) (n = 3)</td>
</tr>
<tr>
<td>4</td>
<td>Mean (± SE) germination of unpassed (Day 0) and passed globemallow, squirreltail and sagebrush seed. Passed seed collected 1, 2, 3, and 4 days after heifers ingested seed (n=12)</td>
</tr>
<tr>
<td>5</td>
<td>Skull Valley soil characterization data</td>
</tr>
<tr>
<td>6</td>
<td>Drill seed mix used by BLM on 2000ha of the Davis Knolls burn in the fall of 1996</td>
</tr>
<tr>
<td>7</td>
<td>Baseline measurements of species presence, including percent of total weight and percent cover at the Davis Knolls seeding in May of 2001. Data were collected outside the perimeter fence</td>
</tr>
<tr>
<td>8</td>
<td>Summary of precipitation and irrigation for the 2002 and 2003 growing seasons at the Skull Valley, Utah study site. Half of the plots were irrigated and the other half received only ambient precipitation</td>
</tr>
<tr>
<td>9</td>
<td>Comparison of intended versus actual number of seeds (mean ± SE) broadcasted/m². Numbers are based on seed collected from 1m² tarps in Experiment II (n=29)</td>
</tr>
<tr>
<td>10</td>
<td>The effect of grazing intensity (none, 50% or 80%) on crested wheatgrass biomass (mean ± SE) in Experiment I. Biomass data for May and November were collected immediately following the grazing treatments</td>
</tr>
<tr>
<td>11</td>
<td>Crested wheatgrass biomass comparisons (mean ± SE) for the control and grazed paddocks in Experiment II before (24 April) and after (30 April) the grazing treatment and at the end of the growing season (10 June)</td>
</tr>
</tbody>
</table>
12 Effect of irrigation by seeding treatment on globemallow emergence (mean number of seedlings/subplot ± SE) ................................................................. 71

13 Effect of seeding treatment on globemallow emergence (mean number of seedlings/cm² ± SE) ................................................................. 72

14 Effect of seeding treatment on globemallow survival (mean ± SE) ......... 74

15 Mean (± SE) dung pat weight and seed recovery/kg of dung for Fall 2001 and Spring 2003 field trials .................................................. 76

16 Mean percent germination (± SE) of undamaged recovered globemallow, squirreltail, sagebrush and shadscale seed. Control seed was unpassed, and seed from dung was collected 2 days after seed ingestion ................. 77

17 Seed recovered/kg (± SE), percent germination, and number of germinable globemallow and squirreltail seeds per 1 kg dung pat after passage through cattle in three different trials. Numbers presented are for collections made at 48 hours post-ingestion for 25,000 globemallow and 30,000 squirreltail seeds per animal ................................................................. 95

18 Analysis of variance for fecal output data.................................................. 101

19 Analysis of variance for cube root-transformed seed recovery data........ 102

20 Analysis of variance for cube root-transformed seed recovery data for Wyoming big sagebrush .................................................. 103

21 Analysis of variance for cube root-transformed seed recovery data for gooseberry globemallow ................................................................. 104

22 Analysis of variance for seed recovery data for bottlebrush squirreltail (cube root-transformed) ................................................................. 105

23 Analysis of variance for globemallow seed germination ............. 106

24 Analysis of variance for bottlebrush squirreltail seed germination (arcsine-transformed) ................................................................. 107

25 Effect of grazing intensity on globemallow emergence (mean seedlings/subplot ± SE) .................................................. 108

26 Effect of grazing intensity on globemallow survival (mean ± SE) ......... 109
27 Effect of grazing intensity on squirreltail emergence (seedlings/dung pat) in fecal seeded paddocks (mean ± SE).................................................................110

28 Effect of grazing intensity on squirreltail survival in fecal seeded paddocks (mean survival ± SE)..................................................................................111

29 Effect of irrigation on globemallow survival (mean ± SE)...........................112

30 Effect of irrigation on squirreltail emergence (seedlings/dungpat) in fecal seeded paddocks (mean ± SE).................................................................113

31 Effect of irrigation on squirreltail survival in fecal seeded paddocks (mean ± SE).................................................................................................114
<table>
<thead>
<tr>
<th>Figure</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>28</td>
</tr>
<tr>
<td>2</td>
<td>52</td>
</tr>
<tr>
<td>3</td>
<td>67</td>
</tr>
</tbody>
</table>


2. Skull Valley, Utah.

CHAPTER I
INTRODUCTION

Wildfires have the ability to significantly alter western ecosystems and generate a need for large-scale restoration (Richards et al. 1998). In 1999, the National Interagency Fire Center reported 3364 fires in the Great Basin that burned over 680,000 ha. Responsible for the Great Basin's increased fire frequency is the proliferation of cheatgrass (*Bromus tectorum* L.), one of the most widespread and flammable fuels in the arid and semiarid West (Whisenant 1990). As the cheatgrass/fire cycle is repeated, perennial species disappear and early successional habitat for new weed invasions is created (Whisenant 1990). In order to move the plant community to a more desirable stable state, human intervention is required (Westoby et al. 1989, Laycock 1991, Monsen 1992).

Following fire, federal land agencies have focused on reestablishing the grass component of rangelands in an effort to slow the proliferation of noxious weeds and to provide immediate watershed protection. The most common grass seeded is crested wheatgrass (Fairway, Nordan and Hycrest varieties, *Agropyron cristatum* (L.) Gaertn., *A. desertorum* (Fisch.) Schult., and *A. desertorum* x *A. cristatum* (Fisher ex Link) Schult., respectively), a cool season bunchgrass from Asia. All varieties have been planted extensively throughout North America, covering between 6 and 10 million ha (Rogler and Lorenz 1983, Holchek 1981). As a long-lived resilient grass, it can stabilize the soil, deter invasive weeds and provide reliable spring forage.
The same attributes that make crested wheatgrass a preferred species for rehabilitation are also cause for concern. Although it is seeded with a variety of species, the seedings can become near-monocultures and provide little improvement, in terms of diversity, compared with untreated burns that become cheatgrass dominated. Therefore, repeatedly seeding this exclusive, well-adapted species is shortsighted and at the expense of ecological diversity on western rangelands (Richards et al. 1998). As fires continue to be fueled by cheatgrass, improved methods of rehabilitation are needed.

In addition to work that has led to a better understanding of arid and semi-arid rangeland ecosystems and the limitations of monocultures (Vitousek 1990), there has been a shift in America’s social, political, and economic values. This shift has altered the way many people view western public rangelands (Box 1995, Kennedy et al. 1995), and as more of the West is urbanized at the expense of open space, rangelands are becoming attractive areas for recreation (Gutknecht 1992). As a result, there is a growing interest in how the lands are managed, which is encouraging the scientific community to develop alternative public range management practices.

The transition from a static rangeland to a more dynamic plant community requires disturbing the dominant vegetation and reseeding. Traditional methods (mechanical tilling and chemical spraying) are expensive and require resources that may not be readily available. Hence, there is a need for inexpensive and more
environmentally-oriented alternatives that satisfy multiple land management goals, including livestock, recreation, watershed, wildlife and genetic preservation.

An inexpensive, low-energy rehabilitation technique that is gaining interest is the use of cattle as seed disseminators. Many studies have been conducted to test seed viability after passage, and the results suggest that fecal seeding may be a promising tool (Simao Neto 1985, Simao Neto et al. 1987, Barrow and Havstad 1992, Ocumpaugh et al. 1996, Akbar et al. 1995, Auman et al. 1998, Shinderman 1999, Doucette et al. 2001). However, since the previous studies focused either on seed passage and post-passage germination or used artificially deposited dung pats in areas with little to no resident vegetation, more exploration is needed.

To address the possible effects of resident vegetation on the recruitment of dung-deposited seeds, Auman et al. (1998) placed artificial dung pats in plots with either cheatgrass or bottlebrush squirreltail \( [Elymus elymoides (Raf.) Swezey] \) and found that fecal seeded crested wheatgrass (Hycrest) did not produce seedlings within cheatgrass plots. However, within bottlebrush squirreltail plots, crested wheatgrass seedlings established successfully. Their study indicates that the success of disseminated seeds may be dependent upon the competitive strategies of the resident vegetation. It also suggests that success of the disseminated seeds may be improved if the resident vegetation is disturbed prior to seeding.

This project combined the practices of livestock seed dissemination and intensive grazing to test the effectiveness of cattle as a grazing management and seed dispersal tool to increase native species diversity on rangelands dominated by crested
wheatgrass. More specifically, the study investigated livestock’s ability to intensively graze crested wheatgrass at a phenological stage that is most susceptible to overgrazing, in an effort to create gaps for seedling establishment. The livestock also served as seeding/trampling agents, dispersing/planting seeds via dung or by trampling broadcast seed. The plant species used were native to the Great Basin [bottlebrush squirreltail, gooseberry globemallow (Sphaeralcea grossulariaefolia (H. & A.) Rydb.), Wyoming big sagebrush (Artemisia tridentata Nutt. ssp. wyomingensis Beetle & Young), and shadscale saltbush (Atriplex confertifolia (Torr. & Frem.)). The projected application of this study is on public Great Basin rangelands where increased species diversity is desired, but conventional reseeding techniques are either impractical due to cost or rough terrain.

To thoroughly investigate the application of fecal seeding and broadcast/trampling as a supplemental rehabilitation technique to reintroduce squirreltail, globemallow, sagebrush and shadscale to crested wheatgrass seedings in the Great Basin, it was necessary to:

1. Investigate seed passage and recovery rates, and post-passage germination of the 4 species to determine their amenability to livestock seed dispersal.
2. Evaluate intensive grazing as a method for suppressing crested wheatgrass to reduce competition between seedlings and resident vegetation.
3. Compare three seeding methods within an intensively grazed crested wheatgrass seeding (fecal seeding, broadcast/trampling and broadcast/raking).
LITERATURE REVIEW

Crested Wheatgrass

Labeled by educators, range managers and scientists as “one of the most important forage grasses of the West” (Dwyer 1986, Sharp 1986), crested wheatgrass remains the most widely used introduced grass in North America. Its popularity is due to its drought tolerance, high forage production, seeding success, and the affordability and availability of its seed (Dwyer 1986, Johnson 1986, Lesica and DeLuca 1996, Richards et al. 1998). In addition, the timing of forage production, early spring, is optimal for lactating cows with young calves (Malechek 1986). It can also form very stable stands that prevent the invasion of cheatgrass (Anderson and Marlette 1986, Johnson 1986, Lesica and DeLuca 1996).

Crested wheatgrass has evolved under 5000 years of heavy utilization in Asia, which has led to physiological adaptations that make it more grazing tolerant than many North American natives (Dwyer 1986). For instance, after crested wheatgrass is grazed, it produces photosynthetic material (tillers) rather than allocating energy to its root system like many native grasses (Caldwell et al. 1981). This helps the grazed plant quickly replace lost carbohydrates (Caldwell and Richards 1986, Olson and Richards 1988). Crested wheatgrass also produces more tillers per plant than most native species; therefore, even in the absence of grazing, it has a higher photosynthetic capacity (Caldwell et al. 1981).
Another physiological advantage of crested wheatgrass is the efficiency at which it can extract soil water and nutrients, enabling it to resume growth in early spring (Trlica and Biondini 1990, Meays et al. 2000). Peak production, between April and June, with 90% of its total annual yield before July (Meays et al. 2000), keeps evaporation and transpiration losses minimal (Miller and Rose 1992). Early spring growth of crested wheatgrass is possible due to its ability to extract soil moisture 2 to 3 weeks earlier than neighboring native plants (Trlica and Biondini 1990). The success of crested wheatgrass is also dependent on its seed release, which occurs throughout the year. This adaptation minimizes seed loss to depredation and increases the chance a seed will land in a patch with favorable germination conditions (Meays et al. 2000). Crested wheatgrass also reproduces by tillers. The tillers produced in the fall over winter in a 1-3 phytomer state and resume growth in early spring (Meays et al. 2000).

Some land managers and scientists are concerned by the permanent stable state created by crested wheatgrass seedings (Anderson and Marlette 1986, Johnson 1986, Lesica and DeLuca 1996). Reasons for concern include reduced plant diversity, visually altered landscapes, a higher percentage of bare ground, less natural succession (Dormaar et al. 1995, Christian and Wilson 1999), and a lower diversity of vertebrates and invertebrates than in areas with greater plant diversity (Lesica and DeLuca 1996). Also, there is the opinion that any non-native plant is a biological invader. In addition to the more noticeable alterations of composition and community structure, monocultures can alter subtle properties of entire ecosystems
including productivity, nutrient cycling and hydrology (Vitousek 1990). Recently an additional subtlety of monocultures has been recognized: reduced biochemical diversity (Provenza et al. 2003). Biochemical diversity is desirable since herbivores utilize available forage more effectively on rangelands that contain an amalgam of chemotypes. With a greater variety of forage, range use can improve and weight gains can increase (Early and Provenza 1998, Villalba and Provenza 1999, Scott and Provenza 1998, 2000, Atwood et al. 2001a,b, Provenza et al. 2003).

Rangeland Rehabilitation Following Fire

The expense associated with fire rehabilitation is enormous. For example, in 1996 more than 800,000 ha burned in the West and only 14% of the land was reseeded, costing over $21 million (Roundy et al. 1997). Similarly in 1999, 680,000 ha burned in the Great Basin. Forty million dollars were spent to reseed 33% of the burns at a cost of $178/ha (USDI 1999). Due to the high cost and the limited number of ha that can be treated each year, cost-effective, large-scale rehabilitation techniques are needed to augment current efforts.

A lack of effective economical and ecological techniques for arid land rehabilitation has proven costly. Herrick et al. (1996) suggest that new remediation technologies focus on an ecologically-based approach in which more limited inputs are targeted to promote natural processes of regeneration. In other words, move away from “forced” agronomic practices to favor more environment-friendly techniques that recognize the importance of maintaining soil, water, air and aesthetic
qualities of natural landscapes (Herrick et al. 1996). Less dependence on expensive agronomic practices will lower costs and maintain more natural landscapes; however, since the process is slower, the risk of weedy invasions and erosion is increased.

Current agronomic practices can cause similar susceptibilities when large-scale disturbances are used to clear vegetation prior to seeding. If seedings fail following vegetation removal, weed and erosion problems are exacerbated. Herbicide treatments are less harmful to soil resources, but they are expensive and oftentimes ineffective or short-lived. Herbicides can also have negative impacts on water resources and non-target species (Herrick et al. 1996).

To create a shift in rangeland remediation practices, Herrick et al. (1996) suggest using readily-available “natural” dispersal systems as an alternative to conventional seeding methods. Areas of study have included using livestock and rodents as seed dispersal agents (Herrick et al. 1996). Others (MacMahon 1987, Rendente and DePuit 1988, Hironaka 1994, Brown and Amacher 1997) have suggested planting native species that are early successional to help jumpstart a natural successional process on degraded rangelands. The high cost and low availability of native seeds, however, can be prohibitive.

Learning to rebuild a functioning ecosystem by seeding within established plant communities will require more research. More needs to be understood concerning the mechanisms that promote germination, seedling establishment and plant community development to successfully establish and maintain biologically
diverse ecosystems (Call and Roundy 1991, Richards et al. 1998, Chambers 2000). As the complex interrelationships among plants, animals, microorganisms, soil processes and climatic factors are better understood, ecologists and land managers will be better equipped with methodologies to develop successful and biologically diverse plant communities.

Grazing as a Vegetation Manipulation Tool

Controlled grazing can be an effective tool for manipulating plant species composition. Careful management that controls the time of grazing and the stocking rate can lead to heavy utilization of undesirable plants and create a shift in plant composition that gives favored species a competitive advantage (Vallentine 1989). More specifically, grazing undesirable plants during a phenological stage that is detrimental to plant production can give land managers increased leverage to prevent the spread or continuation of unwanted species (Vallentine 1989). Well-timed grazing of undesirables can also be used to “open up” an area in preparation for seeding perennials (Vallentine and Stevens 1992).

