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The effects of planting methods and granivory on seedling emergence in a tallgrass prairie reconstruction

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THE EFFECTS OF PLANTING METHODS AND GRANIVORY ON SEEDLING EMERGENCE IN A TALLGRASS PRAIRIE RECONSTRUCTION

An Abstract of a Thesis

Submitted

In Partial Fulfillment

of the Requirements for the Degree

Master of Science

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ABSTRACT

This study investigates effects of various seed incorporation methods (none, culti-pack, rake, rake and culti-pack) and seed predation on prairie species emergence and establishment over two growing seasons. To assess seed incorporation, seed was coated with a fluorescent orange powder and sampled with a black light the night of seeding. Powder coated seed was broadcast seeded in early November 2007. Seed was incorporated into the soil by culti-packing, raking, or a combination of raking followed by culti-packing. Seed was not incorporated into the soil in control plots. Granivore exclosures in the research plots were used to determine the effect of granivory on prairie seedling emergence. Prairie species emergence and granivory were sampled in June of 2008, September of 2008, and June of 2009.

High winds occurred for 7 days after seeding resulting in a 21.5% seed loss in broadcast treatments with no incorporation and no losses in seed incorporation treatments. Low native seedling emergence limited data analysis and interpretation. Initially, raking alone and culti-packing alone increased seedling emergence 25% more than other treatments. The majority of the species that benefited from the seed incorporation treatments were annuals, biennials, and short-lived perennials. However, in year 2, there were no significant ($p<0.05$) differences in seedling emergence between seed incorporation treatments. Seed incorporation had no effect on weed species richness or biomass. Excluding seed predators increased emergence by 19% in the first year and 48% in the second year of the prairie reconstruction. Causes for a low percentage of

native plant emergence from seeds planted are not clearly understood and further research is needed.

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This study by: Justin Vernon Huisman

Entitled: The Effects of Planting Methods and Granivory on Seedling Emergence in a Tallgrass Prairie Reconstruction.

has been approved as meeting the thesis requirements for the

Degree of Master of Science.

5/11/2010 ______________________________
Date Dr. Daryl Smith, Chair Thesis Committee

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Date Dr. Jim Demastes, Thesis Committee Member

5/11/2010 ______________________________
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7/8/10 ______________________________
Date Dr. Sue A. Joseph, Dean, Graduate College

DEDICATION

For Lacey and Sophie

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INTRODUCTION

The tallgrass prairie that once dominated Iowa's landscape has been almost eliminated and replaced by agricultural crop land (Smith 1998). Today efforts are being made to restore prairie remnants. Private land-owners, organizations and agencies are also implementing practices to reconstruct tallgrass prairie. In reconstructing tallgrass prairie, seed must be added to the reconstruction site. Germination and establishment is improved by seeding with incorporation, covering with soil, to insure good seed-to-soil contact (Chambers and MacMahon 1994).

Lack of seed incorporation may have serious consequences for the seed and emergence of seedlings in reconstructed sites. First, a seed must remain on the soil of the planting site long enough to imbibe water and germinate. Wind can move seed about or blow it off the site. Johnson and Fryer (1992) examined the effect of wind on the movement of seed of 4 tree species placed on four different surfaces. Their study suggests that wind can move unincorporated seed and prevent germination. They found that seeds placed on surfaces where seeds weren't allowed to move had adequate time to imbibe water and germinate. Seeds placed on smooth surfaces that allowed the seeds to move without restraint were blown away by the wind and didn't have sufficient time to imbibe water and germinate.

Second, a seed not incorporated into the soil may be washed away from the desired planting site by water runoff. Redbo-Torstensson and Telenius (1995) examined the effects of water flow on the movement of salt sandspurry (*Spergularia salina*) seeds in eastern Sweden and found a significant seed loss after 11 days of exposure to water flow. They observed that one-third of all the seeds, both winged and un-winged, positioned on the bare soil were removed from the site and not recovered. If seed incorporation prevents the loss of one-third of the seed planted on the soil surface, that would be a direct economic benefit to the purchaser of the native seed.

Third, unincorporated seeds, laying on the soil surface are more susceptible to desiccation. Water is one of the most important items a seed must have in order to germinate and become a seedling. Seed laying on the soil surface may not receive a consistent supply of water, is exposed to a lot of sunlight and subject to evaporation. A desiccated seed will not successfully germinate. Burying seeds at shallow depths prevents desiccation by maintaining a humid environment around the seeds and allowing successful germination (Harper and Benton 1966).

Fourth, seed incorporation and exclusion of granivores could significantly reduce seed loss and improve plant emergence. Several researchers have observed that seed incorporation makes seed consumption difficult for seed predators (Chambers and MacMahon 1994, Janzen 1971, Heithaus 1981, Hulme 1994). Burying seed in the soil makes it more difficult for animals to see, reach, and consume it. Reducing availability of seed to predators leaves more seed to germinate and become seedlings. In Ontario, Canada Blaney and Kotanen (2001) compared excluding seed predators to not excluding seed predators in areas with 43 native and exotic old-field seeds. They found that excluding seed predators from seeds increased recovery of seeds by 38.2-45.6%. The large percentage of seed retained by exclusion of granivores could contribute significantly to the number of plants available for emergence.

In summary, seed incorporation can increase the amount of plants and number of species in a reconstruction by reducing seed granivory, seed desiccation, and seed loss due to wind or water erosion. Reducing these factors and not wasting seed is an economic gain.

Research Questions and Hypotheses

Research is needed to determine planting methods that are effective in reducing biotic and abiotic factors that negatively affect seedling emergence. It has been demonstrated that incorporating seeds into soil can reduce granivory as well as improve seedling emergence. I propose that prairie reconstructions can be improved by using seed incorporation to increase seed-to-soil contact, prevent seed loss due to granivory, and curtail seed loss due to wind or water.

I assume incorporating the seed to increase seed-to-soil contact will promote seedling emergence and establishment in a tallgrass prairie reconstruction. I also assume seed incorporation will exclude predators and reduce granivory. The hypotheses for this study to test these assumptions are: (1) Covering the seed by raking it into the soil will increase native plant emergence and increase weeds, (2) pressing the seed into the soil by culti-packing the soil after seeding will increase native plant emergence and reduce weeds, (3) covering the seed by raking it into the soil followed by culti-packing will maximize native plant emergence and reduce weeds, (4) proper seed incorporation will reduce granivory and increase seedling emergence, (5) predator exclusion will reduce granivory and increase seedling emergence.

The objectives of this study to test the hypotheses are to 1) assess and compare how different seed incorporation methods affect weed competition and native seedling emergence, 2) assess and compare the effect of granivory on native seedling emergence in each of the seed incorporation methods and different exclusion treatments.

Literature Review

Prairie seedling establishment is an extremely important component of a prairie reconstruction. Prairie seedlings are the primary constituents and beginning point of a reconstructed prairie. Certain methods of planting and seed incorporation may improve native seedling emergence and subsequent establishment (Packard and Mutel 1997).

Prairie reconstruction guidelines and resource managers both suggest that incorporating native seeds into the soil by compaction, tillage, or sowing will improve seed-to-soil contact and reduce the negative effects of biotic and abiotic factors (Henderson et al. 2009). Negative factors include seed predation, seed desiccation, and seed loss due to wind and water erosion.

Chambers and MacMahon (1994), strong advocates of seed incorporation, indicate that seed dispersion involves two phases before the seeds become stationary to germinate and grow into an adult plant. In phase I, the seed disperse safely from the parent plant to the soil surface. In phase II, the seed undergo vertical and horizontal movement in or on the soil surface before germinating and growing into an adult plant. They state, “once a seed has arrived on a surface, it can remain where it initially came to rest, it can move to a new location (horizontal movement), or it can be incorporated into the soil (vertical movement). The probability of redistribution is determined by the nature of the abiotic or biotic factors acting on the seed and the characteristics of the site where the seed lands." In order to insure successful germination, emergence, and establishment, we must manage the abiotic and biotic factors as much as possible. Chambers and MacMahon (1994) indicate that incorporation of seeds is one way to control biotic (animals) factors because it decreases the probability that seeds will be located and eaten by predators, and also protects the seed from abiotic factors of wind and desiccation.

Janzen (1971) supports the concept of burying seeds primarily to avoid predation. He is of the opinion that predation may be much more intense on seeds on bare ground than in soil, leaf litter, or grass litter. If a seed doesn't land in a "safe site," it must possess chemical or morphological characteristics that allow it to avoid predation.

Several studies have demonstrated that seed predators can significantly reduce the amount of planted seed. The result is decreased emergence of seedlings and limited establishment of the plant community. Heithaus (1981) conducted a field exclosure experiment that excluded seed predators (rodents, ants) from seed in some plots and allowed access to seed in other plots. In this experiment, seeds were exposed on the soil surface. He found a maximum reduction of 39-43% of *Asarum canadense* and *Sanguinaria canadensis* seeds in plots where ants and rodents were allowed access. In addition, he did a laboratory experiment comparing the number of buried and unburied seeds eaten by *Peromyscus leucopus*. *P. leucopus* was able to locate *A. canadense* and *S.*

canadensis seeds 67.5 percent less frequently when the seeds were buried. These results suggest that reducing access of seed predators by burying the seed in the soil will increase the amount of seeds available for germination and emergence.

Hulme (1994) used naturally occurring species of grasses and forbs in the British Isles to compare areas with buried seeds to areas with seeds on the soil surface. He found significant differences in rodent-seed encounters of buried seed compared to surface seeds. During the winter months, burial reduced seed encounters by rodents by over 98 percent in the grassland. Seeds were placed in buried and unburied Petri dishes so seedling emergence could not be measured.

In 1999, Howe and Brown studied bird and rodent granivory of seed broadcast in a prairie planting. During the first growing season, birds and rodents significantly reduced plant density and biomass of forbs and grasses. Their results indicate that broadcasting seed on the soil surface without incorporating the seed into the soil may lead to significant seed loss and negatively affect the composition of the plant community.

Broadcast seeding not only increases the exposure of seeds to granivory, it also reduces the opportunity for seed-to-soil contact. Nelson et al. (1970) compared the effects of broadcast seeding and mechanical drilling of seed into the soil on the emergence of seedlings of seven non-native perennial bunchgrasses in southeastern Washington. They observed in broadcast treatments there was higher predation of seed and the seedlings never appeared to be well-anchored. The broadcast seeded species that germinated the best had smaller seeds. Evidently, smaller seeds had a better chance of falling into soil crevices and maintaining soil contact. They concluded that the main deterrent to germination of the broadcast seeds was the rapid drying of surface soil after brief periods of precipitation and high humidity.

Foster et al. (2007) conducted a multi-species native seeding experiment on an abandoned hayfield in Kansas over 6 years. They compared raking the soil as a disturbance prior to seeding with no disturbance of soil, and plots that were over-seeded to plots that were not over-seeded. Seeds were broadcast seeded into clay loam soil. They examined the effects of sowing treatment on annual and perennial plants. They found biomass production of long-lived perennials and functional guild species diversity was significantly increased by sowing seeds after a soil disturbance. They also found C_4 graminoids and legumes increased in biomass production when sown after a raking disturbance. However, the biomass production of C_3 graminoids, short-lived perennials, and annuals were significantly decreased when the seeds were sown following a raking disturbance.

Small amounts of mechanical tillage is known to promote seedling emergence of some species (Kocher and Stubbendieck 1986). Monti et al. (2001) compared the effects of different till and no-till treatments on emergence of two varieties of *Panicum virgatum* in previously farmed soil in northern Italy. They also examined soil compaction (rolling) effects on emergence of the *P. virgatum* varieties. All seeds were sown with a mechanical drill. The soil was not disturbed in the no-till treatment, but tilling treatments affected soils from depths of 10 to 35 cm. The rolling treatments were done before and after sowing. They found one variety of *P. virgatum* had higher emergence in the no-till treatments while the other variety had higher emergence in the tillage treatments. They also found that rolling improved seedling emergence in all cases. The average emergence of unrolled plots was 20 percent lower than rolled plots. Although, disrupting the soil with tillage was effective in improving seedling emergence of one variety, it may not be the most effective alternative for seeding prairie species in Iowa. Tilling of Iowa farmland could promote non-native weedy species present in the soil seed bank. On the other hand, rolling or raking native seeds into the soil could be a better option because the soil isn't disturbed enough to bring weed seed to the surface.

In an Illinois study, Russell Kirt (2001) compared transplanting of seedlings with broadcasting of seed that was raked and rolled into the soil. Using coefficients of conservatism and numbers of observed native species, Kirt developed a system to compare the two treatments. After 16 growing seasons, the transplanted area had an index value of 30.20 and the broadcast seeded area had a value of 30.11. The similar values indicate that incorporated native seed can produce a reconstructed prairie of a quality equal to using live transplants.

When incorporating the seed into the soil, it's important not to cover the seeds too deeply. Sanderson and Elwinger (2004) examined the effects of planting depth on cool-season grasses. In this Pennsylvania study, grasses were planted at depths of 1, 3, and 6 cm in a mesic silty loam soil type. Grass seedling emergence and size decreased with deeper planting depth. Emergence of all grasses was drastically reduced at the 6 cm planting depth and in some cases no seedlings emerged.

CHAPTER 2

MATERIALS AND METHODS

Site Description

The study was conducted in a previously row cropped area owned by the University of Northern Iowa. The site is located on the west edge of the Cedar Falls, IA just north of West 27th street (42° 31' 02"N; 92° 28' 47"W). It is a 0.612 ha. area adjacent to a fence line to the west dominated by *Bromus inermis* and cropland to the east. Reconstructed prairie is located 15 m from both the north and south ends of the site (Appendix 1).

The experimental site contains a single soil type, 391-B Clyde-Floyd complex, consisting of loam, silty loam, and clay loam (Soil Survey of Black Hawk County 2006). This soil type is somewhat poorly drained to poorly drained with a 1-4 percent slope. This particular slope is probably closer to 4 percent and slopes down from south to north. Annual precipitation is 84.39 centimeters (World Climate 2009).

The site has been farmed with row crops for many years. The last crop prior to initiation of the research was corn harvested in the fall of 2006. In late May 2007, the site contained crop debris from the previous year, but no actively growing vegetation. The adjacent area to the east was planted to corn in 2007. Crops in 2008 and 2009 were soybeans and corn respectively.

Experimental Design and Treatments

The experiment used a randomized block design. There were two 159m X 20m blocks each consisted of twelve, 10m X 20m plots (Appendix 1) with 3m X 20m buffer strips between plots. Each plot within each block was randomly assigned one of four treatments. The randomly assigned treatments were broadcast seeded (control), broadcast seeded and culti-packed, broadcast seeded and raked, and broadcast seeded and raked followed by culti-packing. Each treatment was replicated 3 times in each block. At the west end of each 10m X 20m treatment plot, a 5m X 10m portion was delineated for the granivory study (Appendix 1). The remainder of each 10m X 20m plot, 15m X 10m, was designated for the vegetative portion of this study.