Doescher et al. (1987) advocate the use of domestic livestock grazing to promote the establishment and growth of conifer plantations by controlling livestock numbers, timing and distribution. The studies Doescher et al. (1987) review, demonstrate that livestock, similar to an herbicide treatment, can create open areas for seedling establishment by significantly reducing herbaceous cover. Using
livestock, however, can be less expensive and more environmentally friendly than conventional herbicides (Doescher et al. 1987).

Studies focusing on the intentional reduction of grass species in a rangeland setting are limited to invasive annual species, such as cheatgrass. In Nevada, a clipping study by Tausch et al. (1992) demonstrated that late spring clipping (corresponding to early boot stage) had the largest reduction in both tiller density and biomass of cheatgrass. Another study has shown with only 1 week of intensive late-spring grazing, cheatgrass biomass was reduced, and the desirable perennial grasses were able to recover from a 7.6-cm stubble height when rested in the following weeks (Mosley 1996). Finnerty and Klingman (1962) demonstrated that cheatgrass is significantly reduced with two successive years of grazing by preventing the production of cheatgrass seed. Also, by decreasing the number of cheatgrass seeds produced, the mulch layer necessary for cheatgrass germination is negatively affected (Young and Tipton 1990).

This management practice does have complications. Since cheatgrass can still produce seed after the initial grazing treatment, some have recommended grazing an area twice, approximately 3 to 4 weeks apart (Hulbert 1955). Others are hesitant to recommend two intensive grazing periods, since it may prove more detrimental to the coexisting perennials than to cheatgrass (Tisdale and Hironaka 1981, Young et al. 1987).

Few studies, if any, have focused on grazing to reduce plant biomass and reproductivity in perennial grass communities. In contrast, studies have sought to
find the most grazing resistant phenological stages. For the Great Basin's native and introduced grass communities, short duration grazing that avoids utilization during culm elongation or between the early boot and dough stages is recommended (Stoddart 1946, Olson and Richards 1988, 1989, Miller and Rose 1992, Romo and Harrison 1999). If grazing occurs after culm elongation, the apical meristem and culm leaves are elevated and more susceptible to removal by herbivores (Caldwell et al. 1981). These studies support the practice of monitoring the phenological stages of plant growth in order to direct plant species composition with short, intensive grazing treatments as a proactive management strategy.

Trampling as a Method of Seed Incorporation

The first requirement for germination of a non-dormant seed is to access soil moisture necessary for seed hydration (Fenner 1985). This can be aided by a heterogeneous microtopographic soil surface to reduce seed water loss, thus enhancing germination (Harper et al. 1964, 1970, Sheldon 1974, Oomes and Elberse 1976). For instance, rough soil surfaces aid seeds in water uptake by lowering the energy (the soil's matric potential) needed to draw water from the soil. In contrast, smooth soil surfaces may create matric potentials that are too low for a seed to extract enough water for germination (Fenner 1985).

Due to the inherent difficulties of measuring soil microtopography and quantifying soil disturbance caused by livestock trampling, little research has evaluated it as a technique for incorporating seed into the soil. There are, however, a
few studies that suggest trampling may be a promising tool (Pearson and Ison 1987, Vallentine 1989, Winkel and Roundy 1991a, b, Mosley 1996). In Arizona, Winkel and Roundy (1991b) and Winkel et al. (1991) investigated the effects of light and heavy trampling on grass seed burial and subsequent seedling emergence. They found that trampling buried between 17 and 75% of the broadcast seed with greater emergence for larger-seeded grasses. Smaller-seeded grasses were often buried below their biological limits. The success of trampling (measured by the percentage of seedlings established) was also highly dependent on soil moisture. Similar to the other soil disturbance methods investigated, trampling was most effective when soil moisture was high. Life form of the species, in conjunction with different intensities of trampling, may also affect emergence results. Eckert et al. (1996) found that moderate trampling enhanced perennial grass emergence, but it decreased the emergence of perennial forbs; whereas heavy trampling decreased perennial grass emergence, and on some microsites, enhanced sagebrush and annual forb emergence.

A recent study on the effects of trampling on physical properties of a fine, sandy loam soil in a New Zealand hill land pasture demonstrated that short-term trampling did not have an adverse effect on sediment loss or soil water infiltration if the vegetation (a perennial grass/clover mix) was at least 20-mm tall, and the percentage of bare ground was greater than or equal to 10.8% (Russell et al. 2001). The study concluded that even in the presence of increased surface roughness caused by hoof damage, the presence of vegetation prevented overland flow of water and intercepted enough precipitation to serve as a buffer during rain events. These
results suggest that short periods of intensive grazing to remove resident vegetation and incorporate broadcast seed should not adversely affect a soil’s physical properties. In addition to incorporating seed, trampling has been suggested as a tool to increase infiltration rates. Eldridge and Robson (1997) found that the soil crust on their unplowed and ungrazed study plots experienced more runoff and sediment loss due to lower infiltration rates and suggested livestock trampling as a tool for seedbed preparation to increase infiltration rates.

In contrast to studies and recommendations advocating the possible benefits of trampling, others have concluded that “hoof action” has negative impacts on the physical properties of soil during intensive grazing practices due to lowered aggregate stability and compaction (Warren et al. 1986). As indicated by inconsistencies in the literature, there are many interacting variables (soil moisture, texture, and structure) that determine the effectiveness of trampling as a rehabilitation tool on a site by site basis.

Broadcast Seeding

Broadcast seeding entails scattering seed on a soil surface without soil coverage. It can be accomplished aerially from a plane or helicopter, by hand or with broadcasters mounted on a tractor or tillage implement (Holechek et al. 1989, Vallentine 1989). Because it is a quick method of direct planting on rough terrain where drilling is impractical, it is one of the most widely used seeding techniques.
Broadcast seeding is most effective in areas having little resident vegetation, unconsolidated litter and naturally loose soils (Vallentine 1989). Species successful in broadcast seedings either germinate under brief, favorable conditions or in cool, dry environments (Nelson et al. 1970). Small seeded species, such as Wyoming sagebrush, are easily incorporated into the soil and also respond well (Vallentine 1989, Meyer 1992).

There are many limitations to broadcast seeding, however (Holechek et al. 1989). Due to losses from rodent and bird depredation, a heavy seeding rate is required. Compared to drill seeding, seed is poorly covered and distributed, and establishment can be slow. To ensure a high success rate, good seed-to-soil contact must be accomplished, which typically requires mechanical techniques that can be difficult and expensive when used on rough terrain (Archer and Pyke 1991). As a consequence, low success rates are common.

Fecal Seeding

A possible alternative to conventional rangeland seeding (drill or broadcast) is seed dispersal by livestock. Seeds of desired species are fed to livestock, pass through the gut, and are deposited within a moist, favorable environment for germination (Janzen 1984, Herrick et al. 1996). Because of the nature of dung pat deposition, seeds would be distributed in patches across the landscape, theoretically producing satellites of desirable species that have the potential to gradually increase in size and number through seed propagation or vegetative reproduction (Archer and
Seeding with livestock may be especially effective in remote areas that are inaccessible to conventional seeding equipment (Archer and Pyke 1991, Barrow and Havstad 1992).

Information is limited on the use of livestock as seed dispersal agents in the Great Basin (Auman et al. 1998); however, it is gaining recognition as a method to reintroduce desirable species on degraded rangelands in other geographic areas (Archer and Pyke 1991, Traba et al. 2003). Despite the interest, there has been little applied research testing livestock as seed dispersers in a managerially realistic field environment, hence its applicability warrants testing.

Previous studies on the use of fecal seeding have investigated artificially placed dung pats in a variety of environments. The results have been mixed. Auman et al. (1998) delivered crested wheatgrass seeds via dung to cheatgrass plots with little success. In contrast, dung containing crested wheatgrass seeds effectively suppressed squirreltail and opened up interspaces for the establishment of crested wheatgrass. Another study compared the establishment of fecal and broadcast-seeded switchgrass (*Panicum virgatum*) in south Texas (Ocumpaugh et al. 1996). Fecal-seeded switchgrass had equal to superior recruitment in spite of 1.5 to 1.7 times more pure live seed (PLS) used in the broadcast seeding. The fecal-seeded plots also produced plants with greater biomass, height and culm density, suggesting additional advantages over conventional broadcast seeding. Limitations to this study include a lack of resident vegetation and artificially deposited dung.
Other studies have investigated seed properties and other environmental factors that influence seed viability through mastication and digestion. These include the effect of gut retention time, seed size and hardness, presence or absence of a seed coat and the animal’s diet (Simao Neto et al. 1987, Barrow and Havstad 1992, Ocumpaugh et al. 1996). Seed passage studies have been conducted on various range and agronomic species (Simao Neto et al. 1987, Barrow and Havstad 1992, Akbar 1994, Akbar et al. 1995, Ocumpaugh et al. 1996, Shinderman 1999, Doucette et al. 2001). The results have been varied and species dependent (Doucette et al. 2001). The selection of species with seed properties resistant to digestive processes (to retain high germinability) and properties that reduce retention time in the gut (Gardener et al. 1993) is restrictive but critical, and it demonstrates that livestock seed dispersal is not a viable seeding option for all plant species.

LITERATURE CITED


SIMAO NETO, M. 1985. Recovery viability and potential dissemination of pasture seed passed through the digestive tract of ruminants. Doctoral dissertation, University of Queensland, Brisbane, Australia.


STODDART, L.A. 1946. Some physical and chemical responses of Agropyron spicatum to herbage removal at various seasons. Utah Agricultural Experiment Station Bulletin 324, Utah State University, Logan. 24 pp.


CHAPTER II

RECOVERY AND GERMINABILITY OF NATIVE SEED FED TO CATTLE

ABSTRACT

Fire frequency and intensity are increasing on rangelands in the Great Basin, resulting in simplified plant communities. A nontraditional seeding method, utilizing livestock as seed dispersal agents, may be an effective mechanism to increase species diversity on degraded and previously seeded rangelands. We quantified seed passage and recovery rates and post-passage germinability of a native shrub (Artemisia tridentata Nutt. ssp. wyomingensis Beetle & Young), grass (Elymus elymoides (Raf.) Swezey) and forb (Sphaeralcea grossulariaefolia (H. & A.) Rydb.) by feeding Holstein heifers seeds of each species at 3 levels (15,000, 30,000, and 60,000 seeds) over a period of 3 weeks. One-kg fecal samples were collected 1, 2, 3, and 4 days after seed ingestion. Undamaged seeds were extracted from the samples, placed in a germination chamber on moistened filter paper and tested for germinability. Sphaeralcea had the highest percentage of recovered, undamaged seed, followed by Elymus and Artemisia. Sphaeralcea and Artemisia seed passage was highest on Day 1, after which seed numbers dropped sharply. Elymus passage and recovery were more consistent through time, with higher seed recovery at lower seed feeding levels. Post-passage germinability was highest for Elymus and Sphaeralcea on Day 1. Artemisia germination was negligible. Differences in physical seed properties (size, shape, and seed coat) likely influenced interspecies
variation in passage, recovery and germinability. This study suggests *Sphaeralcea* and *Elymus* seeds are suited for livestock dispersal, but *Artemisia* seeds are not.

**INTRODUCTION**

Livestock seed dispersal is gaining recognition as a method to reintroduce desirable species on degraded rangelands (Archer and Pyke 1991). Seeds fed to livestock pass through the gut and are deposited in a favorable environment for germination and establishment (Janzen 1984, Herrick et al. 1996). Due to the nature of dung pat deposition, seeds are distributed in patches across the landscape. If seeds germinate and become established plants, satellites of desirable species with the potential to increase in size and number through vegetative propagation or seed production are created (Archer and Pyke 1991). Since dung pats persist in arid climates (Bornemissza 1960), livestock seed dispersal may be well-suited to distribute and store long-lived seeds on the landscape until conditions are favorable for germination and establishment. Although slower than more traditional methods, livestock seed dispersal may be a long-term rehabilitation technique that can incrementally increase plant diversity across a landscape.

Seed properties of selected species, such as size, shape, density, and seed coat smoothness and hardness, are important determinants in the success of livestock seed dispersal as a revegetation tool (Gardener et al. 1993, Simao Neto et al. 1987). The selection of species with seed properties resistant to digestive processes (to retain high germinability) and properties that reduce retention time in the gut (Gardener et
al. 1993) is restrictive but critical for success, and demonstrates that livestock seed dispersal is not a viable seeding option for all plant species.

Despite these complexities, interest in this alternative seeding method continues to increase. Several seed feeding trials have quantified seed passage and post-passage germination for a number of plant species (Gökbulak 2002, Doucette et al. 2001, Al-Mashkhi 1993, Simao Neto et al. 1987), and others have quantified seedling emergence and survival in artificial dung pats (Shinderman and Call 2001, Ocumpaugh et al. 1996, Gardener et al. 1993, Barrow and Havstad 1992). Results have been varied and species dependent (Doucette et al. 2001). Many studies have used seed properties to explain differences in rates of passage, recovery and post-passage germinability; however, the results have been inconclusive.

The primary objective of this study was to determine the efficacy of livestock seed dispersal for 3 native species, globemallow (*Sphaeralcea grossulariaefolia* (H. & A.) Rydb.), bottlebrush squirreltail (*Elymus elymoides* (Raf.) Swezey), and Wyoming big sagebrush (*Artemisia tridentata* Nutt. spp. *wyomingensis* Beetle & Young), based on seed passage, recovery and post-passage germinability. We were also interested in the influence of seed level intake and gut retention time on seed passage, recovery, and germinability, and how physical seed characteristics may explain the outcome.
MATERIALS AND METHODS

The 3 plant species selected for this study are cool-season, drought tolerant perennials native to the Great Basin region of the western United States. They represent 3 life forms (grass, forb, and shrub) historically present at a companion field study site in Skull Valley, Utah. Seeds were obtained from a commercial seed source (Granite Seed Company, Lehi, Utah) in July 2001 and stored at 20°C in plastic gunnysacks for 1 month prior to the start of the study. Bottlebrush squirreltail is a short-lived perennial grass species with an elongated seed, and was chosen for this study because of its early seral characteristics (Jones 1998, Hironaka 1994). Gooseberry globemallow, a broadleaf herbaceous species, was chosen for its ability to colonize disturbed areas (Wasser 1982). The seed is dense, kidney-shaped and has a hard, smooth seed coat. Wyoming big sagebrush, an evergreen shrub that provides

Figure 1. Seeds of species fed to Holstein heifers. Clockwise from top: bottlebrush squirreltail, gooseberry globemallow, and Wyoming big sagebrush.
cover and winter forage for wildlife, was chosen because it is disappearing on Great Basin rangelands due to increased fire frequency. Its seed is a very small, delicate achene (Fig. 1).

Seed weight, size (length and width), and relative specific gravity were measured to describe physical seed characteristics for each species (Table 1). Ten 50-seed aliquots of each species were weighed to obtain an average 50-seed weight for each species. One hundred seed lengths and widths of each species were measured with the aid of a dissecting scope and the average value is reported in Table 1. Relative specific gravity was determined by placing three 50-seed replicates of each species in water that contained a drop of dishwashing detergent to reduce surface tension (Ortmann et al. 1998). Sagebrush and globemallow seed sank, in addition to half of the squirreltail seed.

A study was conducted in August 2001 at the Caine Dairy Farm at Utah State University to quantify seed passage rates and seed recovery. Nine Holstein heifers, similar in age (21 ± 4 months old), weight (568 ±79 kg) and gestation (79 ± 23 days pregnant), were kept in separate tie stalls for three 5-day trials. The heifers were fed a standard grass hay diet (Bromus inermis Leysser, Dactylis glomerata L., Festuca arundinacea Schreb., Phleum pratense L., Juncus spp.; 69% in vivo dry matter digestibility, 7.8% crude protein, 63.3% neutral detergent fiber and 39.2% acid detergent fiber) ad libitum in the morning and evening and had continual access to water. For 2 mornings prior to the start of the study and every morning thereafter,
Table 1. Physical characteristics (± SE) of sagebrush, globemallow, and squirreltail seed fed to heifers.

<table>
<thead>
<tr>
<th>Species</th>
<th>50-seed weight (mg)</th>
<th>Length (mm)</th>
<th>Width (mm)</th>
<th>Specific gravity</th>
<th>Volume of bulk seed fed (mL)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>15,000 seeds</td>
</tr>
<tr>
<td>Sagebrush</td>
<td>8 (± 0.2)</td>
<td>1.3 (± 0.0)</td>
<td>0.6 (± 0.0)</td>
<td>&gt;1</td>
<td>113</td>
</tr>
<tr>
<td>Globemallow</td>
<td>50 (± 0.4)</td>
<td>1.6 (± 0.0)</td>
<td>1.3 (± 0.0)</td>
<td>&gt;1</td>
<td>18</td>
</tr>
<tr>
<td>Squirreltail</td>
<td>253 (± 2.5)</td>
<td>9.3 (± 0.1)</td>
<td>1.6 (± 0.0)</td>
<td>≤1</td>
<td>300</td>
</tr>
</tbody>
</table>

500mL of calf feed (IFA Newborn Calf “D” 18% Starter with steamed flaked soybeans and Deccox®) mixed with 30 mL liquid molasses was fed to familiarize the heifers with the medium used to facilitate seed feeding. Between trials, the heifers were released for 48 hours and allowed to move freely.

Three heifers were assigned to each species and fed 15,000, 30,000, or 60,000 seeds, with a different seed feeding level for each of the 3 trials. On the first morning of each trial, the assigned seed amount was added to the calf feed/molasses mixture in a 2:1 ratio of calf feed to seed. Molasses was used to adhere the seed to the calf feed. One kg fecal samples were collected from the rectum 1, 2, 3, and 4 days after the seed was ingested to test for daily variation in seed passage, recovery, and germinability. Samples were weighed on site and immediately washed through a series of sieves. The residual fiber and seed were transported to the lab and air-dried. Samples containing squirreltail and globemallow seeds were run through an air column seed separator to remove the finer material. The remaining material was examined using a 10x-magnifying lens to separate seed from fiber. Sagebrush seed was too light for the seed separator; therefore, the dried samples were sorted by hand.
under a dissecting scope to recover and count the seed. Once extracted from the dung samples, the seeds were divided into 3 categories: damaged, undamaged, and germinated. To determine the effect of seed intake level and gut retention time on seed passage rate and recovery for each species, the cumulative seed count (from the 1kg samples from all 3 trials) for each species/feeding level/collection time was multiplied by the total fecal output/day.

To test germinability following passage, 4 replicates of 25 undamaged seeds for each species, seed intake level, and collection time were placed on moistened filter paper in petri dishes in a germination chamber set at 10°/20°C with a 12-hour photoperiod. The control included 4 replicates of 25 unpassed, undamaged seeds of each species. The seeds were monitored daily for 28 days. As seeds germinated (when coleoptile emerged and the radicle elongated to at least 5 mm, Copeland 1978), they were removed and recorded. Due to the number of samples, petri dishes were stacked 5-6 high. To account for any light or temperature variability within the germination chamber, the petri dishes were rotated daily within the stacks, which were rotated within the chamber. Since a number of treatments had fewer than 100 seeds/kg sample, germinability was reported as a percentage to provide a meaningful comparison between treatment combinations.

Dung was collected from each heifer twice a day and weighed on site to quantify total fecal output/day. One hundred g samples were collected on the 2nd day of the 3rd trial from each heifer, placed in a drying oven for 48 hours at 60°C and re-weighed to quantify moisture content of the dung.
A Latin square experimental design was used, with heifer and trial as the blocking factors. The 3 factors were plant species (sagebrush, globemallow and sagebrush), seed intake (15,000, 30,000, and 60,000 seeds/heifer), and seed collection day (Days 1-4). Fecal output, percent recovery of undamaged seed, and germination were analyzed using analysis of variance when residuals could be normalized (SAS 2001). If normalization was not possible, means and standard errors (SE) were calculated. Fecal output and recovery models included 4 explanatory variables: trial, species, seed intake, and collection day. Percent recovery was also analyzed by individual species using 2 explanatory variables: seed intake and collection day. Seed recovery percentages were cube root-transformed prior to running an analysis of variance.

Germination of undamaged seed for each species was analyzed by time. Arcsine-transformed germination data were used for squirreltail analysis, and raw germination data were used for globemallow analysis. Sagebrush germination residuals could not be normalized.

**RESULTS**

**Fecal Output**

The mean fecal output/heifer/day (± SE) was 14.9 kg (± 0.41). The species of seed eaten and the amount of seed fed were not significant in determining output (p=0.4609 and p=0.4849, respectively) (Appendix Table18). Variation in output was significantly affected by trial and day (p<0.0001 for both). Output gradually
increased from trial 1 to 3 and was highest on Days 2-4. The moisture content of the
dung was 84.6% (± 0.003).

Seed Recovery

Undamaged seed recovery (hereafter, seed recovery) differed among species
and gut retention times (p<0.0001 for both), but not by trial or seed intake level
(p=0.1271 and p=0.7725, respectively) (Appendix Table 19). The effects of gut
retention time and seed intake level on seed recovery were also analyzed by species.
Sagebrush, globemallow, and squirreltail seed recovery were all affected by gut
retention time (p<0.0001, p<0.0001 and p=0.0022, respectively) (Appendix Tables
20-22). Seed intake did not affect seed recovery of sagebrush and globemallow
(p=0.9472 and p=0.8131, respectively); however, it did affect the recovery of
squirreltail seeds (p=0.0003) (Appendix Tables 20-22).

Total seed recovery was highest for globemallow, followed by squirreltail
and sagebrush (Table 2). Seed recovery by day was highest on Day 1 for sagebrush

Table 2. Mean (± SE) seed recovery (% of seed ingested) of sagebrush, globemallow and
squirreltail collected from dung 1, 2, 3, and 4 days after seed ingestion (n = 9).

<table>
<thead>
<tr>
<th>Species</th>
<th>Recovery by day (%)</th>
<th>Total Recovery (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>1</td>
<td>2</td>
</tr>
<tr>
<td>Sagebrush</td>
<td>7.3 (± 2.4)</td>
<td>1.0 (± 0.3)</td>
</tr>
<tr>
<td>Globemallow</td>
<td>28.3 (± 10.5)</td>
<td>16.5 (± 3.9)</td>
</tr>
<tr>
<td>Squirreltail</td>
<td>5.9 (± 1.0)</td>
<td>7.4 (± 1.4)</td>
</tr>
</tbody>
</table>
and globemallow. Sagebrush seed recovery declined progressively from Day 1 to Day 3, and globemallow recovery continued to decline through Day 4. Squirreltail seed recovery was more consistent over time.

Unlike globemallow and sagebrush, squirreltail recovery numbers were dependent on seed intake level (Table 3). When 15,000 squirreltail seeds were fed, percent recovery was consistent over time; however, at the higher seed intake levels, seed recovery declined between Days 2 & 3, and 3 & 4. A comparison of percent seed recovery by day across seed intake levels shows lower squirreltail recovery at the 60,000-intake level on Days 2-4. Total recovery also dropped as the number of seeds fed increased.

Seed Germinability

Post-passage germinability values differed by species and gut retention time (Table 4). Analyzed by species, gut retention time influenced the germinability of globemallow and squirreltail (p=0.0207 and p>0.001, respectively) (Appendix Tables 23 & 24). Post-passage sagebrush germination was negligible (only 1 seed germinated). The reduction in seed germinability due to passage was lowest for globemallow, followed by squirreltail. Germinability was highest for globemallow and squirreltail when gut retention time was minimized. Squirreltail germinability declined from Days 1-3, but leveled off by Day 4. Globemallow germinability declined from Day 1 to Day 2 but not from Day 2 to Day 3. There was an
Table 3. Mean (± SE) squirreltail seed recovery (% of seed ingested) from dung 1, 2, 3, and 4 days after seed ingestion. Heifers were fed 3 quantities of seed (15,000, 30,000, 60,000) (n = 3).

<table>
<thead>
<tr>
<th>Number of seeds fed</th>
<th>Recovery by day (%)</th>
<th>Total recovery (%)</th>
<th>Total number of seeds recovered</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>1</td>
<td>2</td>
<td>3</td>
</tr>
<tr>
<td>15,000</td>
<td>6.8 (± 1.3)</td>
<td>8.3 (± 2.8)</td>
<td>8.7 (± 1.5)</td>
</tr>
<tr>
<td>30,000</td>
<td>6.2 (± 3.1)</td>
<td>10.0 (± 2.7)</td>
<td>4.0 (± 0.5)</td>
</tr>
<tr>
<td>60,000</td>
<td>4.8 (± 0.5)</td>
<td>4.3 (± 0.6)</td>
<td>2.3 (± 0.7)</td>
</tr>
</tbody>
</table>

insufficient number of globemallow seeds recovered on Day 4 to test for germination.

Recovered seeds classified as "germinated" during the recovery process were between 2-4% of the total recovered seed count for globemallow at all collection times, and 3% for squirreltail on Day 1. Four germinated sagebrush seeds (0.11%) were found in the recovered seeds from Day 1.

Table 4. Mean (± SE) germination of unpassed (Day 0) and passed globemallow, squirreltail and sagebrush seed. Passed seed collected 1, 2, 3, and 4 days after heifers ingested seed (n = 12).

<table>
<thead>
<tr>
<th>Species</th>
<th>Mean germination by day (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>0</td>
</tr>
<tr>
<td>Sagebrush</td>
<td>64 (± 7.5)</td>
</tr>
<tr>
<td>Globemallow</td>
<td>40 (± 1.6)</td>
</tr>
<tr>
<td>Squirreltail</td>
<td>90 (± 3.8)</td>
</tr>
</tbody>
</table>

<sup>a</sup> n = 10
§ Too few seeds recovered to test germination
DISCUSSION

Increased gut retention time often correlates to lower recovery rates and post-passage germinability, as found with all 3 species tested in this study. The germinability of squirreltail, globemallow, and sagebrush seed was reduced 56%, 67%, and 100%, respectively, after 1 day in the gut of a heifer. Similar reductions in post-passage germinability have been noted for several other native grass and forb species of western North America, including *Bouteloua curtipendula*, *Poa secunda*, *Pascopyrum smithii*, *Nassella viridula*, *Buchloe dactyloides*, *Panicum virgatum*, *Pseudoroegneria spicata*, *Elymus cinereus*, *Hesperostipa comata*, *Achnatherum hymenoides*, *Alkali sacaton*, *Sporobolus airoides*, *Balsamorhiza sagittata*, *Sphaeralcea coccinea*, *Ratibida columnifera*, and *Linum lewisii* (Gökbulak 2002, Doucette et al. 2001, Shinderman and Call 2001, Gökbulak 1998, Ortmann et al. 1998, Ocumpaugh et al. 1996, Al-Mashikhi 1993, Barrow and Havstad 1992).

Exceptions include legumes with high hard seed content, which are protected from digestive processes and successfully disseminated in dung (Gardener et al. 1993), and species whose seeds require scarification (e.g. *Atriplex canescens*, Barrow and Havstad 1992, *Prosopis glandulosa* var *glandulosa*, Kneuper et al. 2003).

Physical seed properties influence passage, recovery and post-passage germinability of seeds ingested by ruminants. The effect of a seed characteristic on post-passage recovery and germination is often influenced by the morphology of the gastro-intestinal tract. Small, round seeds with smooth exteriors typically have faster passage rates, higher recovery, and improved germinability because they more
readily separate from the digesta than those with rough or elongated seeds (Gardener et al. 1993). Also, the reticulo-omasal orifice in cattle (1-2.5mm in diameter) restricts the passage of large particles from the rumen to the omasum (Poppi et al. 1980). As a result, larger seeds are subject to repeated rumination and mastication.

Materials in the rumen are stratified into 3 primary zones based on their specific gravity; therefore, seed density can influence recoverability and germinability of ingested seed. Ruminal contractions flush lighter solids back into the rumen, and smaller, denser materials are passed through the reticulo-omasal orifice (Church 1988, Van Soest 1994). These physiological occurrences may explain the positive correlation between seed density and seed survival for grasses (Ocumpaugh et al. 1991), and in this study, explain the quick passage of the denser seeds, globemallow and sagebrush, and the more consistent passage of squirreltail.

Seed coat hardness can increase the likelihood of seed survival by protecting the seed from mastication and digestion (Archer and Pyke 1991). Soft-coated seeds can imbibe water, exposing the embryo to a caustic environment within the digestive tract (Mohamed-Yasseen et al. 1994). Very few sagebrush seeds were recovered (approximately 0.6% of the total ingested), and only 1 germinated in the germination experiment. Its soft seed coat (Shaw personal communication 2001) likely superseded its beneficial size and density. The seed coat of squirreltail may be more susceptible to time spent in the gut than globemallow, as indicated by a greater than 50% drop in germination between Day 1 & 2, and Day 2 & 3. Also, germinated
squirreltail seeds were only recovered from the dung samples collected on Day 1, suggesting that imbibed seeds after Day 1 may have been completely digested.

In addition to a less protective seed coat and a specific gravity close to 1, the shape and size of squirreltail may also contribute to consistent passage and recovery rates. The elongated shape of squirreltail seed makes it more susceptible to mastication and less likely to pass through the reticulo-omasal orifice (Russi et al. 1992). In addition, the average length of squirreltail seed is approximately the size of ingesta particles that trigger rumination (10 mm, Welch and Hooper 1988). The precise alignment necessary to exit the rumen may explain the negative effect seed intake level had on squirreltail. As the number of seeds increase, more become trapped, rumination is triggered with damage resulting from repeated mastication.

The physical properties of globemallow seed (dense, with a smooth, hard seed coat) are those favored for high passage rates (Gardener et al. 1993), and likely played a role in the seed’s high passage rate within 2 days of ingestion. Half of the seed ingested was recovered, more than twice the recovery of squirreltail and 6 times the recovery of sagebrush. Globemallow also had the most consistent post-passage germination (8.7-17.7%), with 2-4% of the seed extracted from the dung samples already germinated. A hydrophobic substance on the seed coat of globemallow may have also aided globemallow recovery and germination by preventing some of the seed from imbibing water and prematurely exposing the embryo and cotyledons (Page et al. 1966).
Differences in recovery are difficult to explain solely on the relationship between physical seed properties and digestive tract morphology. For instance, seed of *Poa secunda* are half the size of squirreltail and *Pseudoroegneria spicata* seed. Therefore, based on its smaller size, it is reasonable that *P. secunda* would have the highest recovery (Gökbulak 1998), but it would also be expected that *P. spicata* and squirreltail would have similar recoveries. Instead, *P. spicata* and *P. secunda* recovered on Day 1 in Gökbulak’s study, regardless of amount fed, were 5-6 times that of squirreltail (Gökbulak 1998). This suggests that there are factors, other than the physical seed characteristics discussed here, that affect passage and recovery rates.