To test for granivory, eight - $0.1m^2$ cylindrical exclosures were randomly placed within each 5m X 10m portion immediately after seeding the site. To facilitate vegetative sampling, the 8 exclosure cylinders in each plot, were replaced with $0.1m^2$ hoops prior to sampling the following spring. Four additional hoops were randomly placed within this area as a non-exclosure control for the previously exclosed areas and non-exclosed areas. The 12 hoops, constructed of pex tubing, were permanently stapled to the ground for future sampling of vegetation.

General Statistical Approach

The data for this experiment was analyzed using analysis of variance (ANOVA). The vegetative study used ANOVA with two factors, block comparison and treatment comparison. All possible 2-way and 1-way interactions were analyzed. A 3-way ANOVA with three factors, block comparison, tillage treatment comparison, and exclosure treatment comparison was used for the granivory portion of the study. I also performed a 2-way ANOVA using block comparison and exclosure treatment comparison as factors for the granivory portion of this study. All ANOVA statistics and models were done by using Systat (Wilkinson 1989). A Tukey's test for pairwise comparisons was used to compare means among different treatments (Wilkinson 1989). All comparisons were done at a level of significance of 0.05. Skewness and kurtosis was also calculated for all data and a t-Test was conducted to see if the data had significant skewness or kurtosis from zero (Wilkinson 1989). In some cases, data was normalized by square-root transformations and then back transformed for reporting.

Site Preparation

On June 8, 2007, the research site was seeded with oats at a rate of 3 bushels/acre to control erosion, suppress weeds and provide fuel for a pre-treatment fire. The area was mowed twice during the summer to suppress weeds. Canada thistles were spot sprayed throughout the summer and fall. Just prior to seeding, a prescribed fire was conducted to remove ground cover. Unfortunately, the burn was incomplete and ineffective. Therefore, a 18.5 horsepower Huskee lawnmower was used to mow, bag and remove the vegetation from the site prior to seeding to enhance the probability of seed-to-soil contact.

Seed Preparation and Sowing

Iowa Source Identified seed, Central Region-Iowa Ecotype, was purchased from several seed producers. Prior to seeding, the seed was stored in a seed cooler at a low temperature with low humidity. To insure that a sufficient amount of seed was seeded per meter squared, the amount of Pure Live Seed(PLS) was calculated from the seed purity and percent germination information on the seed tag (Table 1).

Table 1. Seeding rate of species used for the experiment.

Grasses		Seeding Rate (seeds/m^2)
big bluestem	*Andropogon gerardii*	22
side-oats grama	*Bouteloua curtipendula*	22
prairie brome	*Bromus kalmii*	43
Canada wildrye	*Elymus Canadensis*	11
Virginia wildrye	*Elymus virginicus*	11
switchgrass	*Panicum virgatum*	22
little bluestem	*Schizachyrium scoparius*	22
Indian grass	*Sorghastrum nutans*	22
tall dropseed	*Sporobolus asper*	11
Forbs		
lead plant	*Amorpha canescens*	11
thimbleweed	*Anemone cylindrical*	11
prairie sage	*Artemisia ludoviciana*	22
smooth blue aster	*Aster laevis*	33
New England aster	*Aster novae-angliae*	11
Canada milkvetch	*Astragalus canadensis*	22
white wild indigo	*Baptisia leucantha*	3
partridge pea	*Cassia fasiculata*	54
prairie coreopsis	*Coreopsis palmate*	6
purple prairie clover	*Dalea purpurea*	33
showy tick trefoil	*Desmodium canadense*	11
pale purple coneflower	*Echinacea pallida*	11
bigtooth sunflower	*Helianthus grosseserratus*	3
ox-eye sunflower	*Heliopsis helianthoides*	11
great St. Johns wort	*Hypericum pyramidatum*	22
prairie blazingstar	*Liatris pycnostachya*	11
wild bergamot	*Monarda fistulosa*	22
wild quinine	*Parthenium integrifolium*	3
foxglove beardtongue	*Penstemon digitalis*	11
common mt. mint	*Pycnanthemum virginianum*	33
yellow coneflower	*Ratibida pinnata*	33
black-eyed susan	*Rudbeckia hirta*	33
sweet coneflower	*Rudbeckia subtomentosa*	22
wild petunia	*Ruellia humilis*	3
rosinweed	*Silphium integrifolium*	1
compass plant	*Silphium laciniatum*	1
stiff goldenrod	*Solidago rigida*	22
showy goldenrod	*Solidago speciosa*	22
Ohio spiderwort	*Tradescantia ohiensis*	3
hoary vervain	*Verbina stricta*	11
golden alexanders	*Zizia aurea*	11

Seeds for each plot were coated with Day-Glo fluorescent powder and broadcast seeded into each plot on November 2, 2007. A Scott's hand-held broadcast seeder was used for the seeding because only a small amount of seed was needed for each plot. Seed incorporation treatments were done following the broadcast seeding. The broadcast seed was incorporated in each plot with one of the four following treatments: none (control), culti-packed, raked, raked followed by culti-packed. Culti-packing was done with a culti-packer attached to the back of a 950 John Deere tractor. The culti-packer is a 2 meter wide implement with several toothed wheels that press the seed into the soil. Raking was done by dragging a box spring from a household bed across plots with a 950 John Deere tractor.

Buffer strips were placed around the treatment plots to minimize wash-over of seed from one plot to the next. Wash-over was a concern because the research plots are located on a 4% slope. The buffer strips were seeded at the same time the research plots were seeded. The seed planted in the buffer strips was a pasture mix containing the following species: summit timothy, Kentucky bluegrass, 408DP alfalfa, gain festulolium, boost perennial ryegrass, pinnacle ladino clover. The seed mixture was seeded at a rate of 11.22 kg/ha with a 6 row Truax drill attached to a 5325 John Deere tractor.

Mowing

The plots were mowed with a 2 meter wide rotary mower attached to a 950 John Deere tractor. Mowing was done to suppress annual weeds and allow sunlight to reach the smaller and slower developing native perennials. All plots in the research area were mowed from north to south to ensure all plots had the same number of tractor passes across them. The plots were mowed 3 different times in 2008. The mowing was done on June 24, July 27, and August 27, 2008. Each time the vegetation was mowed at a height between 10-15 cm.

The buffer strips between research plots were mowed with a turf-grass riding lawn mower. They were mowed weekly to allow easy access to the research plots.

<u>Granivory Exclosures</u>

Exclosures were used to exclude animals from portions of the seeded areas. Two different types of exclosures were used to ascertain if the exclosures had any effect on the seedlings. Closed-type exclosures excluded all animals (small mammals, birds, and insects). A similarly constructed open-type exclosure allowed animals access to the seed.

The closed exclosures consisted of a 13 centimeter wide cross-section of a plastic 5-gallon pail. One end of the cross-section was covered with 1.27 centimeter wire mesh. The wire mesh was attached to the plastic with Decker's hump hog rings. The open end of the exclosure was pushed 2 centimeters into the seed covered soil. Small mammals and birds were excluded by the plastic side of the exclosure and the wire mesh on the top. Insects were eliminated by placing a granular form of Talstar EZ (FMC corporation) on the soil surface inside each exclosure at a rate of 224.5 kg/ha two different times during the growing season (April 2, 2008 and June 1, 2008).

Open exclosures were constructed in exactly the same manner as the closed exclosures. The only difference was that I drilled four 6.35 centimeter diameter holes in the side of the plastic cross-section to allow small mammals, birds, and insects to enter.

Concerns regarding blocking of light by the closed exclosures were tested prior to beginning the field study. A second generation light meter was used to determine whether or not the exclosures significantly affected the amount of light that reached to the soil surface inside the exclosures. Repeated testing showed that the exclosures didn't significantly effect light levels.

The exclosures were also tested for their ability to exclude small mammals prior to the experiment. Twelve exclosures with peanut butter baited traps inside were placed in habitable areas next to the research site. No small mammals were caught or traps snapped inside the exclosures. This indicated that the animals were unable to enter the closed exclosures.

Sampling and Analysis of Seed Incorporation

No one has developed a method to measure seed incorporation. Consequently, I had to determine a means to quantify the amount of seed incorporated into the soil. As indicated, all seed was coated with Day-Glo fluorescent powder prior to broadcast seeding. After the seeding and seed incorporation treatments, I randomly selected 5 areas in each treatment plot to observe and count the seeds on the soil surface. A random number table was used to locate the 0.1 m^2 quadrat sample areas. A battery powered black light was used to observe the coated seeds within the quadrats. The observation and seed counting was done twice, the night of the seeding and seven nights later. The amount of seeds on the soil surface in each treatment area was recorded. During the one week between samplings, no precipitation events took place so powder wasn't washed off the seeds. However, there were strong winds (17-33mph) for 7 days during this period.

Means of the seed counts for both sets of data (time 1 and time 2) were analyzed to determine if significant differences existed between treatments and blocks (Systat Software, Inc). The analysis included four treatments: no incorporation (control), culti-packing, raking, and raking followed by culti-packing.

Vegetative Sampling and Analysis

Vegetation was sampled in the 10m X 15m portion of each 10m X 20m plot. Sampling was done at three different times throughout the project. The first sampling was done June 6, 2008 and the second sampling on September 16th and 17th of 2008. The third and final sampling was done on June 9, 2009. For vegetative sampling, 10 sample areas were selected within each plot by using a random number table. If the random area selected happened to occur in a wash-out area where no vegetation was apparent, I sampled from an area adjacent to the wash-out. A $0.1m^2$ rectangular quadrat was used to sample the vegetation of the 10 areas. Within the quadrat, native seedlings were identified and counted. Non-native weedy species within each quadrat were identified and recorded as present, but were not counted.

The mean number of native seedlings for each sample date were analyzed to determine if significant ($p<0.05$) differences existed between treatments and blocks. The four treatments used for data analysis of all three sample times were: no incorporation (control), culti-packing, raking, and raking followed by culti-packing. The number of grass, forb, and total native seedlings and species means were all analyzed by block and treatment. Means of the number of non-native weed species were also analyzed for all three samples times.

Granivory Sampling and Analysis

As indicated previously, the granivory portion of the study was done in the 5m X 10m portion on the west end of each 10m X 20m plot. This portion of the area contained the open and closed granivory exclosures that were replaced with $0.1m^2$ pex tubing hoops prior to sampling. Exclosure treatments were open, closed, and no exclosures. An extra set of hoops was added to the granivory section of the plots as a non-exclosure control. Sampling procedures and data collection were the same as in the vegetative sampling except I used the round $0.1m^2$ hoops rather than rectangular quadrats.

The granivory areas were sampled three different times, June 6, 2008, September 16, 2008, and June 9, 2009. Means of the numbers of native and non-native seedlings and species were analyzed to determine if significant ($p<0.05$) differences existed between treatments and between blocks. Data analysis included two different types of treatments, seed incorporation treatment (no incorporation, culti-packing, raking, and raking followed by culti-packing) and exclosure treatment (open, closed, or no exclosure).

Preliminary Tests of Effects of Fluorescent Powder

Effect on Seedling Emergence

In order to observe seed incorporation in this project, the seeds were coated with Day-Glo fluorescent powder. I was unsure if the powder would affect seed germination and the manufacturer (Day-Glo Color Corporation) had no information to answer that question. A preliminary experiment was done in the greenhouse to test the effect of the powder on seedling emergence.

The experiment used a randomized block design. Two sets of twelve .01m^2 plastic greenhouse trays with powdered and unpowdered seeds were randomly placed on one table in the greenhouse. Eight treatments were replicated 3 times in each block of 12 trays. The treatments were: powdered seed with no treatment, powdered seed culti-packed, powdered seed raked, powdered seed raked and culti-packed, unpowdered seed with no treatment, unpowdered seed culti-packed, unpowdered seed raked, unpowdered seed raked and culti-packed.

Five forb species and five grass species were used in each of the treatments (Table 2).

Table 2. Species used in greenhouse experiment.

Grass Species	Forb Species
Andropogon gerardii	*Desmodium canadense*
Elymus canadensis	*Heliopsis helianthoides*
Panicum virgatum	*Monarda fistulosa*
Schizachyrium scoparius	*Rudbeckia hirta*
Sorghastrum nutans	*Silphium laciniatum*

Five seeds of each species were counted and placed in a Ziploc bag for a total of 50 seeds in each bag. Following the seed counting, 12 bags of seed were powdered and 12 bags were left unpowdered. The seed was broadcast at 50 seeds/m^2 on sterilized soil (depth of 5 cm) in the plastic greenhouse trays. Culti-packing was simulated with a small paint roller and raking was simulated with a two-tined table fork.

As seedlings emerged, each was identified, recorded, and removed from the trays during a 2 month period. A 2-way ANOVA analysis was used to determine interactions between blocks and treatments.

Effect on Granivory

The goal of this preliminary experiment was to test whether or not the powder affected consumption of the seed by granivores. This study was done at the Tallgrass Prairie Campus Preserve of the University of Northern Iowa in Cedar Falls, Iowa. This is a reconstructed prairie that was initially planted in 1973. This study was conducted from May 12 to May 22, 2008 on an unburned area of the prairie that was surrounded by portions that were burned in April of 2008. This location was selected because many seed granivores would likely be concentrated there because of the burned surroundings.

Five plastic trays with powdered seeds and 5 trays with unpowdered seeds were randomly stapled to the ground within an unburned portion of the prairie near the northwest corner. Trays were 0.1 m^2 with a 1 cm flange on the edges to prevent seeds from being blown away by wind, but allow access by seed predators at the same time. Ten seeds of 5 species were placed on each tray. The seeds included 2 legumes, 2 asters, and one grass in order to give the predators some choice types of seeds. Species used were: *Astragalus canadensis* (Canada milk vetch), *Desmodium canadense* (showy tick-trefoil), *Heliopsis helianthoides* (ox-eye sunflower), *Silphium laciniatum* (compass plant), and *Elymus canadensis* (Canada wild-rye).

Ten days after placement, the viable seeds remaining on each tray were identified and counted. Missing seeds or seeds with a broken seed coat were noted as they would be unavailable or non-viable for germination and establishment. During the 10 days the trays were in the field, no rainfall occurred so any effects on the seeds were likely due to seed predators. A 2-way ANOVA was used to observe powder treatment and species mean differences. A 1-way ANOVA was run to observe powder and no powder differences among species means.

CHAPTER 3

RESULTS

Effects of Day-Glo Fluorescent Powder on Seedling Emergence

Data for seed germination and seedling emergence for this preliminary greenhouse experiment was taken daily over a 2-month period as seedlings emerged and were identified. A 2-way ANOVA was used to analyze the data. Seeds covered with powder germinated and emerged just as well as seeds that weren't covered with powder. I found no significant differences in germination or emergence of the mean number of grasses, forbs, or total natives that were covered with powder versus those not covered with powder (Table 3). All p-values in Table 3 are much greater than 0.05 which means the powder had no significant effect on seedling emergence.

Table 3. Effect of powder on seedling emergence. A two-way ANOVA was used for the analysis of this data.

	Powder	No Powder	P-value
Total Natives	24.50(0.93)	23.80(0.77)	0.582
Native Grasses	10.50(0.50)	9.75(0.49)	0.314
Native Forbs	14.00(0.44)	14.00(0.82)	1.00

Different seed incorporation techniques had no significant effect on seedling emergence. There were no significant ($p<0.05$) differences between broadcast, culti-packed, raked, raked and culti-packed treatments (Table 4). All native seeds planted germinated and emerged equally over the 2 month time period regardless of the incorporation technique.

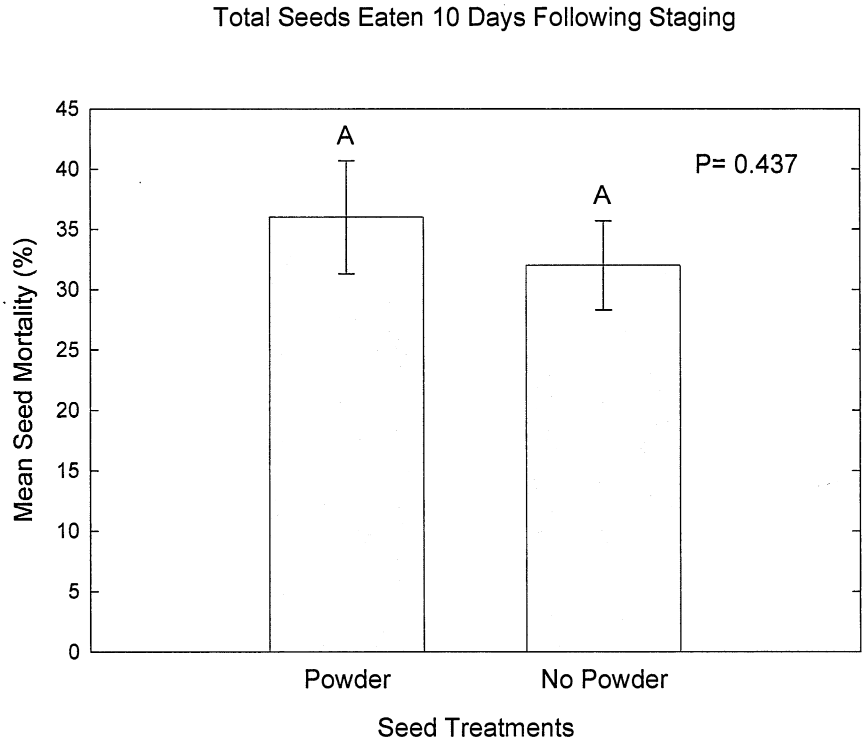
Table 4. Effects of seed incorporation technique on native seedling emergence of greenhouse grown seedlings. A two-way ANOVA was used for analysis of this data.

	Broadcast	Culti-pack	Rake	Rake & Culti-pack	P-value
Total Natives	12.33(0.90)	12.17(0.49)	12.50(0.83)	11.25(0.96)	0.565
Native Grasses	10.00(0.86)	11.17(0.70)	10.00(0.52)	9.33(0.67)	0.372
Native Forbs	14.67(0.80)	13.17(0.40)	15.00(0.52)	13.17(1.47)	0.427

Effects of Day-Glo Fluorescent Powder on Granivory

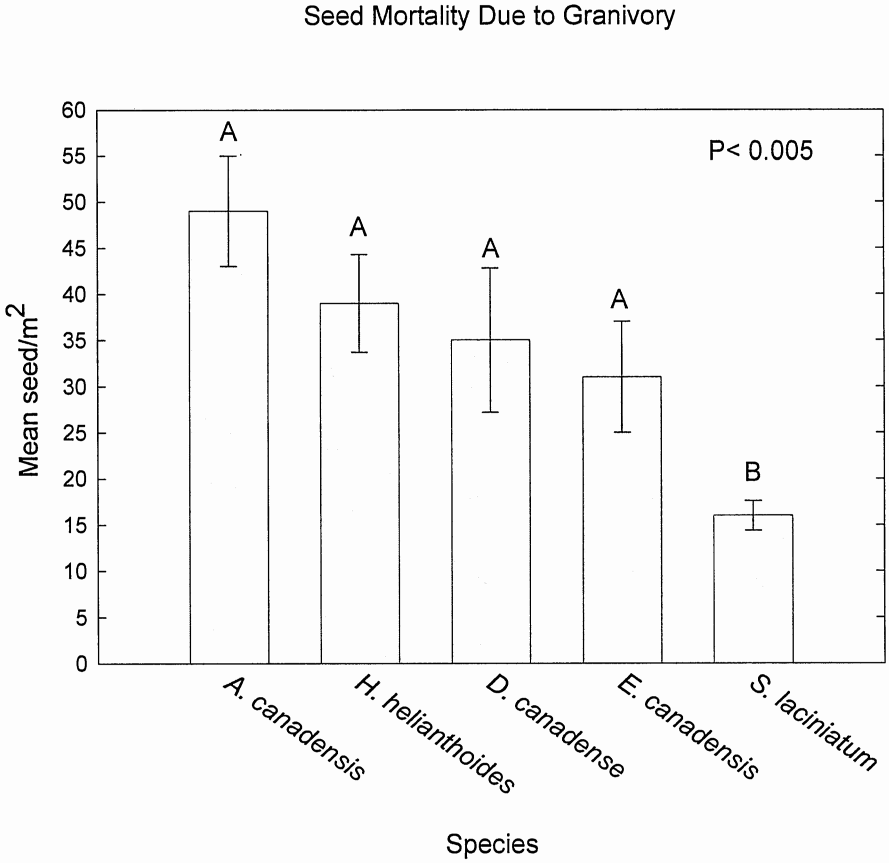
The data for this preliminary experiment was collected on May 22 of 2008 after ten days of exposure to granivores on the Tallgrass Prairie Campus Preserve. A 2-way ANOVA was used to analyze the data. Seed predation did occur during the ten day period as 32-36 percent of the seed disappeared. However, granivores didn't distinguish whether or not the seeds were covered with fluorescent powder. I observed no significant differences between seed with powder compared to seeds without powder (Figure 1). During the 10 days the trays were in the field, no rainfall occurred so any effects on the seeds were likely due to seed predators rather than the elements.

Figure 1: The percent of total seeds eaten by predators after 10 days of staging in May of 2008. A two-way ANOVA using powder treatment and species as factors was done to complete the analysis.



I did observe significant (p = 0.004) differences between species eaten in the experiment (Figure 2). The larger seed, *Silphium laciniatum*, had a significantly smaller amount of seeds/meter squared damaged or removed from the plastic trays than the other four native species. Generally, granivores seemed to prefer seeds with a smaller size and harder seed coat over larger seeds with a papery seed coat.

Figure 2. Mean number of and standard errors of seeds eaten or damaged by granivores during a 10 day time period in May of 2008. A one-way ANOVA using seed species as a factor was used for the data analysis.



Seed Incorporation

Seed count data for this portion of the project was taken the night of the seeding, November 2, 2007 (time 1), and one week after seeding, November 9, 2007 (time 2). Data was analyzed using a 2-way ANOVA. There were no significant differences between blocks (p=0.102) the night of the seeding nor between blocks (p=0.301) one week after the seeding (Table 5). There was a loss of seed in both blocks from the night of the seeding to one week after the seeding (Table 5).

Table 5. Mean number of seeds/m^2 and standard errors for seed counted the night of the seeding and one week following the seeding in blocks 1 and 2. Time 1 and Time 2 data sets were analyzed separately.

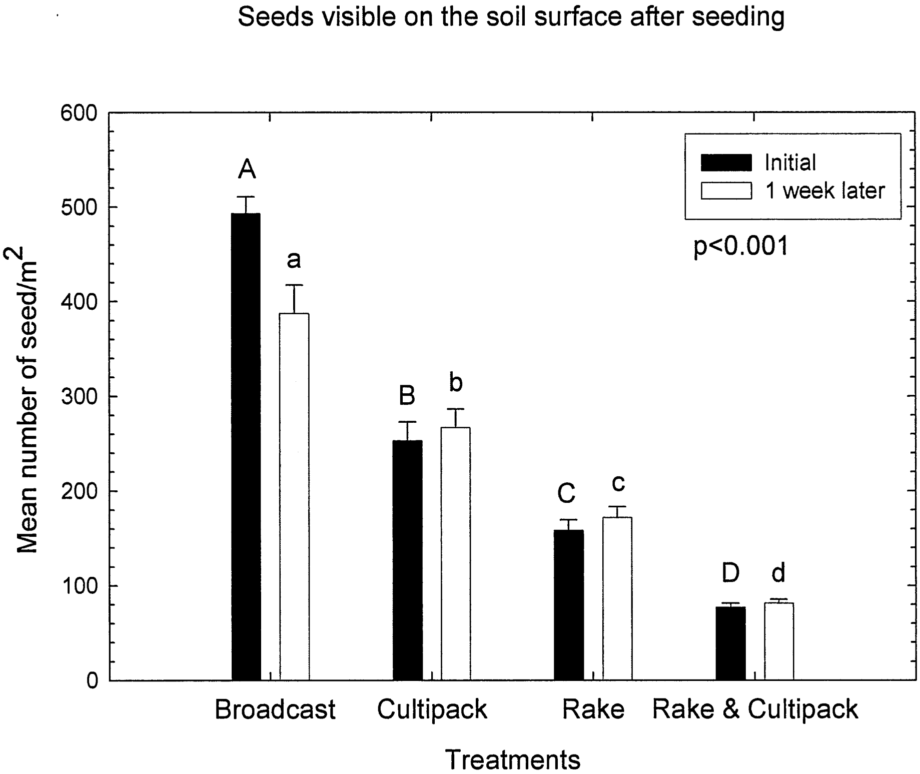
	Block 1	Block 2	P-value
Time 1 (Night of seeding)	230.38(2.19)	250.68(2.31)	0.116
Time 2 (1 week after seeding)	220.51(1.95)	200.80(1.68)	0.392

*significantly different

I did find significant differences ($p<0.001$) between the different seed incorporation treatments. On the night of the seeding, I observed that most of the seed (493 seeds/m^2) in the broadcast only treatment was on the soil surface and not incorporated (Figure 3). In the culti-packed treatment, I observed 253 seeds/m^2 on the soil surface, and 158 seeds/m^2 on the surface in the raked treatment (Figure 3). In the raked followed by culti-packing treatment, I observed only 77 seeds/m^2 on the soil surface (Figure 3).

After one week, the research plots were re-sampled. I observed that the broadcast seeded treatment had lost a significant ($p<0.001$) amount of seed from the soil surface. Initially, 493 seeds/m^2 were on the surface, but after one week I counted only 387 seeds/m^2 (Figure 3). This was a significant loss of 21.5 percent of the seed in the broadcast treatment (Figure 3). In the treatments with seed incorporation, there was not a significant loss of seed from the surface. The number of seeds counted the night of the seeding and one week later were very similar (Figure 3).

Figure 3. Comparison of the mean number of seeds/m^2 on the soil surface the night of the experimental plot seeding and also one week after the plots were seeded.



Native Seedling Emergence

The first sampling of native seedlings was done in June of 2008. A two-way ANOVA was used to analyze this data. There were significant ($p<0.05$) block differences in the number of total seedlings and forb seedlings (Table 6). Block 1 had a mean of 19.75 total seedlings/m^2 while Block 2 had a mean of 33.67 seedlings/m^2 (Table 6). The results of forb seedlings were similar with Block 1 having a mean of 18.41 seedlings/m^2 and Block 2 having a mean of 31.75 seedlings/m^2 (Table 6). There wasn't a significant difference between blocks with respect to the number of grass seedlings (Table 6).

In September 2008, I found there to be no significant ($p<0.05$) differences between the mean number of seedlings found in Block 1 compared to Block 2 (Table 6). There was little variation between Block 1 and Block 2 in the number of total seedlings, forbs, or grasses. The number of grass seedlings observed in September 2008 was much greater than the number of grass seedlings in June of 2008 (Table 6).

In June of 2009, there were significant ($p<0.05$) block differences in the number of forb seedlings/m^2. As in June of 2008, I found more forb seedlings/m^2 in Block 2 than in Block 1 (Table 6). Block 1 had 16.25 seedlings/m^2 and Block 2 had 22.08 seedlings/m^2 (Table 6). I didn't observe any significant differences in the amount of total seedlings or grass seedlings found in each block during the June of 2009 sampling (Table 6).

Table 6. Mean numbers and standard errors of seedlings/m^2 at each sample time. The of each sample time was analyzed separate from the other sample times. Data included in this table is derived from 1-way and 2-way ANOVA's.

	Block 1	Block 2	P-value
June 2008			
Total	19.75(2.32)	33.67(3.40)	0.003*
Forbs	18.41(2.31)	31.75(3.23)	0.003*
Grasses	1.33(0.45)	1.92(0.42)	0.398
September 2008			
Total	31.33(2.20)	31.58(2.73)	0.924
Forbs	23.08(1.67)	24.00(2.54)	0.665
Grasses	8.25(0.99)	7.58(0.88)	0.662
June 2009			
Total	24.90(2.05)	30.25(3.03)	0.150
Forbs	16.25(1.48)	22.08(2.33)	0.050*
Grasses	8.67(0.83)	8.17(0.97)	0.701

*significantly different

In June of 2008, there were no statistically significant differences ($p<0.05$) between treatments, but a trend was noted. Plots where the seed was incorporated into the soil had more seedlings/m^2 than plots where seed wasn't incorporated. The mean number of seedlings/m^2 in the culti-packed (25.83), raked (34.83), and raked and culti-packed (23.17) was higher than in the broadcast (23.00) treatment (Table 7).

In September of 2008, there were significant ($p<0.05$) differences in the mean total number of seedlings and the mean number of forb seedlings between different incorporation treatments. The culti-packed (35.50) and raked (36.00) had the most total native seedlings/m^2 (Table 7, Figure 4). The broadcast (26.67) and raked and culti-packed (26.67) had fewer total seedlings/m^2 (Table 7, Figure 4). The culti-packed (28.83) and raked (27.00) treatments had more forb seedlings/m^2 while the broadcast only and raked and culti-packed combination treatments had significantly fewer forb seedlings/m^2 (Table 7). Both the broadcast treatment and the raked and culti-packed had 19.17 seedlings/m^2 (Table 7). However, the results indicated a block by treatment interaction which means some treatments in one block had significantly different seedling results than treatments in the other block. Consequently, the data is somewhat less convincing (Appendix 3).