Another factor that may influence seed recovery is seed intake level, which has not been widely explored. Prior to this study, only 6 species (4 grasses and 2 legumes) have been fed in different amounts to test its effect on seed recovery. One study used sheep (Jones and Simao Neto 1987) and the other used steers (Gökbulak 1998). Although we cannot directly compare results since age, size, sex, and species of ruminant can influence digestion (Lyford 1988, Simao Neto et al. 1987), there are some commonalities. For instance, the level of sagebrush and globemallow seed intake did not affect percent seed recovery in Holstein heifers as found in sheep with 4 pasture species, 2 that have similar seed size and weights to globemallow and sagebrush (*Trifolium semipilosum* cv. Safari, a legume and *Axonopus affinis*, a grass) (Jones and Simao Neto 1987). Similarly, Gökbulak (1998) found the level of seed intake did not influence *P. spicata* in Holstein steers. In contrast, we found
squirreltail seed recovery declined as seed intake increased, as Gökbunak (1998) found with *P. secunda* seed. Based on Jones and Simao Neto (1987) and Gökbunak (1998), in addition to this study, it is less common for seed passage to be affected by seed intake level, and the mechanisms that create the effect are not clear.

In addition to the effect of physical seed properties and seed intake, a general relationship between grass morphology and post-passage seed survival has been noted (Gardener et al. 1993). Grass species with high seed survival are generally dense, low-growing rhizomatous or stoloniferous grasses, such as those found in shortgrass prairie. Out of necessity, seeds of these species are better adapted to seed dispersal by ruminants than bunchgrasses because their seed heads are close to, and ingested with, the foliage by grazing animals. For instance, the seeds of *Buchloe dactyloides* (Nutt.) Engelm. (buffalograss) and *Pennisetum clandestinum* Hochst. ex Chivo. cv. Whittet (kikuyu) are small (less than 4 x 4 mm) and have specific gravities greater than 1.0 (Quinn et al. 1994, Gardner et al. 1993). The hard globular diaspor of buffalograss also provides protection during passage (Quinn 1987, 1991, Quinn and Engel 1986). These adaptations are described in detail in the “Foliage is the Fruit” hypothesis proposed by Jansen (1984) and have been revisited by Gardener et al. (1993) and Quinn et al. (1994). Grass seeds not resistant to digestion are those less likely to be eaten. These are found in taller tussock grasses, such as bottlebrush squirreltail.

Although it is unlikely that squirreltail, globemallow and sagebrush are adapted to natural seed dispersal by ruminants based on ruminant physiology, and
plant morphology and phenology, our results indicate that globemallow and squirreltail may be amenable to fecal seeding. Simao Neto et al. (1987) and Auman et al. (1998) suggest feeding seed in smaller quantities, to more animals, and at more frequent intervals to diffuse the effects of seed depredation and increase germinable seed distribution. Therefore, we recommend feeding globemallow and squirreltail seed at a rate of 30,000 seeds/species/cow every 3 days, preferably in the fall. The potential seed distribution, based on the heifers in this study, could be fifteen 1kg dung pats/day with 100 and 29 germinable globemallow seeds/dung pat, and 36 and 27 germinable squirreltail seeds/dung pat, 1 & 2 days post seed ingestion, respectively. At the time of this study, the cost of globemallow and squirreltail seed on a pure live seed basis was $88 and $48/kg, respectively; therefore, the seed cost for each seeding event/cow would be $5.80. More studies on livestock seed dispersal are needed in a realistic, managerial setting; however, if the previously stated seed numbers are sufficient to generate 1 established plant/dung pat or provide a protected cache of seeds until germination conditions are favorable, fecal seeding may be a viable technique, albeit a gradual process, to increase species diversity on degraded and previously seeded rangelands, with fewer disturbances than conventional seeding methods.

LITERATURE CITED


CHAPTER III

USING CATTLE AS SEEDING AGENTS TO INCREASE SPECIES DIVERSITY ON GREAT BASIN RANGELANDS

ABSTRACT

Faced with the threat of weed invasions, soil erosion and failed native species seedings, managers have relied heavily on non-native perennial grass seedings to stabilize degraded rangelands, which can become near-monocultures and provide little improvement, in terms of diversity, over untreated areas. Fecal seeding and broadcast seeding/trampling were evaluated as techniques to establish native plants and increase species diversity in a crested wheatgrass (*Agropyron desertorum* (Fisch.) Schult.) seeding in Skull Valley, Utah. The first grazing treatments, implemented in May 2001, consisted of 0, 50, or 80% crested wheatgrass utilization. In November 2001, seeds of squirreltail (*Elymus elymoides* (Raf.) Swezey), globemallow (*Sphaeralcea grossulariifolia* (H. & A.) Rydb.), and sagebrush (*Artemisia tridentata* Nutt. ssp. *wyomingensis* Beetle & Young) were fed to one group of cows prior to grazing for fecal seeding treatments, and broadcast prior to grazing by another group of cows for seeding/trampling treatments. A third group of cows grazed in a no seeding treatment. Utilization in all grazed paddocks was 96%. Half of the plots in every treatment were irrigated to simulate a wet spring, and the other half were exposed to ambient precipitation. Seedling emergence and survival were followed in 2002 and 2003. Squirreltail emergence and survival were highest
in irrigated fecal seeded treatments that initially were utilized at 50%. Globemallow emergence was highest in non-irrigated fecal seeded treatments utilized at 50%. Survival, however, was best in broadcast/trampled treatments utilized at 80%, regardless of irrigation. No sagebrush seedling emergence was observed in any of the treatments. Drought and heavy infestations of Mormon crickets (*Anabrus simplex*) likely contributed to low seedling emergence and survival. In April 2003 similar treatments were applied, except shadscale [*Atriplex confertifolia* (Torr. & Frem.)] seed was substituted for sagebrush. In addition, a third treatment was added: broadcast seeding/raking. The site was monitored for seedling emergence and survival through August 2003. No seedling emergence was observed. Seeds recovered from dung pats collected from both trials indicated highly variable seed recovery, with lower seed recovery in the spring trial. Globemallow germinability was similar for seeds collected from both trials (11%) and squirreltail germination was highest in the fall seeding (13%). Sagebrush and shadscale had no germination. Although it is still uncertain how viable fecal seeding and broadcast/trampling are for increasing plant species diversity within a heavily grazed crested wheatgrass seeding, we know that an average dung pat from November 2001 (714 g) may have ample germinable seeds of globemallow and squirreltail (133 and 30, respectively) for plant establishment during a favorable precipitation year.
The most common grass seeded following fire is crested wheatgrass (Fairway, Nordan and Hycrest varieties, Agropyron cristatum (L.) Gaertn., A. desertorum (Fisch.) Schult., and A. desertorum x A. cristatum (Fisher ex Link) Schult., respectively), a perennial, cool season bunchgrass from Asia. As a long-lived resilient grass, it can stabilize the soil, deter invasive weeds and provide reliable spring forage. It is also relatively easy to establish, and its seed is inexpensive and widely available, factors that have contributed to its widespread use on 6-10 million ha in the U.S. (Rogler and Lorenz 1983, Holechek 1981).

Despite the benefits of crested wheatgrass, some land managers and scientists are concerned by the permanent stable state it can create (Anderson and Marlette 1986, Johnson 1986, Lesica and DeLuca 1996), which results in reduced plant, vertebrate and invertebrate diversity, visually altered landscapes, a higher percentage of bare ground than native plant communities, and less natural succession (Dormaar et al. 1995, Lesica and DeLuca 1996, Christian and Wilson 1999). In addition to alterations of composition and community structure, monocultures can alter subtle properties of entire ecosystems including productivity, nutrient cycling, hydrology, and plant biochemical diversity (Vitousek 1990, Provenza et al. 2003).

To transition from a static crested wheatgrass planting to a more dynamic plant community would require disturbing the crested wheatgrass and introducing species that can coexist. Traditional vegetation removal methods (mechanical tilling and chemical spraying) are not practical since heavy disturbance could nullify the
beneficial attributes of crested wheatgrass, including erosion and weed control. Instead, there is a need for inexpensive and less disruptive alternatives that can satisfy multiple land management goals, including livestock, recreation, watershed, wildlife and genetic preservation. One such alternative may be the use of cattle as seed disseminators.

In directed fecal seeding, seeds of desired species are fed to livestock, pass through the gut and are deposited within a moist, favorable environment for germination (Janzen 1984, Herrick et al. 1996). Because of the nature of dung pat deposition, seed distribution would occur in patches across the landscape, producing satellites of desirable species that can increase in size and number through seed propagation or vegetative reproduction (Archer and Pyke 1991).

Several seed passage studies have quantified seed recovery and post-passage germination of native and agronomic plant species (Simao Neto et al. 1987, Al-Mashkhi 1993, Gardener et al. 1993a, b, Akbar et al. 1995, Gökbülük 1998, Ortmann et al. 1998, Doucette et al. 2001). Another group of studies have followed emergence and survival in artificial dung pats placed in small plots with little to no resident vegetation (Barrow and Havstad 1992, Ocumpaugh et al. 1996, Auman et al. 1998, Gökbülük 1998, Shinderman and Call 2001). There have also been seed recovery studies where seeds were extracted from fecal material of free-ranging ruminants (Wicklow and Zak 1983, Welch 1985, Russi et al. 1992, Malo and Suárez 1995, Malo et al. 2000, Kneuper et al. 2003). Specific information is limited on the use of livestock seed dispersal in the Great Basin (Auman et al. 1998); however, it is
recognized as a promising method to reintroduce desirable species on degraded rangelands in similar geographic areas (Archer and Pyke 1991).

In a field trial in northern Utah, Auman et al. (1998) found that the success of disseminated seeds may be dependent upon the competitive strategies of the resident vegetation and that seedling emergence may be improved if the resident vegetation is disturbed prior to seeding. Controlled grazing can be an effective tool for manipulating plant species composition, specifically creating a shift in plant composition that gives favored species a competitive advantage (Vallentine 1989). By grazing during a phenological stage that is detrimental to plant production, an area can be opened up in preparation for seeding perennials, similar to an herbicide treatment (Vallentine and Stevens 1992, Doescher et al. 1987). Using livestock, however, may be less expensive and more environmentally friendly than conventional herbicides (Doescher et al. 1987).

Another nontraditional seeding method that has been evaluated and suggested as a promising alternative is livestock trampling to incorporate broadcasted seed into the soil and create a favorable seedbed for germination (Pearson and Ison 1987, Vallentine 1989, Winkel and Roundy 1991a, b, Mosley 1996, Eldridge and Robson 1997). In Arizona, Winkel and Roundy (1991b) and Winkel et al. (1991) investigated the effects of light and heavy trampling on grass seed burial and subsequent seedling emergence. They found that trampling buried between 17 and 75% of the broadcast seed, with greater emergence for larger-seeded grasses. Smaller-seeded grasses were often buried below their biological limits.
The purpose of this study was to investigate nontraditional seeding and vegetation manipulation techniques, moving from more controlled fecal seeding trials with little to no resident vegetation and artificially deposited dung pats to one that is conducted under more realistic conditions where cows are present on the study site and deposit their own dung pats. More specifically, I wanted to evaluate: 1) fecal seeding and broadcast/trampling as techniques to incorporate squirreltail \textit{[Elymus elymoides (Raf.) Swezey]}, globemallow \textit{(Sphaeralcea grossulariaefolia (H. & A.) Rydb.)}, sagebrush \textit{(Artemisia tridentata Nutt. spp. wyomingensis Beetle & Young)}, and shadscale \textit{[Atriplex confertifolia (Torr. & Frem.)]} into a well-established crested wheatgrass seeding; 2) intensive grazing as a means to reduce the competitiveness of crested wheatgrass and increase establishment and survival of seeded species; and 3) quantify the recovery and germinability of seed extracted from dung pats collected in the field.

**METHODS AND MATERIALS**

**Site Description**

The study was conducted along the eastern periphery of the Great Basin physiographic province, approximately 45 km southwest of Tooele, Utah in southeastern Skull Valley (Fig 2). Historically, the study site (1600m elevation) supported a Wyoming sagebrush/perennial grass plant community made up of 45-50\% perennial grasses [bluebunch wheatgrass \textit{(Pseudoroegneria spicata (Pursh) A. Löve)}, Indian ricegrass \textit{(Achnatherum hymenoides (Roemer & J.A. Schultes)}}]
Barkworth) and bottlebrush squirreltail], 30-35% shrubs (Wyoming big sagebrush) and 15% forbs (USDA 2000). Species composition has been altered by the encroachment of cheatgrass and other non-native annuals (Hull and Pechanec 1947, Sparks et al. 1990, Billings 1992, Roberts 1992, Mosley 1996) that provide fuel for frequent fires in otherwise sparsely distributed perennial vegetation (Young et al. 1972). Because sagebrush does not resprout following fire (Young et al. 1972), its displacement can persist for decades (Whisenant 1990).

Soils are loamy, mixed, calcareous Xeric Haplocalcids (very deep, well-drained, gravelly loam Aridisols), and are part of the Hiko Peak-Taylorflat complex (USDA 2000) (Table 5). The average annual precipitation is between 220 and 280 mm (USDA 2000), with 33% occurring between March-May (WRCC 2003). The mean annual temperature is 7-10 °C, with 100 to 140 frost-free days (USDA 2000).
July is the warmest month (average high of 35°C) and January is the coldest (average low of -9°C) (WRCC 2003).

In February 2001 a 2-ha enclosure was built on the southeast corner of a 4½-year-old crested wheatgrass seeding (40° 12' 59" N 112° 38' 22" W). The entire drill seeded area is 2000 ha, and was part of a post-fire revegetation effort by the Bureau of Land Management (BLM) on the 1996 Davis Knolls burn (see Table 6 for seed mix). In May of 2001 a baseline census of species presence, including percent of total weight and percent cover, was completed outside the perimeter fence along three 100-m transects. Plant material was harvested from ten 1-m² quadrats along each transect, oven dried and weighed to determine biomass and percent species composition. Aerial cover was ocularly estimated within each 1-m² to quantify the percent cover of live plants, litter, bare ground and rock. The seeding was dominated by crested wheatgrass (7.4 plants/m²), bur buttercup (*Ranunculus testiculatus* Crantz) and cheatgrass (*Bromus tectorum* L.) (Table 7). The study area included a 0.8-ha holding pen, with the remaining area divided into twenty-one 25 x 25-m paddocks, using 3 strands of electric polytape. Water troughs were placed in each of the grazed paddocks and in the holding pen.

### Table 5. Skull Valley soil characterization data.

<table>
<thead>
<tr>
<th>Horizon</th>
<th>Depth (cm)</th>
<th>Texture</th>
<th>% Sand</th>
<th>% Clay</th>
<th>% Silt</th>
<th>pH</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ap</td>
<td>0-12</td>
<td>loam</td>
<td>15</td>
<td>40</td>
<td>45</td>
<td>8.1</td>
</tr>
<tr>
<td>Bw</td>
<td>12-62</td>
<td>loam</td>
<td>15</td>
<td>35</td>
<td>50</td>
<td>8.2</td>
</tr>
<tr>
<td>Bk1</td>
<td>62-102</td>
<td>very gravelly sandy loam</td>
<td>10</td>
<td>55</td>
<td>35</td>
<td>8.6</td>
</tr>
<tr>
<td>Bk2</td>
<td>102-132</td>
<td>loam</td>
<td>10</td>
<td>50</td>
<td>40</td>
<td>9.4</td>
</tr>
</tbody>
</table>
Experiment I

EXPERIMENTAL DESIGN.---The experiment was set up as a split plot 2-way factorial arranged in a completely randomized design. The 2 main experimental factors included grazing intensity (50% and 80% crested wheatgrass utilization) and seeding method (fecal, broadcast/trampling, and no seeding) with irrigation (yes, no) as the split-plot factor. A no grazing/no seeding treatment was also included as a control. Each seeding/utilization treatment combination was replicated 3 times, and randomized within the 21 paddocks. Seedling emergence and survival in the 6 fecal seeded treatments were followed for 10 dung pats/paddock. In the remaining 15 paddocks, seedling recruitment and survival were followed in ten 1-m² subplots/paddock. Half of the dung pats and 1-m² subplots were irrigated in 2002 to simulate wet spring conditions (spring 1997), and the other half received only ambient precipitation (Table 8).