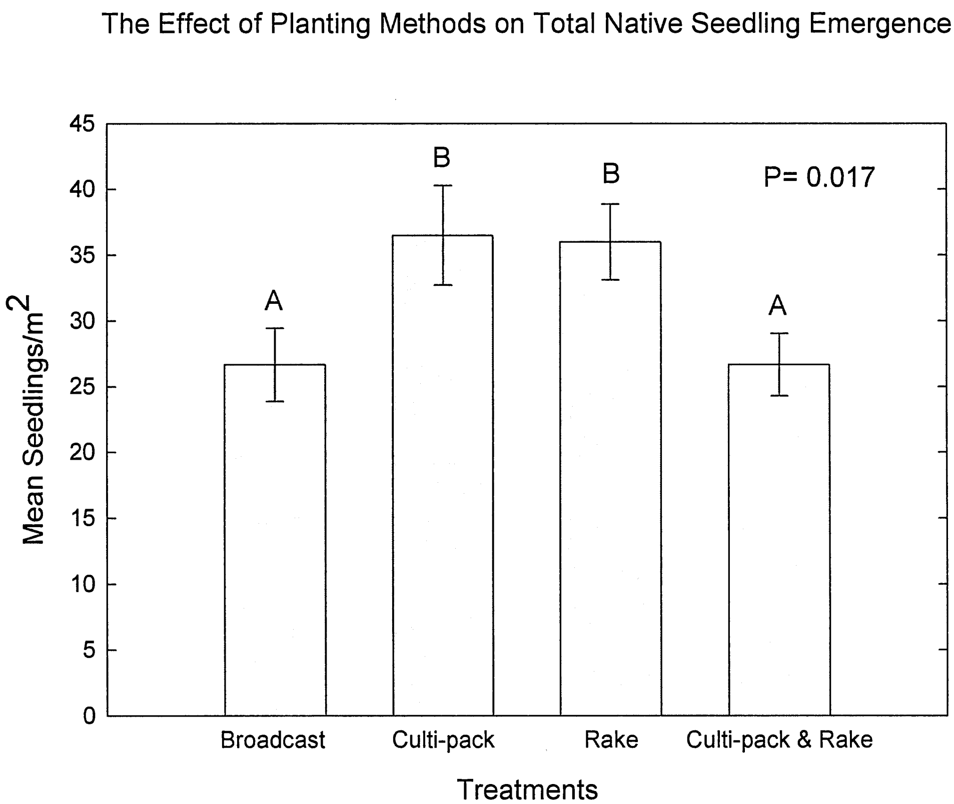
The final sampling in June of 2009 indicated no significant ($p<0.05$) differences between seed incorporation treatments (Table 7). Neither was there a trend like noted in June of 2008 (Table 7). The number of total, forb, and grass seedlings/m^2 were all similar throughout all treatments (Table 7).

Table 7. Mean number and standard errors of seedlings/m^2 observed at each sample time per research treatment. The data of each sample time was analyzed separate from the other sample times. Data included in this table is derived from 1-way and 2-way ANOVA's.

	Broadcast	Culti-pack	Rake	Rake & Culti-pack	P-value
June 2008					
Total	23.00(3.45)	25.83(4.17)	34.83(4.69)	23.17(6.59)	0.161
Forbs	21.33(2.74)	24.67(4.34)	32.50(4.62)	21.83(6.42)	0.193
Grasses	1.67(0.92)	1.17(0.31)	2.33(0.62)	1.33(0.50)	0.631
September 2008					
Total	26.67(2.79)^A	35.50(3.78)^B	36.00(2.90)^B	26.67(2.36)^A	0.017*
Forbs	19.17(2.61)^A	28.83(2.85)^B	27.00(1.93)^B	19.17(2.61)^A	0.006*
Grasses	7.50(1.15)	7.67(1.78)	9.00(1.37)	7.50(1.09)	0.870
June 2009					
Total	28.33(3.52)	28.67(4.15)	25.83(3.45)	27.50(4.71)	0.942
Forbs	19.50(2.72)	20.17(3.47)	18.17(2.82)	18.83(3.54)	0.960
Grasses	8.83(1.58)	8.50(1.02)	7.67(1.23)	8.67(1.43)	0.919

*significantly different

Figure 4. Mean number and standard errors of seedlings/m^2 in September of 2008 per research treatment. Cult-packed and raked treatments have significantly more seedlings/m^2 than the broadcast only and raked and culti-packed treatments. Data included in this graph is derived from 1-way and 2-way ANOVA's.



The final sampling in June of 2009 showed that the mean number of seedlings was 27.58 seedlings/m^2 for all seed incorporation treatments (Table 8). I seeded at a rate of 692 seeds/m^2 and the mean number of seedlings that emerged was 27.58 seedlings/m^2 (Table 8). This is a return of about 4 percent of the seed planted. I didn't find all species in my sample plots, but I did observe all species at some time or another in the treatment plots.

Table 8. Comparison of initial seeding rate and number of seedlings of species observed in June 2009 (N=24).

Grasses		Seeding Rate (seeds/m^2)	Final Seedling Count (seedlings/m^2)
big bluestem	Andropogon gerardii	22	0.17
side-oats grama	Bouteloua curtipendula	22	0.04
prairie brome	Bromus kalmii	43	0.00
Canada wildrye	Elymus canadensis	11	7.58
Virginia wildrye	Elymus virginicus	11	0.04
switchgrass	Panicum virgatum	22	0.00
little bluestem	Schizachyrium scoparius	22	0.17
Indian grass	Sorghastrum nutans	22	0.08
tall dropseed	Sporobolus asper	11	0.00
Forbs			
lead plant	Amorpha canescens	11	0.00
thimbleweed	Anemone cylindrica	11	0.00
prairie sage	Artemisia ludoviciana	22	0.96
smooth blue aster	Aster laevis	33	0.08
New England aster	Aster novae-angliae	11	0.21
Canada milkvetch	Astragalus canadensis	22	0.00
white wild indigo	Baptisia leucantha	3	0.17
partridge pea	Cassia fasiculata	54	4.08
prairie coreopsis	Coreopsis palmata	6	0.00
purple prairie clover	Dalea purpurea	33	0.00
showy tick trefoil	Desmodium canadense	11	0.33
pale purple coneflower	Echinacea pallida	11	1.00
bigtooth sunflower	Helianthus grosseserratus	3	0.42
ox-eye sunflower	Heliopsis helianthoides	11	1.58
great St. Johns wort	Hypericum pyramidatum	22	0.00
prairie blazingstar	Liatris pycnostachya	11	0.00

(table continues)

Forbs		Seeding Rate (seeds/m^2)	Final Seedling Count (seedlings/m^2)
wild bergamot	Monarda fistulosa	22	0.29
wild quinine	Parthenium integrifolium	3	0.00
foxglove beardtongue	Penstemon digitalis	11	0.00
common mt. mint	Pycnanthemum virginianum	33	0.17
yellow coneflower	Ratibida pinnata	33	5.42
black-eyed susan	Rudbeckia hirta	33	1.50
sweet coneflower	Rudbeckia subtomentosa	22	0.00
wild petunia	Ruellia humilis	3	0.00
rosinweed	Silphium integrifolium	1	0.00
compass plant	Silphium laciniatum	1	0.33
stiff goldenrod	Solidago rigida	22	0.42
showy goldenrod	Solidago speciosa	22	0.13
Ohio spiderwort	Tradescantia ohiensis	3	0.00
hoary vervain	Verbena stricta	11	0.00
golden alexanders	Zizia aurea	11	0.96
	TOTAL:	692.0	27.58

The final sampling in September of 2008 and June of 2009 showed differences in total seedlings in each species by treatment. There were significant differences in 2008 but there were no significant differences in the total seedlings/m^2 in 2009 (Table 9).

Table 9. Total seedlings by treatment on September 2008 and June 2009.

Total Seedlings								
	Broadcast Only		Rake		Culti-pack		Rake & Culti-pack	
Species	2008	2009	2008	2009	2008	2009	2008	2009
big bluestem	2	0	1	1	0	0	1	3
side-oats grama	0	0	0	1	1	0	0	0
prairie brome	0	0	0	0	1	0	0	0
Canada wildrye	32	50	37	44	30	50	30	46
Virginia wildrye	4	1	6	0	4	0	4	0
switchgrass	0	0	0	0	0	0	0	0
little bluestem	1	2	4	0	1	0	1	2
Indian grass	1	0	2	0	5	1	2	1
tall dropseed	5	0	4	0	4	0	7	0
lead plant	0	0	0	0	1	0	0	0
thimbleweed	0	0	0	0	0	0	0	0
prairie sage	2	5	6	7	4	7	2	4
smooth blue aster	0	0	1	1	0	0	0	1
New England aster	0	3	2	1	2	2	2	0
Canada milkvetch	0	0	0	0	1	0	0	0
white wild indigo	1	1	3	2	7	1	1	0
partridge pea	12	25	27	23	21	15	25	35
prairie coreopsis	0	0	0	0	0	0	0	0
purple prairie clover	0	0	0	0	0	0	0	0
showy tick trefoil	1	3	6	3	4	0	6	2
pale purple coneflower	12	6	5	6	13	10	10	7
bigtooth sunflower	3	1	0	3	3	2	2	4
ox-eye sunflower	2	10	2	9	5	8	4	11

(table continues)

Total Seedlings								
	Broadcast Only		Rake		Culti-pack		Rake & Culti-pack	
Species	2008	2009	2008	2009	2008	2009	2008	2009
great St. Johns wort	0	0	1	0	1	0	0	0
prairie blazingstar	0	0	0	0	0	0	0	0
wild bergamot	1	2	3	2	6	3	3	1
wild quinine	1	0	0	0	0	0	0	0
foxglove beardtongue	0	0	0	0	0	0	0	0
common mt. mint	1	1	0	1	0	1	1	1
yellow coneflower	36	44	52	28	48	42	31	26
black-eyed susan	22	6	36	10	34	14	17	10
sweet coneflower	0	0	0	0	0	0	0	0
wild petunia	1	0	0	0	0	0	0	0
rosinweed	2	0	0	0	1	0	0	0
compass plant	1	2	0	1	2	3	1	2
stiff goldenrod	8	1	8	2	8	5	2	4
showy goldenrod	0	0	0	0	0	2	1	2
Ohio spiderwort	0	0	0	0	0	0	0	0
hoary vervain	0	0	0	0	0	0	0	0
golden alexanders	9	7	10	10	12	6	7	3
Total:	168	170	216	155	219	172	160	165

Native Species Richness

Native species richness for this experiment was determined by the number of different native species (forbs and grasses) per square meter in the research plots. In June of 2008, I found there were significant differences ($p<0.05$) between Block 1 and Block 2 in number of total species and forb species (Table 10). Block 1 had a lower mean of total species (7.50 species/m^2) and a forb species mean (6.67 species/m^2) than Block 2 with respective means of 9.83 and 8.92 species/m^2 (Table 10). I observed very few grass species and there were no significant differences between the two research blocks (Table 10).

There was an increase in the mean number of total, forb, and grass species from June 2008 to September of 2008 (Table 10). I found there was still a significant difference ($p=0.039$) between the means of the number of total species found in Block 1 and Block 2. The pattern was similar to that observed in June of 2008 (Table 10). There was a mean number of 10.75 species/m^2 in Block 1 and a mean number of 12.58 species/m^2 in Block 2 (Table 10). However, there was no significant difference in mean number of forb species between Block 1 and Block 2 as there had been in June of 2008 (Table 10). Also, I didn't find a significant difference in mean number of grass species between the two blocks (Table 10).

The third and final sampling period showed there to be no significant ($p<0.05$) differences between blocks in the mean number of species/m^2 in any category (Table 10). Overall, there were less species/m^2 present in June of 2009 than in September of 2008 (Table 10). I found a mean of 9.42 total species/m^2 in both blocks (Table 10). There was a mean number of 7.92 forb species/m^2 in Block 1 and 8.17 forb species/m^2 in Block 2 (Table 10) . I found a mean number of 1.50 grass species/m^2 in Block 1 and 1.25 grass species/m^2 in Block 2 (Table 10).

Table 10. Mean number and standard errors of species/m^2 at each sample time per research block. The data of sample time was analyzed separate from the other sample times. Data included in this table is derived from 1-way and 2-way ANOVA's.

	Block 1	Block 2	P-value
June 2008			
Total	7.50(0.52)	9.83(0.73)	0.020*
Forbs	6.67(0.47)	8.92(0.62)	0.012*
Grasses	0.83(0.24)	0.92(0.15)	0.793
September 2008			
Total	10.75(0.49)	12.58(0.74)	0.039*
Forbs	8.17(0.24)	9.25(0.74)	0.150
Grasses	2.58(0.40)	3.33(0.38)	0.212
June 2009			
Total	9.42(0.71)	9.42(0.76)	1.000
Forbs	7.92(0.72)	8.17(0.68)	0.813
Grasses	1.50(0.23)	1.25(0.18)	0.434

*significantly different

Seed incorporation didn't have a significant effect on native species richness. There were no significant ($p<0.05$) differences in the mean number of total, forb, or grass species between the different seed incorporation treatments (Table 11) in June of 2008, September of 2008, or June of 2009.

Table 11. Mean number and standard errors of species/m^2 at each sample time per research treatment. The data of each sample time was analyzed separate from the other sample times. Data included in this table is derived from 1-way and 2-way ANOVA's.

	Broadcast	Culti-pack	Rake	Rake & Culti-pack	P-value
June 2008					
Total	8.17(0.70)	8.50(0.43)	10.17(1.12)	7.83(1.42)	0.305
Forbs	7.50(0.56)	7.50(0.62)	9.00(0.93)	7.17(1.30)	0.396
Grasses	0.67(0.33)	1.00(0.26)	1.17(0.31)	0.67(0.21)	0.599
September 2008					
Total	10.66(0.80)	12.83(1.08)	12.00(0.93)	11.17(0.98)	0.290
Forbs	8.00(0.45)	9.83(0.91)	8.83(0.48)	8.17(1.11)	0.294
Grasses	2.66(0.67)	3.00(0.52)	3.17(0.75)	3.00(0.37)	0.940
June 2009					
Total	9.00(0.93)	9.83(1.20)	9.83(1.08)	9.00(1.07)	0.890
Forbs	7.67(0.98)	8.67(1.09)	8.50(0.42)	7.33(1.05)	0.765
Grasses	1.33(0.33)	1.17(0.17)	1.33(0.33)	1.67(0.33)	0.719

*significantly different

Granivory and Native Seedling Emergence

The first sampling of native seedlings related to granivory was done in June of 2008. A 3-way ANOVA was used to analyze this data. There were no block differences in any of the analyses for seedling data in June of 2008 (Appendix 2). However, I did observe several differences between exclosure treatments. Closed exclosures results were similar to those of open exclosures. Open exclosures had more seedling/m^2 than no exclosure areas, but were statistically similar. The closed exclosure areas had significantly more grasses, forbs, and total native seedlings than the no exclosure sample areas (Table 12). In fact, closed exclosures had a mean number of nearly 42 percent more total seedlings/m^2 and a mean number of 40 percent more forb seedlings than the no exclosure areas (Table 12). There were statistical significant differences (p=0.017) between treatments in regards to the grass seedlings, but very few grass seedlings were present so this significant difference isn't very convincing (Table 12).

Analysis of the data for the September 2008 sampling showed significant differences ($p<0.05$) between exclosure treatments. Unlike the previous sampling, this time the closed exclosures had a significantly ($p=0.002$) higher mean of total seedlings than the open or no exclosure treatments (Table 12). The closed exclosure averaged 25.10 seedlings/m^2, the open 17.50 seedling/m^2, and the no exclosure areas 14.58 seedlings/m^2 (Table 12). This means the closed exclosures averaged somewhere between 30 to 42 percent more total seedlings/m^2 than the other two treatments. The closed exclosures didn't have a significantly higher mean of forb seedlings (20.00 seedling/m^2) compared to the open (15.94 seedlings/m^2), but there was a larger number of forbs in the closed than in the open (Table 12). The closed exclosures had a significantly ($p=0.037$) higher mean number of forbs than the no exclosure (11.88 seedlings/m^2) areas. Grasses were more apparent in this September sampling than they were in the June 2008 sampling. Again, the closed exclosure areas contained a significantly ($p<0.001$) higher mean number of (47-69%) seedlings/m^2 than the open or no exclosure areas (Table 12). There were no block differences seen in the seedling data taken in September of 2009 (Appendix 3).

The final sampling of the study took place in June of 2009. A 3-way ANOVA was used to analyze the results. The closed exclosures had a significantly ($p<0.05$) higher mean number of seedlings/m^2 than the open or no exclosure areas (Table 12, Figure 5). The closed exclosures had a mean of 27.92 seedlings/m^2, the open 20.31

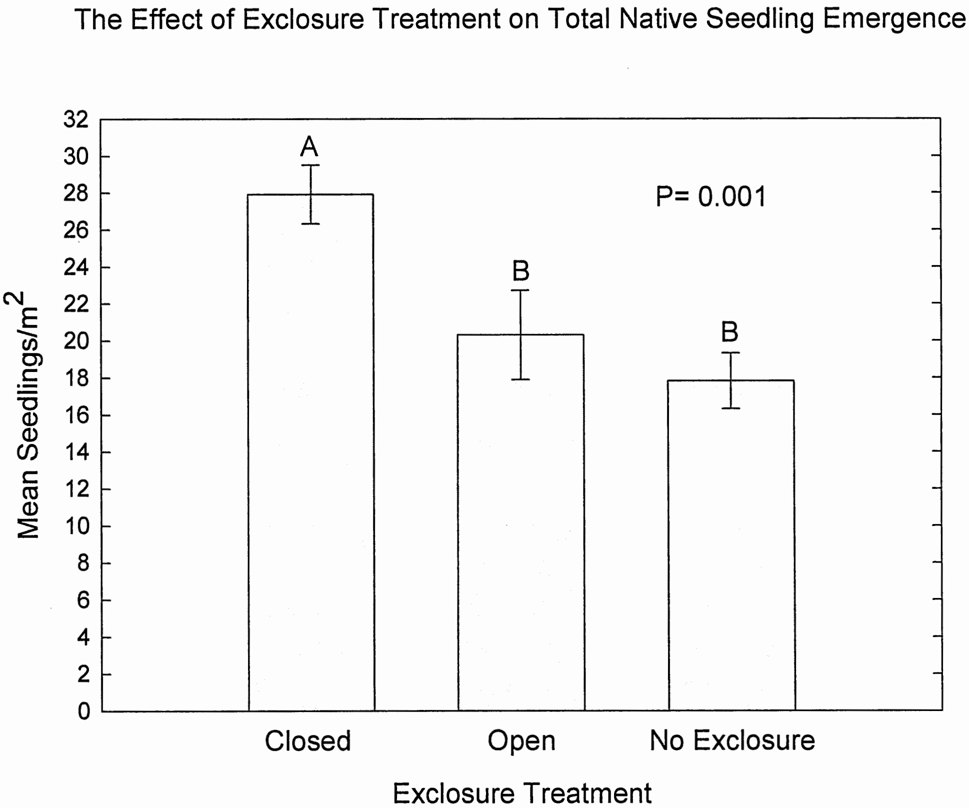
seedlings/m^2, and the no exclosures 17.82 seedlings/m^2 (Table 12, Figure 5). The closed exclosures also had a significantly higher mean number of forbs. The mean number of forb seedlings for the closed was 20.31 seedlings/m^2, the open 16.35 seedlings/m^2, and the no exclosures 13.02 seedlings/m^2 (Table 12). The grass data showed similar results with the closed exclosures having a significantly higher mean number of seedlings/m^2 than the open or no exclosure areas (Table 12). The mean of the closed was 7.60 seedlings/m^2, the open 3.96 seedlings/m^2, and the no exclosures 4.80 seedlings/m^2 (Table 12). On average the closed exclosures averaged between 27-36 % higher than the open exclosures or no exclosures mean numbers of total seedlings/m^2, 19-36 % more forb seedlings/m^2, and 37-48 % more grass seedlings/m^2 (Table 12).

Table 12. Mean number and standard errors of seedlings/m^2 per exclosure treatment. The data taken at each sample time was analyzed separate from the other sample times. Data included in this table is derived from 3-way ANOVA's.

	Open	Closed	No exclosure	P-value
June 2008				
Total	18.85(1.74)^{AB}	24.37(2.26)^{A}	14.27(1.85)^{B}	0.002*
Forbs	18.33(1.74)^{AB}	23.44(2.24)^{A}	14.17(1.85)^{B}	0.005*
Grasses	0.52(0.26)^{AB}	0.94(0.25)^{A}	0.10(0.10)^{B}	0.017*
September 2008				
Total	17.50(1.79)^{B}	25.10(2.31)^{A}	14.58(1.36)^{B}	0.002*
Forbs	15.94(1.65)^{AB}	20.00(2.13)^{A}	11.88(1.21)^{B}	0.037*
Grasses	1.56(0.04)^{B}	5.10(0.70)^{A}	2.71(0.42)^{B}	<0.001*
June 2009				
Total	20.31(1.59)^{B}	27.92(2.41)^{A}	17.82(1.50)^{B}	0.001*
Forbs	16.35(1.40)^{AB}	20.31(1.94)^{A}	13.02(1.51)^{B}	0.009*
Grasses	3.96(0.64)^{B}	7.60(0.95)^{A}	4.80(0.67)^{B}	0.003*

*significantly different

Figure 5. Mean number and standard errors of seedlings/m^2 in June of 2009 per exclosure treatment. Closed exclosures had significantly ($p=0.001$) more seedlings/m^2 than the open or no exclosure treatments. Data included in this graph is derived from a 3-way ANOVA.



<u>Granivory and Species Richness</u>

The effect of granivory on species richness was determined by comparing the number of different species (total, forbs, grasses, and weeds) in exclosures and non-exclosures. In June of 2008, I found no significant differences ($p<0.05$) between Block 1 and Block 2 in total, forb, grass, or weed species (Appendix 2). The only significant difference between treatments was in the mean number of grass species (Table 13). An extremely small amount of grasses were present so the significant difference is questionable.

In the June 2009 data, I found there to be no significant ($p<0.05$) differences between exclosure treatments in species richness of total natives, native forbs, or native grasses, (Table 13).

The results for the September 2008 sampling were similar to those of June 2008 where the only significant differences ($p<0.05$) observed were in the native grasses. At most, one grass species/m^2 was found so the statistical significant differences between exclosure treatments (Table 13) aren't extremely convincing. Total natives, native forbs, and weeds were not significantly different for each of the exclosure treatments (Table 13).

Table 13. Mean number and standard errors of species found per meter squared at each sample time per exclosure treatment throughout the experiment. The data taken at each sample time was analyzed separate from the other sample times. Data included in this table is derived from 3-way ANOVA's.

	Open	Closed	No exclosure	P-value
June 2008				
Total Natives	4.54(0.33)	4.50(0.39)	3.63(0.35)	0.133
Native Forbs	4.38(0.31)	4.13(0.38)	3.58(0.34)	0.261
Native Grasses	0.17(0.08)^{AB}	0.38(0.10)^{A}	0.04(0.04)^{B}	0.012*
Weeds	6.92(0.34)	6.63(0.32)	7.45(0.28)	0.167
September 2008				
Total Natives	4.54(0.37)	4.67(0.41)	4.04(0.30)	0.497
Native Forbs	4.00(0.32)	3.63(0.42)	3.21(0.25)	0.288
Native Grasses	0.54(0.12)^{A}	1.04(0.10)^{B}	0.83(0.12)^{AB}	0.004*
Weeds	4.67(0.24)	4.83(0.33)	5.04(0.35)	0.788
June 2009				
Total Natives	4.96(0.38)	5.42(0.36)	4.58(0.38)	0.242
Native Forbs	4.05(0.36)	4.25(0.35)	3.58(0.40)	0.351
Native Grasses	0.92(0.10)	1.17(0.10)	1.00(0.10)	0.273
Weeds	4.00(0.28)	3.88(0.29)	4.04(0.22)	0.908

*significantly different

Weed Species Richness and Biomass

Weed species richness for this experiment was determined by the number of different weed species/m^2 (forbs and grasses) in the research plots. No species differences ($p<0.05$) were found between Block 1 and Block 2 in the June of 2008 and September of 2008 data (Table 14). However, I did find block differences in June of 2009 (Table 14). Block 1 had a mean number of 6.58 species/m^2 and Block 2 had a mean of 5.17 species/m^2. Upon review of the data, I noted a lot more of the queen anne's lace (*Daucus carota*) species in Block 1 than in Block 2. I also observed block differences between the amount of forb weed biomass in Block 1 as compared to Block 2 in September of 2008 (Table 14). Block 1 had 50 percent more forb weed biomass than Block 2 (Table 14).

Table 14. Block differences in weed species richness and weed biomass. Weed biomass data was also analyzed separate from the species counts. Data included in this table is derived from 1-way and 2-way ANOVA's.

	Block 1	Block 2	P-value
June 2008 Total Weed Species/m^2	5.92(0.62)	9.67(0.39)	0.000
September 2008 Total Weed Species/m^2	7.67(0.47)	9.08(0.50)	0.067
June 2009 Total Weed Species/m^2	6.58(0.38)	5.17(0.24)	0.012*
September 2008 Weed Biomass (g/m^2)			
Forb	60.12(10.58)	30.15(6.70)	0.036*
Grass	238.17(15.84)	245.58(9.50)	0.689

*significantly different

The type of seed incorporation technique did effect the number of weed species found in the research plots. In June of 2008, I found there to be significantly more weed species in the raked treatment (Table 15). The raked treatment had 17 to 30 % higher mean numbers of weed species than the other seed incorporation treatments (Table 15). I didn't find any significant treatment differences in the mean number of total weed species or weed biomass in September of 2008 or June of 2009 (Table 15).

Table 15. Effect of seed incorporation on weed species richness and weed biomass. Weed biomass data was analyzed separate from the species counts. Data included in this table is derived from 1-way and 2-way ANOVA's.

	Broadcast	Culti-pack	Rake	Rake & Culti-pack	P-value
June 2008 Total Weed Species/m^2	7.83(0.87)^{AB}	7.17(1.14)^{AB}	9.50(0.76)^{B}	6.67(1.28)^{A}	0.033*
September 2008 Total Weed Species/m^2	8.00(0.73)	8.00(0.89)	8.33(0.62)	9.2(0.75)	0.635
June 2009 Total Weed Species/m^2	6.00(0.82)	5.50(0.43)	6.17(0.40)	5.83(0.48)	0.808
September 2008 Weed Biomass (g/m^2)					
Forb	47.53(18.81)	34.77(9.45)	61.60(16.60)	36.63(8.56)	0.466
Grass	236.60(19.39)	273.87(10.29)	210.17(22.31)	246.87(10.80)	0.142

*significantly different

Simpson's Index of Dominance

Simpson's Index of Dominance was calculated as the ratio between the number of individuals per the total species sampled in each plot in June of 2008, September of 2008, and June of 2009. The data for Simpson's Index was analyzed with a two-way ANOVA for all portions of this research except the granivory exclosure portion. A 3-way ANOVA was used for the granivory exclosure section of this research. No significant differences ($p<0.05$) were noted between blocks or treatments in June of 2008 (Appendix 2), September of 2008 (Appendix 3), or June of 2009 (Appendix 4).

CHAPTER 4

DISCUSSION

Seed Incorporation and Native Seedling Emergence

This experiment examined the effect of seed incorporation from different perspectives. Few studies have been done regarding seed incorporation and how it affects native species emergence. I compared different methods of seed incorporation and their effect on seedling emergence and granivory.

Many researchers have suggested that seed incorporation and sufficient planting depth are necessary to improve seedling emergence (Monti et al., 2001; Nelson et al., 1970; Girourard et al., 1999; Girourard and Samson, 1998; Teel, 1998; Wolf and Fiske, 1995; Radford 1986). Covering the seed with Day-Glo fluorescent powder enabled me to readily observe and measure the degree of incorporation of the seed into the soil. The number of broadcast seeds left on the soil surface was directly related to the type of seed incorporation treatment (Figure 3). As expected, the broadcast-only treatment resulted in the highest number of seeds visible on the soil while culti-packing, raking, or a combination of raking and culti-packing were increasingly more effective in covering the seed and reducing the number of those visible. All incorporation techniques were effective in preventing seed loss from high winds following planting.

The effects of seed incorporation on seedling emergence varied from the first year to the second year. It is possible that the depth of the seed in the soil and type of life cycle contributed to the differences in results of emergence. At the end of the first year, a single method of seed incorporation, rake alone or culti-pack alone, significantly increased emergence of forbs over broadcast seeding. However, combining these two seed incorporation methods, rake and culti-pack, did not increase seedling emergence. This may be due to the amount of soil covering the seed. Teel (1998) found that placement of seed too deep in the soil can result in poor seedling emergence. Perhaps, one method of seed incorporation adequately covers seed and promotes emergence while over-incorporation with two methods covers the seed to a depth that is detrimental to seedling emergence. Raking followed by culti-packing may have pushed the seed too deeply into the soil creating conditions less favorable for seedling emergence and negating the advantage over broadcast seeding. The results showing that a single method of seed incorporation was most beneficial the first year concurred with the results of Grygiel et al. (2009) who found that a small amount of tillage is sufficient for a fall seeding.