Table 6. Drill seed mix used by BLM on 2000ha of the Davis Knolls burn in the fall of 1996.

<table>
<thead>
<tr>
<th>Common name</th>
<th>Scientific name</th>
<th>Percent of seed mix</th>
</tr>
</thead>
<tbody>
<tr>
<td>Nordan crested wheatgrass</td>
<td><em>Agropyron desertorum</em></td>
<td>50%</td>
</tr>
<tr>
<td>Western wheatgrass</td>
<td><em>Pascopyrum smithii</em></td>
<td>19%</td>
</tr>
<tr>
<td>Indian ricegrass</td>
<td><em>Achnatherum hymenoides</em></td>
<td>15%</td>
</tr>
<tr>
<td>Yellow sweetclover</td>
<td><em>Melilotus officinalis</em></td>
<td>11%</td>
</tr>
<tr>
<td>Bozoisky Russian wildrye</td>
<td><em>Psathyrostachys juncea</em></td>
<td>4%</td>
</tr>
<tr>
<td>Tall wheatgrass</td>
<td><em>Elytrigia elongata</em></td>
<td>1%</td>
</tr>
</tbody>
</table>
### Table 7. Baseline measurements of species presence, including percent of total weight and percent cover at the Davis Knolls seeding in May of 2001. Data were collected outside the perimeter fence.

<table>
<thead>
<tr>
<th>Common name</th>
<th>Scientific name</th>
<th>Percent of total wt.</th>
<th>Percent cover</th>
</tr>
</thead>
<tbody>
<tr>
<td>Crested wheatgrass</td>
<td><em>Argopyron desertorum</em></td>
<td>65.3</td>
<td>25.3</td>
</tr>
<tr>
<td>Bur buttercup</td>
<td><em>Ranunculus testiculatus</em></td>
<td>17.1</td>
<td>11.6</td>
</tr>
<tr>
<td>Cheatgrass</td>
<td><em>Bromus tectorum</em></td>
<td>7.9</td>
<td>7.6</td>
</tr>
<tr>
<td>Western wheatgrass</td>
<td><em>Pascopyrum smithii</em></td>
<td>3.2</td>
<td>1.6</td>
</tr>
<tr>
<td>Filaree</td>
<td><em>Erodium cicutarium</em></td>
<td>2.6</td>
<td>2.5</td>
</tr>
<tr>
<td>Flixweed</td>
<td><em>Descurainia sophia</em></td>
<td>1.8</td>
<td>2.7</td>
</tr>
<tr>
<td>Squirreltail</td>
<td><em>Elymus elymoides</em></td>
<td>0.3</td>
<td>0.4</td>
</tr>
<tr>
<td>Sandberg bluegrass</td>
<td><em>Poa secunda</em></td>
<td>0.2</td>
<td>0.5</td>
</tr>
<tr>
<td>Shadscale</td>
<td><em>Atriplex confertifolia</em></td>
<td>trace</td>
<td>trace</td>
</tr>
<tr>
<td>Alyssum</td>
<td><em>Alyssum spp.</em></td>
<td>trace</td>
<td>trace</td>
</tr>
<tr>
<td>Goatsbeard</td>
<td><em>Tragopogon dubius</em></td>
<td>trace</td>
<td>trace</td>
</tr>
<tr>
<td>Russian thistle</td>
<td><em>Salsola iberica</em></td>
<td>trace</td>
<td>trace</td>
</tr>
<tr>
<td>Rock</td>
<td>-</td>
<td>-</td>
<td>trace</td>
</tr>
<tr>
<td>Litter</td>
<td>-</td>
<td>-</td>
<td>24.8</td>
</tr>
<tr>
<td>Bare ground</td>
<td>-</td>
<td>-</td>
<td>28.2</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>98.4</strong></td>
<td><strong>105.2</strong></td>
<td></td>
</tr>
</tbody>
</table>

1 Due to several species that were a trace of the total, total weight does not equal 100.  
2 Total exceeds 100% because of bur buttercup's presence under the canopy of some species.

**NATIVE SPECIES SELECTION.**—The exclusive nature of crested wheatgrass made it a challenge to find native species that might be hardy enough to establish and persist in a seemingly niche-free environment. Minimum requirements for species selection included: cool-season, drought tolerant, perennial, palatable forage to wildlife and livestock, and native to the Great Basin. Additionally, in an effort to
create a simple plant community, species selected needed to represent different life forms.

Bottlebrush squirreltail was selected for the grass component. It is a short-lived perennial bunchgrass that is very drought tolerant (230-330 mm annual precipitation) (Simonin 2001), and is recognized as a favorable rehabilitation species for disturbed arid and semiarid systems (Brown and Amacher 1997, Booth et al. 2003). Squirreltail behaves as a pioneer species on disturbed sites (Beckstead 1994) and has been documented to "invade" and persist in cheatgrass stands (Jones 1998, Humphery and Schupp 1999, Booth et al. 2003). Squirreltail reproduces from seeds and tillers, initiating growth in early spring while temperatures are still cool (Stubbendieck et al. 1992). Squirreltail germinates and matures quickly, and a second flowering can occur with favorable fall moisture (Stubbendieck et al. 1992, Jones 1998). Squirreltail has a self-pollinating system (Jones 1998), and produces

Table 8. Summary of precipitation and irrigation for the 2002 and 2003 growing seasons at the Skull Valley, Utah study site. Half of the plots were irrigated and the other half received only ambient precipitation.

<table>
<thead>
<tr>
<th>Year</th>
<th>Month</th>
<th>Precipitation (cm)</th>
<th>Precipitation + Irrigation (cm)</th>
<th>50-year mean (cm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>2002</td>
<td>March</td>
<td>3.6</td>
<td>3.6</td>
<td>1.9</td>
</tr>
<tr>
<td></td>
<td>April</td>
<td>3.8</td>
<td>8.4</td>
<td>2.1</td>
</tr>
<tr>
<td></td>
<td>May</td>
<td>1.2</td>
<td>6.8</td>
<td>2.5</td>
</tr>
<tr>
<td></td>
<td>June</td>
<td>0</td>
<td>8.3</td>
<td>1.4</td>
</tr>
<tr>
<td>2003</td>
<td>March</td>
<td>1.4</td>
<td>1.4</td>
<td>1.9</td>
</tr>
<tr>
<td></td>
<td>April</td>
<td>2.5</td>
<td>2.5</td>
<td>2.1</td>
</tr>
<tr>
<td></td>
<td>May</td>
<td>3.2</td>
<td>7.2</td>
<td>2.5</td>
</tr>
<tr>
<td></td>
<td>June</td>
<td>0.7</td>
<td>2.3</td>
<td>1.4</td>
</tr>
</tbody>
</table>
many germinable seeds when exposed to the right environmental cues (Hironaka and Tisdale 1963, Young and Evans 1977). It is also fire tolerant (Jones 1998) and can resprout from a surviving root crown (West 1994). Squirreltail provides fair to good winter and spring forage for livestock and wildlife (Stubbendieck et al. 1992), with leaves remaining green and succulent through winter (Cook et al. 1954).

Seeding is recommended in the fall at a rate of 60-110 PLS/m² (Granite Seed 2000).

Gooseberry globemallow, a tall (62 to 87 cm) winter-hardy perennial forb (Wasser 1982), was chosen as the broadleaf herbaceous component of the study because of its drought tolerance and ability to colonize disturbed areas (Granite Seed 2000). Its branched taproot with surface feeding roots help it acquire moisture in dry open sites on coarse to medium textured soils (Wasser 1982). Growth resumes in early spring, and with fall precipitation a second green-up can occur (Wasser 1982). Gooseberry globemallow is tolerant of grazing if close defoliation in late spring is avoided (Wasser 1982). It is not tolerant of fire; however, its ability to thrive in bare spaces allows it to quickly regenerate from the seed bank (Wasser 1982). As a forage species, it is moderately palatable to livestock and big game while green (Wasser 1982). Winter and fall plantings are preferred to give the seed better access to late winter and early spring moisture. It also has greatly improved germination rates following a period of prechilling (Wasser 1982). The recommended seeding rate is 75-150 PLS/m² (Granite Seed 2000).

The 3rd species selected was Wyoming big sagebrush, a perennial evergreen shrub that grows to a height of 27 to 83 cm (Stubbendieck et al. 1992). It reproduces
from seed, flowering in the fall (Stubbendieck et al. 1992). Wyoming big sagebrush requires a minimum of 185 mm of annual precipitation and grows best in full sun on well drained, moderately coarse to medium-textured soils (Granite Seed 2000). It provides good winter forage for wildlife as well as cover for small mammals and birds, such as sage grouse (*Centrocercus urophasianus*) (Stubbendieck et al. 1992). Sagebrush has a very small seed (5,200,000 seeds/kg); therefore, broadcasting (rather than drill seeding) is recommended (Jacobsen and Welch 1987, Meyer and Monsen 1990). Germination success is increased when the seedbed is loose with some roughness to create a variety of microhabitats (Jacobsen and Welch 1987, Meyer and Monsen 1990). The recommended seeding rate is 50-100 PLS/m² (Meyer 1992).

**CRESTED WHEATGRASS UTILIZATION.---** To thoroughly stress crested wheatgrass and create a less competitive environment for dispersed seeds, it was grazed twice in 2001: first in late spring during early boot stage (May 10th-12th) and again in the fall (November 10th-14th) to provide little recovery time before winter. Before and after each grazing treatment, crested wheatgrass was harvested from three 1m² subplots/paddock, dried at 60°C for 48 hours and weighed to quantify utilization. The number of crested wheatgrass plants in each subplot was also counted to estimate density and utilization/plant.

**SEEDING.---** In November 2001, when the area was grazed a 2nd time, 12 of the 21 paddocks received a seeding treatment (6 broadcast and 6 fecal), 3 served as an experimental control (no seeding and no grazing) and 6 were grazed at 2 different intensities (3 at 50% and 3 at 80%) but not seeded. The 6 grazed/unseeded paddocks
were included to control for any effects due to an active seedbank that may be triggered by grazing and trampling.

In November 2001, 18 cows, 3 and 4-year-old black and red Angus-cross, weighing approximately 454 kg were fed seed off-site. In groups of 3, each cow was fed 30,000, 25,000 and 120,000 seeds of squirreltail, globemallow and sagebrush, respectively, in a 2:1 ratio of calf feed to seed. Molasses was used to adhere the seed to the calf feed and prevent it from collecting at the bottom of the trough. Seed was consumed within 2 hours. All cows were observed eating the seed/feed mixture; however, because they were fed in groups, the number of seeds ingested/cow could not be tightly controlled. Twenty-four hours after the seed was ingested, during the period of highest seed passage (Al-Mashiki 1993), the cows were hauled to the study site.

Three seed-fed cows were placed into each fecal seeded paddock. Approximately 24-48 hours later (48-72 hours post-seed ingestion), they were moved into the broadcast/trampled and the unseeded paddocks. The broadcast/trampled paddocks were hand-seeded prior to grazing at a rate of 111, 151, and 117 PLS/m² of globemallow, squirreltail and sagebrush, respectively. Three dung pats were collected from each fecal seeded paddock to determine total and germinable seed recovery rates (n=18). A 100-g sample from each dung pat was oven-dried at 60°C for 48 hours to quantify moisture content.

Within the broadcast/trampled, unseeded, and control paddocks, ten 1m² subplots were established to follow emergence and survival (150 subplots total). In

---

1 IFA Newborn Calf “D” 18% Starter with steamed flaked soybeans and Deccox®
each fecal-seeded paddock, 10 dung pats were monitored to census emergence and survival. Over the winter, ravens shredded 8 out of the 60 dung pats selected for censusing. To compensate, additional dung pats were selected in order to have 10 intact dung pats/paddock. The shredded dung pats were also followed to investigate any differences in seedling emergence or survival. Conical cages made of chicken wire were placed over all dung pats and fastened with wire staples to protect them from future raven activity. Within each paddock, half of the subplots (either 1m² quadrats or dung pats) were irrigated with a watering can to simulate 1997's above average spring precipitation.

For 2 consecutive growing seasons, 2002 and 2003, seedling emergence and survival were recorded for the 218 subplots. Observed seedlings were tallied and marked. Analysis of the response variables (total seedling emergence and survival) was limited to descriptive statistics (mean, standard error, minimum and maximum values) because the residuals could not be normalized due to low emergence and survival values.

Experiment II

Although it is generally recognized that fall seeding is preferable in the Great Basin, a 2nd trial was conducted in the spring of 2003 in the event of a wet spring.

SPECIES SELECTION.—Post-passage sagebrush germination from the seed passage study (see Chapter 2), and emergence in Experiment I were not positive; therefore, shadscale replaced sagebrush in the seed mix for the 2nd field trial.
Shadscale seed was purchased from a commercial seed source in March 2003 and stored at 20°C in a plastic gunnysack for 1 month prior to seeding. The seed had a PLS rating of 31.7%.

Shadscale is a compact native shrub, 15-90 cm tall (Stubbendieck et al. 1992), and is considered evergreen to partially deciduous (Mozingo 1987, Institute for Land Rehabilitation 1979). It is very drought tolerant, requiring only 100-200 mm of precipitation annually (Branson et al. 1967, Institute for Land Rehabilitation 1979), and prefers well-drained (Comstock and Ehleringer 1992, Ewing and Dobrowolski 1992, Gates et al. 1956), moderately saline soils (Blaisdell and Holmgren 1984, Comstock and Ehleringer 1992) where groundwater is below the rooting zone. It inhabits a wide variety of textural classes, from fine to sandy and gravelly soils (Welch et al. 1987). In the Great Basin, the majority of shadscale communities occur below the highest historical level of the pluvial lakes (Young et al. 1976). Although indicative of salt desert ecosystems, it can be found intermixed with sagebrush in its upper habitat boundary. Plants are relatively short-lived (Blaisdell and Holmgren 1984, Chambers and Norton 1993), and reproduce solely through seed (Sanderson and Stutz 1994). The fruit is a small utricle (4-12 mm long and wide) that typically bears 1 seed (1.5-2 mm broad) (Welch et al. 1987). Shadscale fruits and leaves provide a source of palatable, nutritious forage for livestock (Blaisdell and Holmgren 1984) and wildlife (deer, pronghorn, small rodents, jackrabbits, game birds and songbirds) (Dumas and Sanders 1990, Kochert et al. 1999). Shadscale does not readily recover from fire (Banner 1992, Bunting
1989), other than establishment through seed (Sanderson and Stutz 1994, West 1994), which has resulted in its removal from many areas where fire frequency has increased due to the invasion of weedy annuals. Transplanting is recommended for reestablishing shadscale because its pronounced seed bracts provide a mechanical barrier to germination and must breakdown before seeds can germinate (Dumas and Sanders 1990). If propagating from seed, it should be planted prior to dependable moisture at a depth of 1.2 cm (Foiles 1974). The Salt Lake office of the BLM has used seeding rates of 24 PLS/m² in Skull Valley rehabilitation projects.