In the second year, seedling emergence was similar across all seed incorporations treatments (Table 7). This may be due to the longevity of the life cycle of the species. Of the 31 forbs in the seeding mixture, 63% of the seedlings detected in year 1 were annuals, biennials, and short-lived perennials, partridge pea, (*Cassia fasciculata*), black-eyed Susan (*Rudbeckia hirta*), and yellow coneflower (*Ratibida pinnata*), that establish easily (Houseal 2009). Collectively, the number of seedlings of these species declined by 31% from year 1 to year 2 (Table). These species take advantage of initial bare soil conditions, establish and mature quickly, and then decline in abundance when other native species become established as the planting ages. According to Schramm (1990), the seedlings that emerged in year 1 and 2 in this reconstruction are representative of the initial developmental stage of a prairie reconstruction. If this prairie planting continues to develop in stages similar to those observed by Schramm, one should observe larger numbers of different species appearing along with a decline in the amount of annuals, biennials, and short-lived perennials.

Among the treatments, the volatility in numbers of emerged seedlings occurred in the short-lived native forbs. Changes in the number of emerged seedlings were most striking for black-eyed Susan that is variously listed as an annual, biennial or perennial. In all treatments, as expected for this species, many black-eyed Susan seedlings germinated, emerged, and flowered the first year while less emerged the second year. Establishment mowing during the first growing season prevented seed production and insured that any new germinates the second season were from the original seeding mixture. A single method of seed incorporation clearly improved emergence of black-eyed Susan (Table 9). Planting depth may be the factor responsible for this result. Optimal planting depth is 1/16 inch for black-eyed Susan (Sheffield Seed Company, USDA-NRCS 2009). Evidently, a single method of seed incorporation placed black-eyed Susan seeds at the proper depth in the soil to aid in emergence. However, the benefits of a single method of seed incorporation on black-eyed Susan emergence did not carry over to year 2. Far fewer black-eyed Susan seedlings were found in the plots in year 2 (Table 9). The decline in black-eyed Susan seedlings from year 1 to year 2 would be expected of an annual as the seedlings would not persist into the second year. However, if the black-eyed Susan seedlings were biennials, then the decline in year 2 seedlings could be attributed to over-winter mortality. Early emerging species like black-eyed Susan are important for the establishment of tallgrass prairie. They can help control the growth of weeds by emerging early and gaining a competitive edge on invasives. They can help control erosion by supplying fast growing roots to hold the soil in place. In the first year of a planting, the flowers of these plants increase the aesthetics of the site and add native seed to the seed bank.

The emergence response for partridge pea, a true annual, was different than black-eyed Susan. Any method of seed incorporation improved emergence of partridge pea (Table 9). Optimal planting depth for partridge pea is ¼ to ¾ of an inch (Sheffield Seed Company, USDA-NRCS 2009). It appears that partridge pea seed needs to be covered with soil to improve emergence and can tolerate being planted deeper than black-eyed Susan. As with black-eyed Susan, year 1 and year 2 results for partridge pea were quite different. In year 2, emergence doubled for broadcast seeding and increased by 40% for the combination treatment while declining for the single methods of raking and culti-packing (Table 9). It is possible that the partridge pea seeds may have taken longer to be incorporated into the soil by weather related factors such as freezing and thawing, rain, and snow pack in the broadcast treatments. On the other hand, the raking combined with culti-packing treatments may have buried the seeds too deeply and delayed germination.

Yellow coneflower was the most prolific in terms of seedling establishment. Like black-eyed Susan, a single method of seed incorporation improved year 1 emergence for yellow coneflower (Table 9). It had the highest number of seedlings detected, and also had the highest number of seedlings detected in each of the seed incorporation treatments in year 1 (Table 9). However, seedlings declined from year 1 to year 2 in all three seed incorporation treatments and increased in the broadcast treatment (Table 9). Yellow coneflower is known to be a short-lived perennial (Houseal 2009). Perhaps over-winter mortality in the first year of establishment contributes to the decline of this short-lived perennial in a planting. However, it also appears that seed of this species can overwinter and emerge in subsequent years when favorable conditions develop as evidence by the broadcast treatment of this experiment. Seeds that have the ability to survive in the soil and emerge when the conditions are optimal certainly have an edge on species that can't do this. Species that germinate when conditions are not optimal for growth often die shortly there after while seeds that delay germination until growth conditions are optimal mature into adult plants.

Most recommendations for seed planting density in prairie reconstruction projects range from 40-80 seeds per square foot (Henderson 2009). I seeded at a rate of 692 seeds/m^2 (64 seeds/ft^2). The seedlings that emerged in this study represented 4% of the planted seed mix. Although, this percentage is somewhat less than other studies such as Williams et. al (2007) who reported seedling emergence of 9.5% of the planted seed, it is not out of line with early seedling establishment in prairie reconstructions (Williams 2009). Morgan et al. (1995) indicated that one seedling per square foot, while not great, is an acceptable level for early seedling establishment. However, the low number of seedlings that emerged make statistical interpretations of data comparing different seed incorporation techniques somewhat tenuous.

As 2/3 of the grasses in the seeding mixture were warm season species, much of the low percentage of emergence of grass seedlings was likely due to seeding time.

Warm season grasses such as big bluestem, little bluestem, Indian grass, side-oats grama, switchgrass, and tall dropseed are more successful when seeded in late spring and early summer (Meyer and Gaynor, 2002). In fact, Henderson et. al (2009) recommended that seeding rates of grasses in a fall planting should be 25% higher than a spring planting to allow for seed mortality over winter. My grass seeding rate was initially designed for a spring seeding; when I switched to a fall seeding I did not increase the seeding rate of the warm season grasses.

On the other hand, Canada wildrye, a cool-season grass, germinated very well in this experiment. A study of the effect of seeding date on native grass establishment by Meyer and Gaynor (2002) suggests that cool season native grasses are more likely to successfully establish than warm season grasses when sown later in the growing season or as a dormant seeding. In this dormant seeding, Canada wildrye showed significantly better establishment than the warm season grasses. In fact, the high amount of emergence of Canada wildrye skewed the overall grass emergence data. On the average, 69% of the Canada wildrye seeds emerged as seedlings while the percentage of seedlings for the other grass species ranged from 0 – 0.3%. Thus, of the average of 8.08 grass seedlings that emerged per meter squared, 7.58 of the seedlings were Canada wildrye. Therefore, any statistical comparisons of incorporation of the grass seeds were actually only comparing Canada wildrye seed.

Species richness may have been affected by the number of seedlings that could be detected in the sampling. The number of species sampled decreased from year 1 to year 2 (Table 11). Seven of eight species detected in year 1 and not found in year 2 had three or fewer seedlings (Table 9). It is possible that because there were so few individuals detected in the plots, in year 1 that there was little chance of them being re-sampled in year 2. In addition, some species of forbs and grasses in the mixture weren't detected in sampling. The following species were not detected by sampling: great St. Johns wort, prairie blazingstar, wild quinine, foxglove beardtongue, sweet coneflower, wild petunia, Ohio spiderwort, hoary vervain, purple prairie clover, prairie coreopsis, Canada milkvetch, thimbleweed, lead plant, switchgrass, prairie brome, and side-oats grama. However, I did observe six of these sixteen, Ohio spiderwort, hoary vervain, purple prairie clover, Canada milkvetch, switchgrass, and side-oats grama, growing in the experimental plots. Obviously, the sampling procedure did not pick up all of the species, especially those present in small amounts. It's possible that sampling later in the summer would have picked up seedlings of these species and added to the species richness data.

Abiotic and design related factors may have contributed to the lack of effects from seed incorporation. It is possible that the removal of soybean stubble and thatch prior to seeding may have increased the opportunity for the broadcast seed to make good seed-to-soil contact. This would decrease the need for additional seed incorporation. On the other hand, if the plant debris had been left on the field, seed incorporation might have been necessary for good contact with the soil. In addition, fall planting instead of spring planting may have been more of a factor than anticipated. The seeds that were fall planted in this experiment were in soil beneath snow that had drifted upon them during the winter prior to germination and emergence. Having seed in the soil buried under approximately 6 feet (2 m) of snow during winter and early spring allowed ample time for the broadcast or unincorporated seed to undergo several episodes of freezing and thawing and to be redistributed in the soil. Therefore, natural processes could have incorporated the broadcast seeds. Possibly, seed incorporation may be more necessary for a spring planting when there is less opportunity for seed-to-soil contact to occur from processes like freezing and thawing.

Wind and water erosion may have contributed to the low seedling emergence in the experiment. During the first week after seeding, the experimental site was subjected to 7 days of winds with speeds ranging from 17-33 mph (NOAA 2007). Although the incorporated seed was apparently not affected, a significant amount (21.5%) of the broadcast seed was no longer present one week after sowing (Figure 3). As there was no rainfall during the week, wind was the most likely cause of the seed loss although predation by granivores may have been involved. In the spring following the fall seeding, I noticed several rills running through the experimental plots. These rills were miniature gullies caused by water from thawing snow and rainfall washing down hill through the plots. Therefore, the seeds in the plots were likely washed down slope into buffer strips between plots. As a consequence, they would have been lost from the test plots prior to sampling. The rills contained no native plants and I had to adjust my sampling techniques to avoid sampling them. I expected that erosion from wind and water would be factors to consider from the beginning of this experiment. This expectation of erosion taking place is the reason I placed buffers between plots and increased the seeding rate. In addition, I measured the amount of seed lost to wind. Obviously, all of these abiotic factors made it very difficult to compare seed incorporation differences in this project. This added to the data interpretation problems resulting from the low, 4%, emergence of native seedlings.

Abiotic factors could have contributed to block differences in the project. The greater numbers of native seedlings and native species observed in the lower block (Block 2) in year 1 may have been due to one or more of the following: differences in weed competition between the two blocks, a delay in germination in one block, surface soil erosion causing seeds from the uphill block to wash downhill into the lower block, or topographical differences causing the lower block to retain more moisture than the uphill block. In year 2, there were also unusual block differences in this project. Although, there were no differences in the number of species, I observed more forb seedlings in the lower block (Block 2) than in the uphill block (Block 1) (Table 6). The lower block is located down slope and would likely collect and retain more rainfall than the upper block. The work of O'Keefe (1996) lends some support to the moisture difference idea. He observed in an eastern Iowa study that more species occurred in plantings where more moisture was present. O'Keefe seeded several prairies at similar seeding rates and at similar times during the growing season over a nine year period. He observed that prairie plantings seeded during years that received more rainfall seemed to have more native species than plantings done in years with lower amounts of rainfall.

The results of this experiment indicate that seed incorporation may be unnecessary in fall seedings. Apparently, broadcast seeding in the fall on bare soil provides sufficient seed-to-soil contact for germination and emergence. However, several abiotic influences must be in place for fall seeding onto bare soil to be sufficient.

In the case of this experiment, broadcast seeding was an adequate choice which can provide benefits because it requires less implements and takes less time than including seed incorporation in the process. This can save time and money.

Seed Incorporation and Weeds

This planting resembled a typical new prairie reconstruction with several types of annual weeds appearing initially. *Setaria* (foxtail) species and *Chenopodium album* (lambs quarters) were the primary species of weeds observed and sampled in the project. Weeds appeared even though the site was previously treated with herbicide and tilled while being farmed. In addition, the site was seeded with oats to help suppress weed growth. I hypothesized that the raked treatment would have more weed species and biomass. This was based on the idea that the raking treatment would disturb the soil more and bring more weed seed to the surface. I assumed the raking effect would be similar to cultivation which often results in an increase in weed emergence (Grundy et al. 1999; Sauer and Struik 1964). Initially, that seemed to be the case as the first sampling in June showed more weed species in the raking treatment than the other treatments (Table 15). However, subsequent samples showed no significant effect on the weed species composition and aboveground weeds by any of the incorporation treatments. Consequently, I must reject my hypotheses that seed incorporation would have significant effects on the weedy competitors.

In June of year 2, the weeds were greatly reduced and a large number of native grasses and forbs were present. However, this was more likely due to the establishment mowing during the first growing season than seed incorporation. Establishment mowing during the first season has a twofold effect. It reduces annual weed growth by removing almost all of the photosynthetic tissue and reducing or eliminating seed production. Mowing by removing larger annuals also gives the native perennials a competitive advantage over the larger annuals by allowing sunlight to reach the smaller perennial plants. Kurtz (1994) has shown that mowing the first season after planting is effective in reducing weeds and allowing native species to flourish.

Statistical analysis of queen Anne's lace in of year 2, indicated a block difference with more plants in the uphill block than in the lower block. I have no explanation for these differences. Perhaps conditions were more favorable for queen Anne's lace growth in the uphill block or it contained more seed in the seed bank than the lower block. It's known that weed species seeds can survive in the seed bank for several years before germinating and showing themselves after tillage or a disturbance (Roberts 1986). Queen Anne's lace (*Daucus carota*) is a good example of variable weed emergence in an early prairie reconstruction.

Granivory and Native Seedling Emergence

Granivory can be a significant factor in a newly seeded planting. Previous research has shown that granivory can cause a huge loss of native seeds (Hemsath 2007; Howe and Brown 2000; Hulme 1994). However this experiment , showed that the seed loss from granivory can affect both native plant abundance and composition. When granivores were excluded, native species averaged 31.5 percent more total seedlings/m^2, 27.5 percent more forb seedlings/m^2, and 42.5 percent more grass seedlings/m^2 (Table 12, Figure 5). Granivores appeared to prefer to consume grass seed over forb seed. This suggests that consideration be given to differentially increasing seeding rates of grasses and forbs to compensate for seed loss from granivory. The extent of granivory was unexpected because the sample site was adjacent to a monoculture of *Bromus inermis* in the fence line and a crop field where granivore populations were likely low. As hypothesized, predator exclusion reduced granivory and thus increased seedling emergence of the grass and forb groups. Statistical analysis on the effect of granivory on individual species could not be done due to low seedling numbers.

From this study, it is apparent that granivory can play a significant role in the outcome of a prairie reconstruction as seed loss through granivory can affect plant emergence. It is important to be aware that granivory has a negative impact on establishment of prairie vegetation and can affect the reconstruction process. Awareness of the problem should encourage resource managers and land-owners to take measures to reduce granivory when planting a prairie.

<u>Granivory, Seed Incorporation, and Native Seedling Emergence</u>

I hypothesized that seed incorporation would reduce granivory by reducing access to seed and increase seedling emergence. However, there appeared to be no relationship between granivory and seed incorporation as expressed by seedling emergence. Seedling emergence was so low (4%) in the experiment that the effects of granivory combined with seed incorporation could not be detected. Therefore, this hypothesis can not be tested.

To summarize, granivory and seed incorporation are both factors to be considered in a prairie reconstruction. There were indications that incorporating seed into the soil improved seedling emergence over no seed incorporation and that too much incorporation can reduce seedling establishment. I didn't observe any indication of seed incorporation affecting species richness. It appears that some species can germinate and emerge whether they are planted deep or on the surface. Improving good seed-to-soil contact by culti-packing appears to favor forb establishment over grasses. Since forbs are the most costly component of a prairie seed mix, it makes sense to culti-pack after seeding to maximize forb emergence. As this study was a fall seeding, it would be interesting to see if a spring seeding yielded similar results. While seed incorporation appeared to have no effect on weed species abundance and growth, establishment mowing was likely critical to early native plant establishment.

Excluding granivores from seeded areas significantly improved seedling emergence. However, there was no evidence from seedling emergence that seed incorporation affected granivory. However low native plant emergence in the experiment made it impossible to test this.

Conclusion

Low native seedling emergence in the experiment limited data analysis and interpretation. However, from this study it can be concluded that (1) Seed incorporation can prevent up to 21.5% seed loss under high wind conditions; (2) Initially, two different methods of seed incorporation increased native seedling emergence over broadcast seeding(no incorporation) or raking and culti-packing; (3) The majority of the species that benefited from seed incorporation treatments were annuals, biennials, or short-lived perennials; (4) Seed incorporation had no effect on weed species richness or biomass; (5)

Fall seeding appeared to promote seedling emergence of the cool-season grass – Canada wild rye and to be detrimental to seedling emergence of warm-season grasses included in this experiment; (6) Absence of significant differences among seed incorporation treatments suggests that weather related factors, such as freeze-thaw cycles and snow pack after fall seeding can contribute to seed incorporation; (7) The causes for very low native plant emergence in this experiment as compared to the total number of seeds sowed are not clearly understood and further research is needed; (8) Granivores can reduce native plant emergence by as much as 48%.

CHAPTER 5

FUTURE RESEARCH

Research has focused primarily on determining which planting method is most effective in seeding monocultures (Sanderson and Elwinger 2004, Monti et al. 2001). There has been little research on different prairie planting methods. Most information regarding effective prairie planting methods is anecdotal. Broadcast seeding is one method of planting prairie. My study examined the effects of broadcast seeding and various seed incorporation techniques on seedling emergence and granivory. Other widely used seeding methods like drilling and hydro-seeding should be compared with broadcast seeding for effectiveness in increasing seedling emergence.

Research has shown granivory plays a significant role in native seed loss (Howe and Brown 2000). This study demonstrated that granivore exclusion significantly increased seedling emergence and probably benefited establishment. Future research is needed to find an effective and practical way to exclude seed predators from seeds on a larger scale.

Overall, I observed that only 4 % of the planted seed emerged as seedlings (Table 8). I also observed in the preliminary granivory experiment that 32-36 % of the seed was lost to granivory (Figure 1). With the loss of 32-36 % of seed to predation, there are many questions regarding the fate of the remaining 60 percent. Certainly, some of the seed loss is to wind erosion, water erosion, and seed desiccation. In addition, some seed may have been lost to fungal and bacterial infection. Research is needed to determine the factors responsible for the huge loss of seed resulting in seedling establishments of only 4 %.

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APPENDIX A

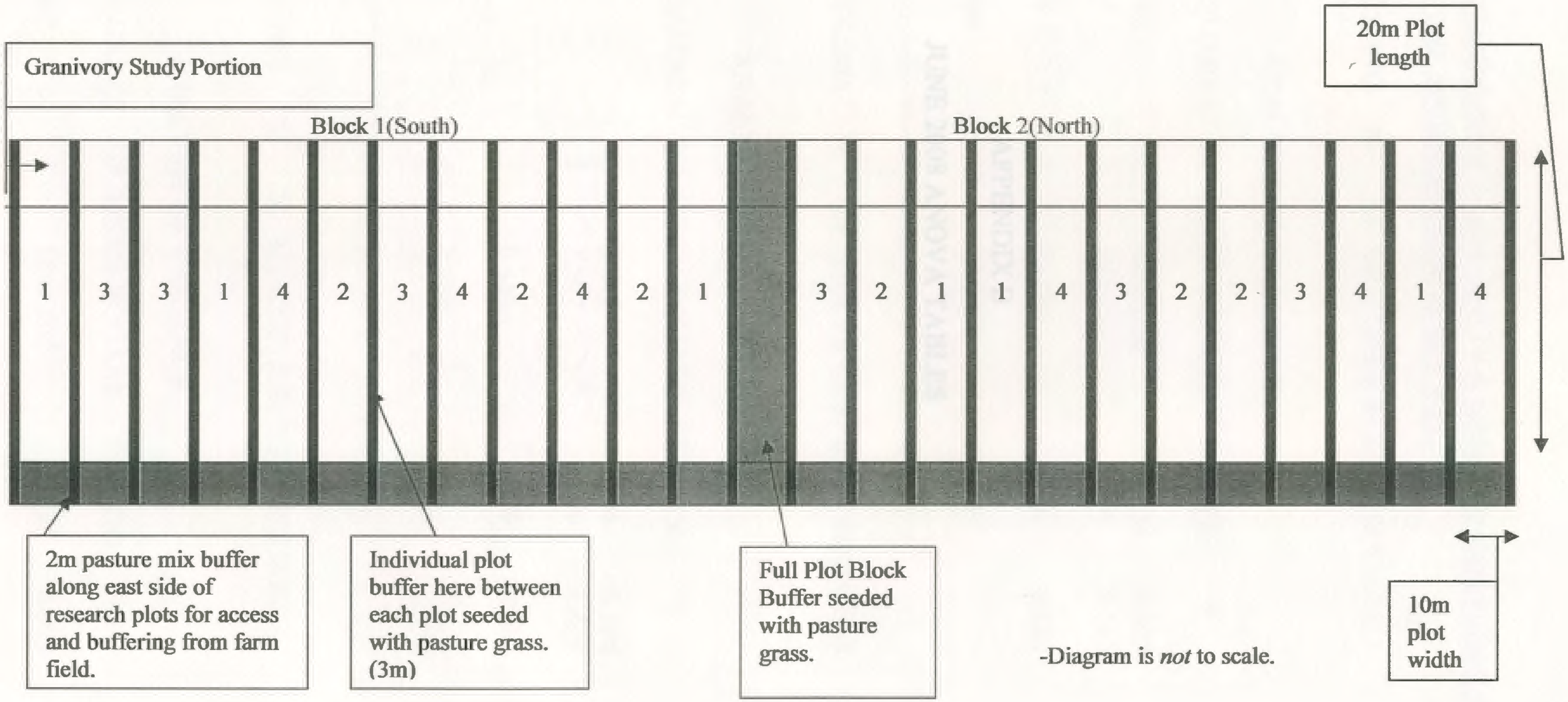
SITE AERIAL PHOTO AND DESIGN LAYOUT

Research Plot Aerial Photo taken in the summer of 2008. Plots are located on University of Northern Iowa property around 1000 meters west of the UNI-dome and 600 meters northwest of the UNI Tallgrass Prairie Center. Research plots are outlined with red. Photo was received from the Iowa Geographic Map Server on June 15, 2009.

The Effects of Planting Methods and Granivory on Seedling Emergence in a Tallgrass Prairie Reconstruction.
Experimental Design Layout

Each Plot: 10 * 20 meters ($200m^2$)
Each individual plot buffer: 3 * 20 meters ($60m^2$)
Area of each block including buffers: $3060m^2$
Area of each block not including buffers: $2400m^2$
Area of total research plots excluding buffers: $4800m^2$

<u>Treatments:</u>
1= Control broadcast
2= Broadcast and culti-packed
3= Broadcast and raked
4= Broadcast and raked and culti-packed



-Diagram is *not* to scale.

APPENDIX B

JUNE 2008 ANOVA TABLES

All Native Seedling Establishment 2-way ANOVA tables for data collected in June of 2008. Data was not transformed in any way.

DEP VAR: TOTAL SEEDLING N: 24 MULTIPLE R: 0.744 SQUARED MULTIPLE R: 0.553

ANALYSIS OF VARIANCE

SOURCE	SUM-OF-SQUARES	DF	MEAN-SQUARE	F-RATIO	P
BLOCK	1162.042	1	1162.042	12.232	0.003
TRTMT	558.458	3	186.153	1.960	0.161
BLOCK* TRTMT	158.458	3	52.819	0.556	0.652
ERROR	1520.000	16	95.000		

DEP VAR: GRASS SEEDLING N: 24 MULTIPLE R: 0.401 SQUARED MULTIPLE R: 0.161

ANALYSIS OF VARIANCE

SOURCE	SUM-OF-SQUARES	DF	MEAN-SQUARE	F-RATIO	P
BLOCK	2.042	1	2.042	0.754	0.398
TRTMT	4.792	3	1.597	0.590	0.631
BLOCK* TRTMT	1.458	3	0.486	0.179	0.909
ERROR	43.333	16	2.708		

DEP VAR: FORB SEEDLING N: 24 MULTIPLE R: 0.736 SQUARED MULTIPLE R: 0.542

ANALYSIS OF VARIANCE

SOURCE	SUM-OF-SQUARES	DF	MEAN-SQUARE	F-RATIO	P
BLOCK	1066.667	1	1066.667	11.835	0.003

TRTMT	478.833	3	159.611	1.771	0.193
BLOCK* TRTMT	158.333	3	52.778	0.586	0.633
ERROR	1442.000	16	90.125		

DEP VAR: TOTAL SPECIES N: 24 MULTIPLE R: 0.654 SQUARED MULTIPLE R: 0.427

ANALYSIS OF VARIANCE

SOURCE	SUM-OF-SQUARES	DF	MEAN-SQUARE	F-RATIO	P
BLOCK	32.667	1	32.667	6.644	0.020
TRTMT	19.333	3	6.444	1.311	0.305
BLOCK* TRTMT	6.667	3	2.222	0.452	0.719
ERROR	78.667	16	4.917		

DEP VAR: GRASS SPECIES N: 24 MULTIPLE R: 0.349 SQUARED MULTIPLE R: 0.122

ANALYSIS OF VARIANCE

SOURCE	SUM-OF-SQUARES	DF	MEAN-SQUARE	F-RATIO	P
BLOCK	0.042	1	0.042	0.071	0.793
TRTMT	1.125	3	0.375	0.643	0.599
BLOCK* TRTMT	0.125	3	0.042	0.071	0.974
ERROR	9.333	16	0.583		

DEP VAR: FORB SPECIES N: 24 MULTIPLE R: 0.665 SQUARED MULTIPLE R: 0.442

ANALYSIS OF VARIANCE

SOURCE	SUM-OF-SQUARES	DF	MEAN-SQUARE	F-RATIO	P
BLOCK	30.375	1	30.375	7.924	0.012
TRTMT	12.125	3	4.042	1.054	0.396
BLOCK* TRTMT	6.125	3	2.042	0.533	0.666
ERROR	61.333	16	3.833		

DEP VAR: WEED SPECIES N: 24 MULTIPLE R: 0.865 SQUARED MULTIPLE R: 0.748

ANALYSIS OF VARIANCE

SOURCE	SUM-OF-SQUARES	DF	MEAN-SQUARE	F-RATIO	P
BLOCK	84.375	1	84.375	34.322	0.000
TRTMT	27.458	3	9.153	3.723	0.033
BLOCK* TRTMT	4.792	3	1.597	0.650	0.595
ERROR	39.333	16	2.458		

DEP VAR: SIMPSON INDEX N: 24 MULTIPLE R: 0.551 SQUARED MULTIPLE R: 0.303

ANALYSIS OF VARIANCE

SOURCE	SUM-OF-SQUARES	DF	MEAN-SQUARE	F-RATIO	P
BLOCK	0.008	1	0.008	2.321	0.147
TRTMT	0.008	3	0.003	0.768	0.528
BLOCK* TRTMT	0.008	3	0.003	0.778	0.523
ERROR	0.052	16	0.003		

All Granivory Exclosure 3-way ANOVA tables for data collected in June of 2008. Data was not transformed in anyway.

DEP VAR: TOTAL SEEDLING N: 72 MULTIPLE R: 0.625 SQUARED MULTIPLE R: 0.390

ANALYSIS OF VARIANCE

SOURCE	SUM-OF-SQUARES	DF	MEAN-SQUARE	F-RATIO	P
BLOCK	100.347	1	100.347	1.038	0.313
TILLTRTM	418.056	3	139.352	1.441	0.242
EXCTRTMT	1228.646	2	614.323	6.353	0.004
BLOCK* TILLTRTM	203.819	3	67.940	0.703	0.555
BLOCK* EXCTRTMT	57.465	2	28.733	0.297	0.744
TILLTRTM* EXCTRTMT	482.465	6	80.411	0.832	0.552
BLOCK* TILLTRTM* EXCTRTMT	480.035	6	80.006	0.827	0.555
ERROR	4641.667	48	96.701		

DEP VAR: GRASS SEEDLING N: 72 MULTIPLE R: 0.583 SQUARED MULTIPLE R: 0.340

ANALYSIS OF VARIANCE

SOURCE	SUM-OF-SQUARES	DF	MEAN-SQUARE	F-RATIO	P
BLOCK	0.202	1	0.202	0.486	0.489
TILLTRTM	0.885	3	0.295	0.708	0.552
EXCTRTMT	3.357	2	1.679	4.029	0.024
BLOCK* TILLTRTM	1.325	3	0.442	1.060	0.375
BLOCK* EXCTRTMT	1.101	2	0.551	1.321	0.276
TILLTRTM* EXCTRTMT	2.639	6	0.440	1.056	0.402
BLOCK*					

TILLTRTM* EXCTRTMT	0.776	6	0.129	0.310	0.929
ERROR	20.000	48	0.417		

DEP VAR: FORB SEEDLING N: 72 MULTIPLE R: 0.609 SQUARED MULTIPLE R: 0.371

ANALYSIS OF VARIANCE

SOURCE	SUM-OF-SQUARES	DF	MEAN-SQUARE	F-RATIO	P
BLOCK	83.420	1	83.420	0.863	0.357
TILLTRTM	488.455	3	162.818	1.685	0.183
EXCTRTMT	1034.896	2	517.448	5.356	0.008
BLOCK* TILLTRTM	188.455	3	62.818	0.650	0.587
BLOCK* EXCTRTMT	48.090	2	24.045	0.249	0.781
TILLTRTM* EXCTRTMT	410.243	6	68.374	0.708	0.645
BLOCK* TILLTRTM* EXCTRTMT	483.160	6	80.527	0.833	0.550
ERROR	4637.500	48	96.615		