**Utilization and Seeding.---**This trial was conducted in April 2003 in the previous study’s holding pen that was divided into 6 paddocks. Three paddocks were fecally seeded and the others were broadcast seeded and trampled. The 6 paddocks were utilized heavily (80-90%) 3 times: May 2001, November 2001 and April 2003. Grass hay was fed to reach similar amounts of time spent trampling and fecal seeding. The control paddocks from the previous study served as the control. Methods for feeding seed and seed amounts were similar to Experiment I, except that the available cattle were yearling steers of the same breed. The steers weighed significantly less (314 kg) than the previously used cows. Broadcasted seed amounts were the same for squirreltail and globemallow. Shadscale was seeded at a rate of 24 PLS/m² or 30,000 seeds/steer.

Other additions to the experiment included quantifying the number of seeds broadcast/m² and adding a third seeding treatment (broadcast/rake) to the fecal seeded paddocks. The number of broadcast seed/m² was determined by laying out
ten 1m² tarps/paddock while broadcasting. Captured seed was collected and counted (Table 9). The additional seeding treatment was added after the steers were removed from the study area. Ten 1m² subplots were hand seeded and raked in each fecal seeded paddock (n=30) with the same seed mix ratio as the broadcast/trampled treatments. As in Experiment I, half of the subplots for each treatment combination were irrigated. All subplots (n=90), including the 10 dung pats and ten 1m² quadrats in the broadcast/trampled paddocks, were checked 3 times for seedling recruitment and survival during the 2003 growing season. There was no emergence, and analysis was not necessary.

Twelve dung pats (4 from each paddock) were collected to quantify germinable seed recovery. In addition, 100g of each dung pat were oven dried at 60°C for 48 hours to quantify moisture content.

Table 9. Comparison of intended versus actual number of seeds (mean ± SE) broadcasted/m². Numbers are based on seed collected from 1m² tarps in Experiment II (n=29).

<table>
<thead>
<tr>
<th>Species</th>
<th>Intended</th>
<th>Actual</th>
</tr>
</thead>
<tbody>
<tr>
<td>Globemallow</td>
<td>151</td>
<td>71 (± 12.3)</td>
</tr>
<tr>
<td>Squirreltail</td>
<td>111</td>
<td>77 (± 7.3)</td>
</tr>
<tr>
<td>Shadscale</td>
<td>24</td>
<td>11 (± 1.4)</td>
</tr>
</tbody>
</table>
Experiment III

To prevent moisture loss, dung collected from both field trials was transported to the lab in plastic bags. Samples were weighed, washed through a series of sieves and air-dried. Samples from Experiment I were sorted by hand under a dissecting scope. Recovered seeds were separated by species, counted and categorized as damaged, undamaged or germinated. The seed in the dung pats collected from Experiment II were large enough to run through an air-column seed separator to remove the finer material. The remaining material was examined using a 10x-magnifying lens to separate the seed from the larger fibrous material. Again, the seeds were divided by species, counted and categorized as damaged, undamaged or germinated.

From each dung pat, 4 replicates of 25 undamaged recovered seeds (no visible damage to seed coat) were placed on moistened filter paper in petri dishes. For the control, 4 replicates of 25 unpassed, undamaged seeds/species were included. The petri dishes were stacked 11-12 high in cellophane bags and placed in a germination chamber set at 10°C/20°C with a 12-hour photoperiod. The 27 stacks were rotated daily within the chamber, and the dishes were rotated within the stacks to negate the effect of light or temperature variability within the chamber. The seeds were checked for germination for a period of 28 days. As the seeds germinated (when coleoptile emerged and the radicle elongated to at least 5 mm, Copeland 1978), they were removed and recorded. Since a number of treatments had fewer
than 100 seeds/dung pat, germinability was reported as a percentage to provide a meaningful comparison between treatment combinations.

Data from Experiment I and II were analyzed separately. Species was the only main effect; time since seed consumption and seed feeding level were similar for all dung pats collected. Descriptive statistics were used to present the variability of seed passage and recovery. Germination percentages of undamaged seed were analyzed by species using the Means procedure in SAS (2001). Standard errors were used to compare mean recovery and germination.

RESULTS AND DISCUSSION

Winter (December-March) and summer (June-August) precipitation were lower than average for both growing seasons (Fig. 3). Average summer monthly temperatures in 2001-2002 and 2002-2003 were similar to the 50-year average, with cooler than average winter temperatures in December, February, and March of 2001-2002 and warmer than average temperatures in December and January of 2002-2003. Although soil moisture was not monitored, it is likely that minimal snow cover during the winters of 2001-2002 and 2002-2003 contributed little to soil moisture recharge needed for germination, seedling establishment and survival. Little snow cover may have also had a negative impact on seedling emergence and survival because of increased seed depredation by small mammals and birds. Winter moisture can be particularly important for fecal seeding to help breakdown and
soften the dung pats, making it easier for seedlings to penetrate the dung (Akbar 1994).

Experiments I and II

CRESTED WHEATGRASS UTILIZATION.—In Experiment I, May utilization was slightly higher than planned (55% and 83%), and regrowth between May and November was less than anticipated (only 2.6-3.0 g/m²). During the 2nd utilization treatment, over utilization could not be avoided since we had to allow time for the animals to produce a sufficient number of dung pats in the fecal seeded treatments. Consequently, biomass differences for the 2 utilization levels were lost, and final utilization was very high (96%) (Table 10). Crested wheatgrass utilization was also very high in Experiment II (98%) (Table 11).

Intensive grazing reduced crested wheatgrass biomass for all sampling dates (Tables 10 & 11). Biomass in the control increased over time, with a 39% increase during the 3rd growing season (June 2003). The increase in crested wheatgrass biomass production may have been aided by a reduction in cricket herbivory (they were treated with Sevin®² in 2002 and absent in 2003). Post-grazing biomass in Experiment I, regardless of grazing intensity, partially rebounded during the 2002 growing season; however, it did not continue to increase in 2003 and did not exceed the initial biomass (63.1 g/m²) measured in May 2001. In contrast, plant density remained relatively constant throughout the study.

² Active ingredient is Carbaryl (1-napthyl N-methylcarbamate)
Figure 3. Monthly precipitation (a) and average temperature (b) recorded at Dugway Proving Grounds, Utah for 2001-2002 and 2002-2003, and the 53 year average (1950-2002) (Western Regional Climate Center 2003).
Table 10. The effect of grazing intensity (none, 50% or 80%) on crested wheatgrass biomass (mean ± SE) in Experiment I. Biomass data for May and November were collected immediately following the grazing treatments.

<table>
<thead>
<tr>
<th>Sampling date</th>
<th>Biomass (g/m²)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>0% utilizationᵃ</td>
</tr>
<tr>
<td>May 2001</td>
<td>63.1 (± 8.9)</td>
</tr>
<tr>
<td>November 2001</td>
<td>65.4 (± 0.7)</td>
</tr>
<tr>
<td>July 2002</td>
<td>71.6 (± 7.3)</td>
</tr>
<tr>
<td>June 2003</td>
<td>116 (± 15.0)</td>
</tr>
</tbody>
</table>

ᵃ n = 9
ᵇ n = 27

Although not previously exploited, grazing has been suggested as a means to reduce the abundance of crested wheatgrass in the Northern Great Plains (Romo et al. 1994). We found in Experiment I that grazing twice, regardless of intensity, first during the early boot stage, when the apical meristem and culm leaves are elevated and susceptible to removal, and again prior to winter dormancy, reduced crested wheatgrass biomass by nearly 50% for 2 growing seasons. Similar results have been noted in other grass communities (both native and introduced) in the Great Basin (Stoddart 1946, Caldwell et al. 1981, Olson and Richards 1988, 1989, Miller and Rose 1992, Romo and Harrison 1999). Grazing earlier in the spring, prior to the boot stage in Experiment II, was not as effective at reducing crested wheatgrass biomass and only delayed, rather than prevented, flowering.

SEEDLING EMERGENCE AND SURVIVAL.--- Seedling emergence and survival in Experiment I were low for globemallow and squirreltail. Globemallow emerged in 6% of the subplots (dung pats and 1m² quadrats). Half of these subplots were in
paddocks that were not seeded (either no seeding treatments or controls), and therefore, were volunteers. Globemallow seedling mortality was 93%. Squirreltail emerged in 63% of the dung pats, with 86% mortality. No sagebrush emergence was observed.

No seedlings were observed in Experiment II during the 3 census events in 2003: 21 May, 10 June and 13 August; therefore, unless noted, the following discussion of the results refers to Experiment I.

EFFECT OF GRAZING INTENSITY.---Globemallow emergence was not affected by grazing intensity (Appendix Table 25). Globemallow survival was highest (75% ± 25%) in the intensively grazed/trampled treatments; however, survival in moderately grazed/trampled treatments did not differ from those in ungrazed/untrampled treatments (Appendix Table 26). Squirreltail emergence and survival did not differ between moderate and intensive grazing in the fecal seeded treatment (Appendix Tables 27 & 28).

Auman et al. (1998) found that resident vegetation can influence seedling emergence and survival in dung pats; however, in this study, drought and Mormon

<table>
<thead>
<tr>
<th>Sampling date</th>
<th>Biomass (g/cm²) 0% utilization</th>
<th>Biomass (g/cm²) 80% utilization</th>
</tr>
</thead>
<tbody>
<tr>
<td>24 April 2003</td>
<td>71.8 (± 11.2)</td>
<td>17.8 (± 3.1)</td>
</tr>
<tr>
<td>30 April 2003</td>
<td>71.8 (± 11.2)</td>
<td>0.3 (± 0.1)</td>
</tr>
<tr>
<td>10 June 2003</td>
<td>116 (± 15.0)</td>
<td>14.2 (± 1.5)</td>
</tr>
</tbody>
</table>

+ n = 9
§ n = 18
cricket herbivory in 2001 and 2002 may have overridden any beneficial effects of reduced crested wheatgrass biomass production. Low emergence and survival numbers for squirreltail and globemallow make it difficult to evaluate the effectiveness of grazing as a means to reduce crested wheatgrass biomass and open up interspaces for establishment. Analysis of survival for both species is especially problematic because of small sample sizes.

EFFECT OF IRRIGATION.---For globemallow emergence, there was an interaction between irrigation and seeding treatment. Irrigation negatively affected emergence in the fecal treatment, and positively affected emergence in the control (Table 12). However, regardless of seeding treatment, globemallow survival was not affected by irrigation (Appendix Table 29). There was no effect of irrigation on squirreltail emergence or survival in the fecal treatments (Appendix Tables 30 & 31). The negative effect of irrigation on globemallow emergence in dung pats is probably an indication of a small sample size rather than a biological response.

One of the most influential factors in arid rangeland revegetation is the amount and timing of precipitation. In areas similar to Skull Valley where annual precipitation is less than 600 mm, revegetation is constrained because low precipitation can override revegetation practices regardless of species, seedbed preparation and weed control methods used (Bleak et al. 1965, Robocker et al. 1965, Tadmor et al. 1968, DePuit 1986). Although we tried to offset the effects of drought by irrigating half of the subplots, we were unable to mimic climatic conditions that accompany rain such as cooler temperatures, increased cloud cover and humidity.
Table 12. Effect of irrigation by seeding treatment on globemallow emergence (mean number of seedlings/subplot ± SE).

<table>
<thead>
<tr>
<th>Seeding treatment</th>
<th>n</th>
<th>Irrigation</th>
<th>Seedlings/subplot</th>
</tr>
</thead>
<tbody>
<tr>
<td>Broadcast/trampled</td>
<td>30</td>
<td>No</td>
<td>0.033 (± 0.033)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Yes</td>
<td>0.233 (± 0.233)</td>
</tr>
<tr>
<td>Fecal seeding</td>
<td>34</td>
<td>No</td>
<td>0.853 (± 0.765)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Yes</td>
<td>0.029 (± 0.029)</td>
</tr>
<tr>
<td>No seeding/trampled</td>
<td>30</td>
<td>No</td>
<td>0.033 (± 0.033)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Yes</td>
<td>0.067 (± 0.046)</td>
</tr>
<tr>
<td>Control</td>
<td>15</td>
<td>No</td>
<td>0.000 (± 0.0)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Yes</td>
<td>0.267 (± 0.153)</td>
</tr>
</tbody>
</table>

Favorable conditions for establishment in semiarid regions of Australia are estimated to occur 1 in 4 years (Silcock 1986), and on salt desert shrublands in the Great Basin, as infrequently as 1 in 15 years (Bleak et al. 1965). Revegetation processes on arid and semiarid rangelands are regulated by episodic rather than average environmental conditions (Call and Roundy 1991); therefore, seeding failures are an inherent risk in revegetation.

EFFECT OF SEEDING TREATMENT.---Globemallow emergence was greatest in the fecal seeded treatment based on a seedling/area comparison (Table 13). The mean dung pat area was 530±71 cm², compared to 10,000 cm² for the 1-m² subplots. Globemallow survival, however, was higher in the broadcast/trampled treatment than in the control or fecal seeded treatments, but equivalent to the no seeding/trampled treatment (Table 14). Again, the small sample sizes do not support a robust analysis.
The effect of seeding treatment could not be determined for squirreltail emergence and survival since all grass seedlings observed remained in the 2-leaf stage and could not be positively identified in the non-fecal seeded treatments.

Although we did not find seedling emergence and survival from broadcast seed affected by trampling intensity, it has been shown to be an influential factor (Eckert et al. 1986, 1987, Winkel and Roundy 1991, Winkel et al. 1991b), and a means to bury seeds to improve survival by increasing seed-to-soil contact and water flow to the seed, increasing radical penetration and reducing predation (Collis-George and Sands 1959, Cox and Martin 1984, Campbell and Swain 1973). In addition to trampling intensity, the studies noted that seedling success was more dependent on soil moisture than burial method. In addition to the importance of soil moisture, Eckert et al. (1987) found that life form of the seeded species can also influence the effectiveness of trampling intensity on seedling emergence.

Due to low seedling emergence and survival in this study, it is difficult to assess trampling as a seedbed preparation and burial technique for broadcasted seeds. Of the 4 species monitored for emergence and survival, only 3 globemallow

<table>
<thead>
<tr>
<th>Seeding treatment</th>
<th>n</th>
<th>Seedlings/cm²</th>
</tr>
</thead>
<tbody>
<tr>
<td>Control</td>
<td>30</td>
<td>$13.3 \times 10^{-6}$ (± 7.9 x $10^{-6}$)</td>
</tr>
<tr>
<td>Fecal</td>
<td>68</td>
<td>$830.8 \times 10^{-6}$ (± 721.5 x $10^{-6}$)</td>
</tr>
<tr>
<td>Broadcast/trampled</td>
<td>60</td>
<td>$5.0 \times 10^{-6}$ (± 3.7 x $10^{-6}$)</td>
</tr>
<tr>
<td>No seeding/trampled</td>
<td>60</td>
<td>$5.0 \times 10^{-6}$ (± 2.8 x $10^{-6}$)</td>
</tr>
</tbody>
</table>
seedlings were documented in the broadcast/trampled treatment, one of which survived. The subplot in which the seedling survived was one that had very little resident vegetation (4 crested wheatgrass plants/m²). Squirreltail survival and emergence could not be determined in the trampled treatments; however, a study by Eckert et al. (1987) in central Nevada’s big sagebrush rangelands found that moderate trampling enhanced squirreltail seedling emergence when compared to untrampled conditions.

Trampling did not positively affect the emergence and survival of sagebrush and shadscale. The germination chamber results indicate that the sagebrush seed used in the field trials was germinable; therefore, it is likely that climatic conditions were not favorable for the broadcasted seed and/or the seed was buried below its biological limit. Eckert et al. (1986), however, concluded that heavy trampling could enhance sagebrush emergence on some microsites. The failure of shadscale in Experiment II may be due to dormancy, in addition to low soil moisture throughout the study period (2001-2003), since the seed did not germinate in the germination chamber even though it was rated 33% germinable (Granite Seed 2000). It may be necessary to mechanically scarify the seed before seeding as it can increase germination by 15% (Dumas and Sanders 1990), or plant in the fall for the beneficial effects of natural leaching, oxidative processes and winter chilling (Garvin et al. 1996). Hall and Anderson (1999) were successful in establishing 1 shadscale plant/m² in disturbed areas of the Nellis Air Force Range in Nevada with seed; however, establishment from container stock provides the highest probability for
Table 14. Effect of seeding treatment on globemallow survival (mean ± SE).

<table>
<thead>
<tr>
<th>Seeding treatment</th>
<th>n</th>
<th>Survival (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Control</td>
<td>3</td>
<td>0 (± 0)</td>
</tr>
<tr>
<td>Fecal</td>
<td>4</td>
<td>0 (± 0)</td>
</tr>
<tr>
<td>Broadcast/trampled</td>
<td>2</td>
<td>75 (± 25)</td>
</tr>
<tr>
<td>No seeding/trampled</td>
<td>2</td>
<td>50 (± 50)</td>
</tr>
</tbody>
</table>

successful revegetation (Crofts and Van Epps 1975, Clary and Slayback 1985).

Another factor limiting seeding success may have been seed depredation. There were signs of rodent activity in the spring seeded broadcast/trampled paddocks.

Fecal seeding produced a total of 30 and 104 globemallow and squirreltail seedlings, respectively. Twenty-six of the globemallow seedlings were recorded in one 3-cm thick dung pat in April 2003, and within a month all the seedlings had died from desiccation. The thickness of the dung pat may have made it difficult for the roots to reach the soil surface, and without moisture the dung pat hardness may have made root growth prohibitive. The other 4 globemallow seedlings occurred on 3 different dung pats and also survived for less than a month. The majority of the squirreltail seedlings were located on the periphery of the dung pats, their emergence or survival not affected by grazing intensity or irrigation treatment. All 12 seedlings that survived were on the periphery of 9 dung pats.

Previous fecal seeding studies have investigated artificially placed dung pats in a variety of environments with mixed results. In northern Utah, Auman et al. (1998) had little success establishing crested wheatgrass when the resident vegetation was dominated by cheatgrass. In contrast, when the resident vegetation
was dominated by squirreltail, dung effectively suppressed the resident vegetation and opened up interspaces for the establishment of crested wheatgrass. In south Texas fecal-seeded switchgrass (Panicum virgatum L.) had equal to superior recruitment compared to broadcast seeding in spite of 1.5 to 1.7 times more pure live seed (PLS) used in the broadcast seeding (Ocumpaugh et al. 1996). The fecal-seeded plots also produced plants with greater biomass and height and culm density, suggesting additional advantages over conventional broadcast seeding.

In this study, support for fecal seeding is limited; however, seeding in the fall is more promising than in the spring. Welch (1985) found similar results on heather moorlands in northeast Scotland in a study that documented seed dispersal and plant establishment in dung deposited by free-roaming animals. Broadcast seeding/trampling results also support fall seeding recommendations in the Great Basin. Emergence was low in the fall seeding; however, there was no emergence or survival from the spring seeding. Fall seeding is favored because it is not dependent solely on spring precipitation for germination. Also, germination rates of some seeds (shadscale) improve with cold stratification. Over-wintering can benefit fecal seeding because snow cover can prevent crust formation that inhibits seedling emergence (Akbar et al. 1995). Less seed depredation by rodents and birds is also likely following a fall seeding (Vallentine 1989).
Experiment III

DUNG PAT WEIGHT AND MOISTURE CONTENT.---The mean weight of dung pats collected from the November 2001 trial was over twice that of dung pats collected from the April 2003 trial (Table 15). Mean dung moisture content was 74.2% in Experiment I and 88.6% in Experiment II.

SEED RECOVERY.---Undamaged seed recovery/kg was greater for globemallow than squirreltail and sagebrush in the fall trial (Table 15). In the spring seeding trial, globemallow and shadscale had greater recoveries than squirreltail. Seed recovery for globemallow and squirreltail was 2-3 times higher in the fall trial. Variability in recovery was highest for globemallow and shadscale.

POST-PASSAGE GERMINABILITY.---Globemallow seed germinability extracted from dung in both field trials was 11% (Table 16). Post-passage squirreltail germinability was higher in November 2001 dung pats than in April 2003 dung pats. Post-passage sagebrush and shadscale seeds did not germinate. The germinability of

Table 15. Mean (± SE) dung pat weight and seed recovery/kg of dung for Fall 2001 and Spring 2003 field trials.

<table>
<thead>
<tr>
<th>Date</th>
<th>Dung pat wt (g)</th>
<th>Number of seeds recovered/kg</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Globemallow</td>
</tr>
<tr>
<td>November 2001¹</td>
<td>714 (± 130)</td>
<td>1694 (± 531)</td>
</tr>
<tr>
<td>April 2003²</td>
<td>285 (± 36)</td>
<td>645 (± 158)</td>
</tr>
</tbody>
</table>

§ Species not tested.

¹ n = 18
² n = 12
globemallow, squirreltail, and sagebrush seed was reduced by 76%, 82%, and 100%, respectively, after being retained in the gut for 24 to 48 hours.

Many studies have investigated seed properties and other environmental factors that influence seed survival during mastication and digestion (see Chapter 2). These include the effect of gut retention time, seed size and hardness, presence or absence of a seed coat, and the animal’s diet (Simao Neto et al. 1987, Barrow and Havstad 1992, Ocumpaugh et al. 1996). The high variability in seed recovery of globemallow and shadscale in the field trials may be an indication of the variability possible in managerial applications. High variability may be due to the animals having free choice. In the Caine Dairy Farm seed passage trial, where seed intake could be controlled, it was found that globemallow had a quick passage that peaked early, whereas the passage of squirreltail was much more consistent over time (see

---

Table 16. Mean percent germination (± SE) of undamaged recovered globemallow, squirreltail, sagebrush and shadscale seed. Control seed was unpassed, and seed from dung was collected 2 days after seed ingestion.

<table>
<thead>
<tr>
<th>Treatment</th>
<th>Globemallow (± SE)</th>
<th>Squirreltail (± SE)</th>
<th>Sagebrush (± SE)</th>
<th>Shadscale</th>
</tr>
</thead>
<tbody>
<tr>
<td>Control&lt;sup&gt;a&lt;/sup&gt;</td>
<td>46.0 (± 3.8)</td>
<td>74.0 (± 8.1)</td>
<td>53.0 (± 4.4)</td>
<td>0</td>
</tr>
<tr>
<td>November 2001</td>
<td>10.9 (± 1.2)&lt;sup&gt;b&lt;/sup&gt;</td>
<td>13.1 (± 1.6)&lt;sup&gt;c&lt;/sup&gt;</td>
<td>0&lt;sup&gt;c&lt;/sup&gt;</td>
<td>§</td>
</tr>
<tr>
<td>April 2003</td>
<td>11.3 (± 1.7)&lt;sup&gt;d&lt;/sup&gt;</td>
<td>7.8 (± 2.4)&lt;sup&gt;e&lt;/sup&gt;</td>
<td>§</td>
<td>0&lt;sup&gt;d&lt;/sup&gt;</td>
</tr>
</tbody>
</table>

<sup>§</sup> Species not tested.

<sup>a</sup> n = 4
<sup>b</sup> n = 64
<sup>c</sup> n = 56
<sup>d</sup> n = 42
<sup>e</sup> n = 26
Chapter 2, Tables 2 & 3). These differences may be attributable to differences in physical seed properties. The elongated shape of squirreltail seed hinders its passage and as more are eaten, fewer are passed. Sagebrush seed is small and very delicate, and the low recovery numbers suggest that it is digested rather than passed. Therefore, hindered passage of squirreltail and digestion of sagebrush keep the recovery of both species less variable, regardless of the number of seeds eaten. The compact, dense, smooth-coated seed of globemallow aids in quick passage and little seed damage (Gardener et al. 1993a). In addition to differences in seed intake during the field trials, variability in seed recovery may be attributable to physiological differences between individual animals. In contrast to seed recovery, germinability is fairly consistent for globemallow and squirreltail. Germination rates (mean ±SE) for globemallow 48 hours post-ingestion from the dairy trial, Experiment I and II were 8.7% (± 1.9), 10.9% (± 1.2), and 11.3% (± 1.7), respectively, and for squirreltail were 13.3% (± 2.2), 13.1% (± 1.6), and 7.8% (± 2.4), respectively.

SUMMARY AND MANAGEMENT IMPLICATIONS

We found that with very little precipitation, emergence of globemallow and squirreltail from dung still occurred, albeit in low numbers. For globemallow, emergence is possible during the 2nd growing season. More field trials with naturally deposited dung pats are needed to verify if, in a favorable precipitation year with no Mormon crickets, better emergence and survival of seeded species are possible in
Skull Valley. An effort should also be made to monitor the distribution of emerging plants in dung pats.

In our field experiments, factors such as weight and sex of the animals used may have affected the recovery, germination, emergence and survival of the fecally seeded species, making the interpretation of the results difficult. Also, emergence and survival numbers were too low to provide a convincing argument for or against the seeding techniques tested. However, seed recovery numbers and germination are promising for globemallow and squirreltail, and in a good moisture year, may provide enough seeds for seedling emergence and survival.

Interseeding to enhance species composition in areas dominated by crested wheatgrass and cheatgrass is possible within the Intermountain West when the resident vegetation has been temporarily eliminated (Stevens 1992). We found that crested wheatgrass biomass can be reduced by 50% for 2 years when it is utilized twice, first in the spring during boot stage and again in the fall prior to winter dormancy. This may be a sufficient reduction in biomass to allow the establishment of fecal seeded and broadcast seeded/trampled species. It is during the 2nd grazing period that we recommend seeding to take advantage of the most predictable moisture of the year, winter and early spring. We found that globemallow is amenable to emergence following the trampling/broadcast treatment, and squirreltail and sagebrush emergence results from trampling studies by Eckert et al. (1986, 1987) show promise if these species are seeded and trampled in the fall prior to a wet winter. Shadscale seeded in the fall should benefit from over wintering to help break
dormancy. Although the post-passage germinability of globemallow and squirreltail seed is 11-13%, significantly lower than the germinability of unpassed seed, their distribution by fecal seeding may still be a viable seeding option on degraded or previously seeded rangelands. Cows fed at similar seed numbers could fecally distribute 12 dung pats/day (Marsh and Campling 1970) with as many as 185 and 42 germinable globemallow and squirreltail seeds per 1-kg dung pat, respectively, 2 days after seed intake. These seeds would be distributed in patches across the landscape and stored as reserves for a time when germination requirements are met. As noted by Welch (1985), cows have a mean defecation area of 600 cm², which can cover 10% of the ground surface over a 4-year period. The gradual, low impact distribution of broadcast/trampled and fecal seeded seeds may be effective methods to increase species diversity within an established plant community on public and private rangelands currently running cattle that have areas inaccessible to conventional seeding equipment (Archer and Pyke 1991, Barrow and Havstad 1992).

LITERATURE CITED


GRANITE SEED. 2000. The Granite Seed Company. Lehi, UT.


INSTITUTE FOR LAND REHABILITATION. 1979. Selection, propagation, and field establishment of native plant species on disturbed arid lands. Bulletin 500, Agricultural Experiment Station, Utah State University, Logan.


STODDART, L.A. 1946. Some physical and chemical responses of Agropyron spicatum to herbage removal at various seasons. Utah Agricultural Experiment Station Bulletin 324, Utah State University, Logan.


CHAPTER IV
SYNTHESIS

Faced with the threat of weed invasions, soil erosion and failed native species seedings, managers have relied heavily on non-native perennial grass seedings, namely crested wheatgrass (*Agropyron desertorum* (Fisch.) Schult.), to stabilize degraded rangelands. To transition from the near-monocultures created by crested wheatgrass seedings to a more dynamic plant community requires disturbing the resident vegetation and introducing species that can co-exist. Traditional vegetation removal methods are not practical since heavy disturbance can nullify beneficial attributes of a seeding, such as erosion and weed control. Instead, there is a need for inexpensive and less disruptive alternatives that can satisfy a multitude of land management uses (wildlife habitat, livestock grazing, recreation) and objectives (watershed, soil, and native species protection). Alternative methods to integrate native species into crested wheatgrass seedings may include the use of cattle as seed disseminators (Archer and Pyke 1991) and cultivators by means of hoof action to prepare the seedbed and to incorporate broadcasted seed into the soil (Pearson and Ison 1987, Vallentine 1989, Winkel and Roundy 1991a, b, Mosley 1996, Eldridge and Robson 1997).

Several seed feeding trials have quantified seed passage and post-passage germination for a number of plant species (Gökbulak 2002, Doucette et al. 2001, Al-Mashkhi 1993, Simao Neto et al. 1987), and others have quantified seedling emergence and survival in artificial dung pats (Shinderman and Call 2001,
Ocumpaugh et al. 1996, Gardener et al. 1993, Barrow and Havstad 1992), with results being varied and species dependent (Doucette et al. 2001). The purpose of this study was to quantify seed passage, recovery, and post-passage germinability of several species native to the Great Basin, and investigate nontraditional seeding techniques (fecal seeding and broadcast seeding/trampling). In contrast to previous fecal seeding studies, which were conducted under more controlled conditions and included little to no resident vegetation and artificially deposited dung pats (Shinderman and Call 2001, Ocumpaugh et al. 1996, Gardener et al. 1993, Barrow and Havstad 1992), cows were present on the study site and deposited their own dung. An additional goal of the study was to investigate the ability of livestock to intensively graze crested wheatgrass at a phenological stage that is most susceptible to overgrazing, in an effort to create gaps for seedling establishment.

Bottlebrush squirreltail (*Elymus elymoides* (Raf.) Swezey), gooseberry globemallow (*Sphaeralcea grossulariaeefolia* (H. & A.) Rydb.), Wyoming big sagebrush (*Artemisia tridentata* Nutt. spp. *wyomingensis* Beetle & Young), and shadscale [*Atriplex confertifolia* (Torr. & Frem.)], cool-season, drought tolerant perennials native to the Great Basin region of the western United States, were selected for the study. Squirreltail was chosen because of its early seral characteristics (Jones 1998, Hironaka 1994), gooseberry globemallow was chosen for its ability to colonize disturbed areas (Wasser 1982), and Wyoming big sagebrush and shadscale were chosen because of their disappearance on Great Basin rangelands due to increased fire frequency. Post-passage sagebrush germination from the seed
passage study, and emergence from the fall seeding were not positive; therefore, shadscale replaced sagebrush in the seed mix for the spring field trial.

The seed passage trial conducted at the USU Caine Dairy Farm in Logan, Utah quantified squirreltail, globemallow, and sagebrush seed passage, recovery, and post-passage germinability, and determined the influence of seed level intake and gut retention time. Holstein heifers were fed seeds of each species at 3 levels (15,000, 30,000, and 60,000 seeds) over a period of 3 weeks. One kg fecal samples were collected 1, 2, 3, and 4 days after seed ingestion. Undamaged seed extracted from the samples were tested for germinability. Globemallow had the highest percentage of recovered, undamaged seed, followed by squirreltail and sagebrush. Globemallow and sagebrush seed passage was highest on Day 1, after which seed numbers dropped sharply. Squirreltail passage and recovery were more consistent through time, with higher seed recovery at lower seed feeding levels. Post-passage germinability was highest for squirreltail and globemallow on Day 1. Sagebrush germination was negligible. Differences in physical seed properties (size, shape, density, and seed coat) likely influenced interspecies variation in passage, recovery, and germinability. We conclude globemallow and squirreltail seeds are suited for livestock dispersal, but sagebrush seeds are not.

Fecal seeding and broadcast seeding/trampling were evaluated as techniques to establish native plants and increase species diversity in a crested wheatgrass seeding in Skull Valley, Utah. The first grazing treatments, implemented in May 2001, consisted of 50 or 80% crested wheatgrass utilization. In November 2001,
seeds of squirreltail, globemallow, and sagebrush were fed to one group of cows prior to grazing for fecal seeding treatments, and broadcast prior to grazing by another group of cows for seeding/trampling treatments. A 3rd group of cows grazed in a no seeding treatment. Fall utilization in all grazed paddocks was 96%. Half of the plots in every treatment were irrigated to simulate a wet spring, and the other half were exposed to ambient precipitation. Seedling emergence and survival were followed in dung pats and 1m² quadrats during the 2002 and 2003 growing seasons. Globemallow emerged in 6% of the subplots. Half of these subplots were in paddocks that were not seeded (either no seeding treatments or controls), and therefore, were volunteers. Overall seedling mortality was 93%. Squirreltail emerged in 63% of the dung pats, with 86% mortality. No sagebrush emergence was observed. Drought and heavy infestations of Mormon crickets (Anabrus simplex) likely contributed to low seedling emergence and survival. In April 2003 similar treatments were applied, except shadscale was substituted for sagebrush, and a 3rd seeding treatment was added (broadcast seeding/raking). The site was monitored for seedling emergence and survival through August 2003. No seedling emergence was observed. Seed recovery from dung pats collected from both trials was variable, with lower seed recovery in the spring trial. Globemallow germinability was similar for seeds collected from both trials (11%) and squirreltail germination was highest in the fall seeding (13%). Sagebrush and shadscale seed did not germinate. Globemallow recovery in the 2 field trials was higher than the dairy seed passage trial, and squirreltail recovery was highest in the fall seeding trial (Table 17).
Germinability, however, was more consistent between trials. Post-passage globemallow germination, regardless of trial, was similar; however, squirreltail germination was lower in the spring field trial. The greatest number of germinable seeds per dung pat for both species occurred during the fall field trial. Greater seed recovery in the field trials may be a result of individual animal size and diet. The field animals were smaller than the dairy cows and were not fed ad libitum. A result may be a larger seed to fecal matter ratio; however, we cannot verify this because the total fecal output for the field animals is not known. If the field animals were less limited to space and forage, the seed concentrations may have been lower, similar to the dairy animals. If fecal seeding is implemented in a managerial setting where the seed is distributed in feed troughs, seed numbers per dung pat deposited may be highly variable due to a less controlled seed feeding environment.

Table 17. Seed recovered/kg (± SE), percent germination, and number of germinable globemallow and squirreltail seeds per 1 kg dung pat after passage through cattle in three different trials. Numbers presented are for collections made at 48 hours post-ingestion for 25,000 globemallow and 30,000 squirreltail seeds per animal.

<table>
<thead>
<tr>
<th>Trial</th>
<th>Species</th>
<th>Seeds recovered per kg</th>
<th>Germination (%)</th>
<th>Germinable seeds per 1 kg dung pat</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dairy trial</td>
<td>Globemallow</td>
<td>275 (± 145)</td>
<td>8.7 (± 1.9)</td>
<td>24</td>
</tr>
<tr>
<td></td>
<td>Squirreltail</td>
<td>200 (± 31)</td>
<td>13.3 (± 2.2)</td>
<td>27</td>
</tr>
<tr>
<td>Fall field trial</td>
<td>Globemallow</td>
<td>1694 (± 531)</td>
<td>10.9 (± 1.2)</td>
<td>185</td>
</tr>
<tr>
<td></td>
<td>Squirreltail</td>
<td>324 (± 66)</td>
<td>13.1 (± 1.6)</td>
<td>42</td>
</tr>
<tr>
<td>Spring field trial</td>
<td>Globemallow</td>
<td>645 (± 158)</td>
<td>11.3 (± 1.7)</td>
<td>73</td>
</tr>
<tr>
<td></td>
<td>Squirreltail</td>
<td>153 (± 34)</td>
<td>7.8 (± 2.4)</td>
<td>12</td>
</tr>
</tbody>
</table>
Although the viability of fecal seeding and trampling broadcasted seed for increasing plant species diversity within heavily grazed crested wheatgrass seedlings is still uncertain, we know that an average dung pat from November 2001 (714 g) may have ample germinable seeds of globemallow and squirreltail (132 and 30, respectively) for plant establishment during a favorable precipitation year. Trampling broadcasted seed may be a viable seeding technique for all species based on emergence of globemallow in the fall seeding and results reported in the literature for squirreltail and sagebrush (Eckert et al. 1986, 1987). The establishment of shadscale may be possible if its seed is scarified prior to broadcasting (Dumas and Sanders 1990), or seeded in the fall to benefit from the effects of natural leaching, oxidative processes and winter chilling (Garvin et al. 1996).

The projected application of this study is on public Great Basin rangelands where increased species diversity is desired, but conventional reseeding techniques are impractical because of cost or rough terrain. Due to the nature of dung pat deposition, seeds would be distributed in patches across the landscape, creating satellites of desirable species that have the potential to increase in size and number through vegetative propagation or seed production (Archer and Pyke 1991). Since dung pats persist in arid climates (Bornemissza 1960), livestock seed dispersal may also be well-suited to distribute and store long-lived seeds on the landscape until conditions are favorable for germination and establishment. Slower than more traditional methods, livestock seed dispersal would be a long-term rehabilitation
technique that has the potential to incrementally increase plant diversity across a landscape.

More research is needed to realize the full potential of alternative seeding techniques within intensively grazed crested wheatgrass stands. Because revegetation processes on arid and semiarid rangelands are regulated by episodic rather than average environmental conditions (Call and Roundy 1991), and favorable conditions for establishment can occur as infrequently as 1 in 15 years on Great Basin salt desert shrublands (Bleak et al. 1965), repeated seeding applications for several years could help determine the extent precipitation plays as a limiting factor in establishment and survival for fecal seeding and broadcast seeding/trampling. It would also be useful to further quantify seedling establishment through time, to verify the potential of dung pats as seed storage sites, and to document the potential of dung pats to create nuclei of desirable species (Archer and Pyke 1991).

LITERATURE CITED


Table 18. Analysis of variance for fecal output data.

<table>
<thead>
<tr>
<th>Source of variation</th>
<th>df</th>
<th>SS</th>
<th>MS</th>
<th>F</th>
<th>P</th>
</tr>
</thead>
<tbody>
<tr>
<td>Trial</td>
<td>2</td>
<td>460.6778</td>
<td>230.3389</td>
<td>16.32</td>
<td>&lt;0.0001</td>
</tr>
<tr>
<td>Day</td>
<td>3</td>
<td>540.2585</td>
<td>180.0862</td>
<td>12.76</td>
<td>&lt;0.0001</td>
</tr>
<tr>
<td>Species</td>
<td>2</td>
<td>22.0353</td>
<td>11.0177</td>
<td>0.78</td>
<td>0.4609</td>
</tr>
<tr>
<td>Seed intake</td>
<td>2</td>
<td>20.5754</td>
<td>10.2877</td>
<td>0.73</td>
<td>0.4849</td>
</tr>
<tr>
<td>Error</td>
<td>98</td>
<td>1382.8215</td>
<td>14.1104</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Corrected total</td>
<td>107</td>
<td>2426.3685</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Table 19. Analysis of variance for cube root-transformed seed recovery data.

<table>
<thead>
<tr>
<th>Source of variation</th>
<th>df</th>
<th>SS</th>
<th>MS</th>
<th>F</th>
<th>P</th>
</tr>
</thead>
<tbody>
<tr>
<td>Trial</td>
<td>2</td>
<td>0.1058</td>
<td>0.0529</td>
<td>2.11</td>
<td>0.1271</td>
</tr>
<tr>
<td>Species</td>
<td>2</td>
<td>1.7410</td>
<td>0.8705</td>
<td>34.65</td>
<td>&lt; 0.0001</td>
</tr>
<tr>
<td>Seed intake</td>
<td>2</td>
<td>0.0130</td>
<td>0.0065</td>
<td>0.26</td>
<td>0.7725</td>
</tr>
<tr>
<td>Time</td>
<td>3</td>
<td>2.0256</td>
<td>0.6752</td>
<td>26.88</td>
<td>&lt; 0.0001</td>
</tr>
<tr>
<td>Error</td>
<td>98</td>
<td>2.4621</td>
<td>0.0251</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Corrected total</td>
<td>107</td>
<td>6.3475</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Table 20. Analysis of variance for cube root-transformed seed recovery data for Wyoming big sagebrush.

<table>
<thead>
<tr>
<th>Source of variation</th>
<th>df</th>
<th>SS</th>
<th>MS</th>
<th>F</th>
<th>P</th>
</tr>
</thead>
<tbody>
<tr>
<td>Time</td>
<td>3</td>
<td>1.012</td>
<td>0.3373</td>
<td>32.79</td>
<td>&lt; 0.0001</td>
</tr>
<tr>
<td>Seed intake</td>
<td>2</td>
<td>0.0011</td>
<td>0.0006</td>
<td>0.05</td>
<td>0.9472</td>
</tr>
<tr>
<td>Error</td>
<td>30</td>
<td>0.3086</td>
<td>0.0103</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Corrected total</td>
<td>35</td>
<td>1.3218</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Table 21. Analysis of variance for cube root-transformed seed recovery data for gooseberry globemallow.

<table>
<thead>
<tr>
<th>Source of variation</th>
<th>df</th>
<th>SS</th>
<th>MS</th>
<th>F</th>
<th>P</th>
</tr>
</thead>
<tbody>
<tr>
<td>Time</td>
<td>3</td>
<td>1.2808</td>
<td>0.4269</td>
<td>16.40</td>
<td>&lt; 0.0001</td>
</tr>
<tr>
<td>Seed intake</td>
<td>2</td>
<td>0.0108</td>
<td>0.0054</td>
<td>0.21</td>
<td>0.8131</td>
</tr>
<tr>
<td>Error</td>
<td>30</td>
<td>0.7809</td>
<td>0.0260</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Corrected total</td>
<td>35</td>
<td>2.0726</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Table 22. Analysis of variance for seed recovery data for bottlebrush squirreltail (cube root-transformed).

<table>
<thead>
<tr>
<th>Source of variation</th>
<th>df</th>
<th>SS</th>
<th>MS</th>
<th>F</th>
<th>P</th>
</tr>
</thead>
<tbody>
<tr>
<td>Time</td>
<td>3</td>
<td>0.0660</td>
<td>0.0220</td>
<td>6.13</td>
<td>0.0022</td>
</tr>
<tr>
<td>Seed intake</td>
<td>2</td>
<td>0.0781</td>
<td>0.0391</td>
<td>10.88</td>
<td>0.0003</td>
</tr>
<tr>
<td>Error</td>
<td>30</td>
<td>0.1077</td>
<td>0.0036</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Corrected total</td>
<td>35</td>
<td>0.2518</td>
<td></td>
<td></td>
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</tr>
</tbody>
</table>
Table 23. Analysis of variance for globemallow seed germination.

<table>
<thead>
<tr>
<th>Source of variation</th>
<th>df</th>
<th>SS</th>
<th>MS</th>
<th>F</th>
<th>P</th>
</tr>
</thead>
<tbody>
<tr>
<td>Time</td>
<td>3</td>
<td>606.6726</td>
<td>202.2242</td>
<td>3.67</td>
<td>0.0207</td>
</tr>
<tr>
<td>Error</td>
<td>37</td>
<td>2039.6150</td>
<td>55.1247</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Corrected total</td>
<td>40</td>
<td>2646.2874</td>
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</tr>
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</table>
Table 24. Analysis of variance for bottlebrush squirrel tail seed germination (arcsine-transformed).

<table>
<thead>
<tr>
<th>Source of variation</th>
<th>df</th>
<th>SS</th>
<th>MS</th>
<th>F</th>
<th>P</th>
</tr>
</thead>
<tbody>
<tr>
<td>Time</td>
<td>3</td>
<td>1.0426</td>
<td>0.3475</td>
<td>22.42</td>
<td>&lt;0.0001</td>
</tr>
<tr>
<td>Error</td>
<td>44</td>
<td>0.6821</td>
<td>0.0155</td>
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</tr>
<tr>
<td>Corrected total</td>
<td>47</td>
<td>1.7247</td>
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</tbody>
</table>
Table 25. Effect of grazing intensity on globemallow emergence (mean seedlings/subplot ± SE).

<table>
<thead>
<tr>
<th>Grazing intensity</th>
<th>n</th>
<th>Seedlings/subplot</th>
</tr>
</thead>
<tbody>
<tr>
<td>None</td>
<td>30</td>
<td>0.133 (± 0.079)</td>
</tr>
<tr>
<td>50%</td>
<td>98</td>
<td>0.337 (± 0.266)</td>
</tr>
<tr>
<td>80%</td>
<td>90</td>
<td>0.089 (± 0.078)</td>
</tr>
</tbody>
</table>
Table 26. Effect of grazing intensity on globemallow survival (mean ± SE).

<table>
<thead>
<tr>
<th>Grazing intensity</th>
<th>n</th>
<th>Survival (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>None</td>
<td>3</td>
<td>0 (± 0)</td>
</tr>
<tr>
<td>50%</td>
<td>6</td>
<td>16.67 (± 16.67)</td>
</tr>
<tr>
<td>80%</td>
<td>2</td>
<td>75 (± 25)</td>
</tr>
</tbody>
</table>
Table 27. Effect of grazing intensity on squirreltail emergence (seedlings/dung pat) in fecal seeded paddocks (mean ± SE).

<table>
<thead>
<tr>
<th>Grazing intensity</th>
<th>n</th>
<th>Seedlings/dung pat</th>
</tr>
</thead>
<tbody>
<tr>
<td>50</td>
<td>38</td>
<td>1.816 (± 0.358)</td>
</tr>
<tr>
<td>80</td>
<td>30</td>
<td>1.233 (± 0.310)</td>
</tr>
</tbody>
</table>
Table 28. Effect of grazing intensity on squirreltail survival in fecal seeded paddocks (mean survival ± SE).

<table>
<thead>
<tr>
<th>Grazing intensity</th>
<th>n</th>
<th>Survival (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>50</td>
<td>24</td>
<td>11.81 (± 5.35)</td>
</tr>
<tr>
<td>80</td>
<td>18</td>
<td>11.81 (± 6.43)</td>
</tr>
</tbody>
</table>
Table 29. Effect of irrigation on globemallow survival (mean ± SE).

<table>
<thead>
<tr>
<th>Irrigation</th>
<th>n</th>
<th>Survival (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>No</td>
<td>5</td>
<td>20 (± 20)</td>
</tr>
<tr>
<td>Yes</td>
<td>6</td>
<td>25 (±17.08)</td>
</tr>
</tbody>
</table>
Table 30. Effect of irrigation on squirreltail emergence (seedlings/dungpat) in fecal seeded paddocks (mean ± SE).

<table>
<thead>
<tr>
<th>Irrigation</th>
<th>n</th>
<th>Seedlings/dung pat</th>
</tr>
</thead>
<tbody>
<tr>
<td>No</td>
<td>34</td>
<td>1.676 (± 0.375)</td>
</tr>
<tr>
<td>Yes</td>
<td>34</td>
<td>1.441 (±0.314)</td>
</tr>
</tbody>
</table>
Table 31. Effect of irrigation on squirreltail survival in fecal seeded paddocks (mean ± SE).

<table>
<thead>
<tr>
<th>Irrigation</th>
<th>n</th>
<th>Survival (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>No</td>
<td>20</td>
<td>7.29 (± 3.70)</td>
</tr>
<tr>
<td>Yes</td>
<td>22</td>
<td>15.91 (± 6.98)</td>
</tr>
</tbody>
</table>