DEP VAR: TOTAL SPECIES N: 72 MULTIPLE R: 0.620 SQUARED MULTIPLE R: 0.385

ANALYSIS OF VARIANCE

SOURCE	SUM-OF-SQUARES	DF	MEAN-SQUARE	F-RATIO	P
BLOCK	6.722	1	6.722	2.316	0.135
TILLTRTM	15.000	3	5.000	1.722	0.175
EXCTRTMT	12.861	2	6.431	2.215	0.120
BLOCK* TILLTRTM	18.500	3	6.167	2.124	0.109
BLOCK* EXCTRTMT	0.361	2	0.181	0.062	0.940
TILLTRTM*					

EXCTRTMT	20.583	6	3.431	1.182	0.332
BLOCK* TILLTRTM* EXCTRTMT	13.083	6	2.181	0.751	0.612
ERROR	139.333	48	2.903		

DEP VAR: GRASS SPECIES N: 72 MULTIPLE R: 0.591 SQUARED MULTIPLE R: 0.350

ANALYSIS OF VARIANCE

SOURCE	SUM-OF-SQUARES	DF	MEAN-SQUARE	F-RATIO	P
BLOCK	0.056	1	0.056	0.364	0.549
TILLTRTM	0.278	3	0.093	0.606	0.614
EXCTRTMT	1.361	2	0.681	4.455	0.017
BLOCK* TILLTRTM	0.500	3	0.167	1.091	0.362
BLOCK* EXCTRTMT	0.528	2	0.264	1.727	0.189
TILLTRTM* EXCTRTMT	0.972	6	0.162	1.061	0.399
BLOCK* TILLTRTM* EXCTRTMT	0.250	6	0.042	0.273	0.947
ERROR	7.333	48	0.153		

DEP VAR: FORB SPECIES N: 72 MULTIPLE R: 0.602 SQUARED MULTIPLE R: 0.362

ANALYSIS OF VARIANCE

SOURCE	SUM-OF-SQUARES	DF	MEAN-SQUARE	F-RATIO	P
BLOCK	5.556	1	5.556	2.030	0.161
TILLTRTM	17.611	3	5.870	2.146	0.107
EXCTRTMT	7.861	2	3.931	1.437	0.248

BLOCK* TILLTRTM	14.333	3	4.778	1.746	0.170
BLOCK* EXCTRTMT	1.194	2	0.597	0.218	0.805
TILLTRTM* EXCTRTMT	14.472	6	2.412	0.882	0.516
BLOCK* TILLTRTM* EXCTRTMT	13.583	6	2.264	0.827	0.555
ERROR	131.333	48	2.736		

DEP VAR: WEED SPECIES N: 72 MULTIPLE R: 0.636 SQUARED MULTIPLE R: 0.404

ANALYSIS OF VARIANCE

SOURCE	SUM-OF-SQUARES	DF	MEAN-SQUARE	F-RATIO	P
BLOCK	20.056	1	20.056	9.500	0.003
TILLTRTM	10.889	3	3.630	1.719	0.176
EXCTRTMT	8.583	2	4.292	2.033	0.142
BLOCK* TILLTRTM	8.611	3	2.870	1.360	0.266
BLOCK* EXCTRTMT	0.861	2	0.431	0.204	0.816
TILLTRTM* EXCTRTMT	9.861	6	1.644	0.779	0.591
BLOCK* TILLTRTM* EXCTRTMT	9.806	6	1.634	0.774	0.594
ERROR	101.333	48	2.111		

DEP VAR: SIMPSON INDEX N: 72 MULTIPLE R: 0.635 SQUARED MULTIPLE R: 0.403

ANALYSIS OF VARIANCE

SOURCE SUM-OF-SQUARES DF MEAN-SQUARE F-RATIO P

BLOCK	0.001	1	0.001	1.904	0.174
TILLTRTM	0.001	3	0.000	0.592	0.623
EXCTRTMT	0.003	2	0.001	3.586	0.035
BLOCK* TILLTRTM	0.002	3	0.001	1.968	0.131
BLOCK* EXCTRTMT	0.000	2	0.000	0.659	0.522
TILLTRTM* EXCTRTMT	0.001	6	0.000	0.434	0.852
BLOCK* TILLTRTM* EXCTRTMT	0.004	6	0.001	1.947	0.092
ERROR	0.017	48	0.000		

APPENDIX C

SEPTEMBER 2008 ANOVA TABLES

All Native Seedling Establishment 2-way ANOVA tables for data collected in September of 2008. Data was not transformed in any way.

DEP VAR: TOTAL SEEDLING N: 24 MULTIPLE R: 0.778 SQUARED MULTIPLE R: 0.605

ANALYSIS OF VARIANCE

SOURCE	SUM-OF-SQUARES	DF	MEAN-SQUARE	F-RATIO	P
BLOCK	0.375	1	0.375	0.009	0.924
TRTMT	551.792	3	183.931	4.565	0.017
BLOCK* TRTMT	435.125	3	145.042	3.600	0.037
ERROR	644.667	16	40.292		

DEP VAR: GRASS SEEDLING N: 24 MULTIPLE R: 0.295 SQUARED MULTIPLE R: 0.087

ANALYSIS OF VARIANCE

SOURCE	SUM-OF-SQUARES	DF	MEAN-SQUARE	F-RATIO	P
BLOCK	2.667	1	2.667	0.198	0.662
TRTMT	9.500	3	3.167	0.235	0.870
BLOCK* TRTMT	8.333	3	2.778	0.206	0.890
ERROR	215.333	16	13.458		

DEP VAR: FORB SEEDLING N: 24 MULTIPLE R: 0.815 SQUARED MULTIPLE R: 0.665

ANALYSIS OF VARIANCE

SOURCE	SUM-OF-SQUARES	DF	MEAN-SQUARE	F-RATIO	P
BLOCK	5.042	1	5.042	0.195	0.665

TRTMT	469.458	3	156.486	6.058	0.006
BLOCK* TRTMT	346.125	3	115.375	4.466	0.018
ERROR	413.333	16	25.833		

DEP VAR: TOTAL SPECIES N: 24 MULTIPLE R: 0.700 SQUARED MULTIPLE R: 0.489

ANALYSIS OF VARIANCE

SOURCE	SUM-OF-SQUARES	DF	MEAN-SQUARE	F-RATIO	P
BLOCK	20.167	1	20.167	5.042	0.039
TRTMT	16.333	3	5.444	1.361	0.290
BLOCK* TRTMT	24.833	3	8.278	2.069	0.145
ERROR	64.000	16	4.000		

DEP VAR: GRASS SPECIES N: 24 MULTIPLE R: 0.505 SQUARED MULTIPLE R: 0.255

ANALYSIS OF VARIANCE

SOURCE	SUM-OF-SQUARES	DF	MEAN-SQUARE	F-RATIO	P
BLOCK	3.375	1	3.375	1.687	0.212
TRTMT	0.792	3	0.264	0.132	0.940
BLOCK* TRTMT	6.792	3	2.264	1.132	0.366
ERROR	32.000	16	2.000		

DEP VAR: FORB SPECIES N: 24 MULTIPLE R: 0.658 SQUARED MULTIPLE R: 0.433

ANALYSIS OF VARIANCE

SOURCE	SUM-OF-SQUARES	DF	MEAN-SQUARE	F-RATIO	P
BLOCK	7.042	1	7.042	2.284	0.150
TRTMT	12.458	3	4.153	1.347	0.294
BLOCK* TRTMT	18.125	3	6.042	1.959	0.161
ERROR	49.333	16	3.083		

DEP VAR: WEED SPECIES N: 24 MULTIPLE R: 0.566 SQUARED MULTIPLE R: 0.321

ANALYSIS OF VARIANCE

SOURCE	SUM-OF-SQUARES	DF	MEAN-SQUARE	F-RATIO	P
BLOCK	12.042	1	12.042	3.853	0.067
TRTMT	5.458	3	1.819	0.582	0.635
BLOCK* TRTMT	6.125	3	2.042	0.653	0.592
ERROR	50.000	16	3.125		

DEP VAR: SIMPSON INDEX N: 24 MULTIPLE R: 0.371 SQUARED MULTIPLE R: 0.138

ANALYSIS OF VARIANCE

SOURCE	SUM-OF-SQUARES	DF	MEAN-SQUARE	F-RATIO	P
BLOCK	0.001	1	0.001	0.680	0.422
TRTMT	0.001	3	0.000	0.164	0.919
BLOCK* TRTMT	0.002	3	0.001	0.460	0.714
ERROR	0.022	16	0.001		

All Granivory Exclosure 3- way ANOVA tables for data collected in September of 2008. Data was square-root transformed prior to running the 3-way ANOVA.

DEP VAR: TOTAL SEEDLING N: 72 MULTIPLE R: 0.581 SQUARED MULTIPLE R: 0.338

ANALYSIS OF VARIANCE

SOURCE	SUM-OF-SQUARES	DF	MEAN-SQUARE	F-RATIO	P
BLOCK	0.000	1	0.000	0.000	0.985
TILLTRTM	5.728	3	1.909	1.422	0.248
EXCTRTMT	16.017	2	8.008	5.966	0.005
BLOCK* TILLTRTM	2.930	3	0.977	0.728	0.541
BLOCK* EXCTRTMT	0.229	2	0.115	0.085	0.918
TILLTRTM* EXCTRTMT	4.052	6	0.675	0.503	0.803
BLOCK* TILLTRTM* EXCTRTMT	3.944	6	0.657	0.490	0.813
ERROR	64.431	48	1.342		

DEP VAR: GRASS SEEDLING N: 72 MULTIPLE R: 0.738 SQUARED MULTIPLE R: 0.545

ANALYSIS OF VARIANCE

SOURCE	SUM-OF-SQUARES	DF	MEAN-SQUARE	F-RATIO	P
BLOCK	0.180	1	0.180	0.258	0.614
TILLTRTM	0.807	3	0.269	0.385	0.764
EXCTRTMT	17.559	2	8.780	12.563	0.000
BLOCK* TILLTRTM	11.549	3	3.850	5.508	0.002
BLOCK* EXCTRTMT	0.239	2	0.119	0.171	0.843
TILLTRTM*					

EXCTRTMT	8.938	6	1.490	2.132	0.067
BLOCK* TILLTRTM* EXCTRTMT	0.872	6	0.145	0.208	0.973
ERROR	33.545	48	0.699		

DEP VAR: FORB SEEDLING N: 72 MULTIPLE R: 0.524 SQUARED MULTIPLE R: 0.274

ANALYSIS OF VARIANCE

SOURCE	SUM-OF-SQUARES	DF	MEAN-SQUARE	F-RATIO	P
BLOCK	0.155	1	0.155	0.097	0.756
TILLTRTM	7.377	3	2.459	1.541	0.216
EXCTRTMT	9.593	2	4.797	3.006	0.059
BLOCK* TILLTRTM	1.989	3	0.663	0.416	0.743
BLOCK* EXCTRTMT	1.142	2	0.571	0.358	0.701
TILLTRTM* EXCTRTMT	6.126	6	1.021	0.640	0.698
BLOCK* TILLTRTM* EXCTRTMT	2.570	6	0.428	0.269	0.949
ERROR	76.581	48	1.595		

DEP VAR: TOTAL SPECIES N: 72 MULTIPLE R: 0.467 SQUARED MULTIPLE R: 0.218

ANALYSIS OF VARIANCE

SOURCE	SUM-OF-SQUARES	DF	MEAN-SQUARE	F-RATIO	P
BLOCK	0.002	1	0.002	0.008	0.930
TILLTRTM	0.505	3	0.168	0.837	0.480
EXCTRTMT	0.248	2	0.124	0.617	0.544
BLOCK*					

TILLTRTM	0.747	3	0.249	1.237	0.307
BLOCK* EXCTRTMT	0.140	2	0.070	0.347	0.708
TILLTRTM* EXCTRTMT	0.848	6	0.141	0.702	0.649
BLOCK* TILLTRTM* EXCTRTMT	0.211	6	0.035	0.175	0.982
ERROR	9.661	48	0.201		

DEP VAR: GRASS SPECIES N: 72 MULTIPLE R: 0.704 SQUARED MULTIPLE R: 0.496

ANALYSIS OF VARIANCE

SOURCE	SUM-OF-SQUARES	DF	MEAN-SQUARE	F-RATIO	P
BLOCK	0.000	1	0.000	0.000	1.000
TILLTRTM	0.389	3	0.130	0.736	0.536
EXCTRTMT	2.471	2	1.235	7.011	0.002
BLOCK* TILLTRTM	2.713	3	0.904	5.132	0.004
BLOCK* EXCTRTMT	0.014	2	0.007	0.041	0.960
TILLTRTM* EXCTRTMT	2.280	6	0.380	2.157	0.064
BLOCK* TILLTRTM* EXCTRTMT	0.445	6	0.074	0.421	0.862
ERROR	8.458	48	0.176		

DEP VAR: FORB SPECIES N: 72 MULTIPLE R: 0.533 SQUARED MULTIPLE R: 0.284

ANALYSIS OF VARIANCE

SOURCE SUM-OF-SQUARES DF MEAN-SQUARE F-RATIO P

BLOCK	0.010	1	0.010	0.041	0.840
TILLTRTM	0.892	3	0.297	1.230	0.309
EXCTRTMT	0.573	2	0.287	1.186	0.314
BLOCK* TILLTRTM	0.934	3	0.311	1.288	0.289
BLOCK* EXCTRTMT	0.034	2	0.017	0.070	0.933
TILLTRTM* EXCTRTMT	1.679	6	0.280	1.158	0.344
BLOCK* TILLTRTM* EXCTRTMT	0.471	6	0.079	0.325	0.921
ERROR	11.601	48	0.242		

DEP VAR: WEED SPECIES N: 72 MULTIPLE R: 0.589 SQUARED MULTIPLE R: 0.347

ANALYSIS OF VARIANCE

SOURCE	SUM-OF-SQUARES	DF	MEAN-SQUARE	F-RATIO	P
BLOCK	0.461	1	0.461	3.892	0.054
TILLTRTM	0.363	3	0.121	1.023	0.391
EXCTRTMT	0.060	2	0.030	0.253	0.778
BLOCK* TILLTRTM	0.119	3	0.040	0.336	0.799
BLOCK* EXCTRTMT	0.137	2	0.068	0.577	0.565
TILLTRTM* EXCTRTMT	0.691	6	0.115	0.973	0.454
BLOCK* TILLTRTM* EXCTRTMT	1.183	6	0.197	1.666	0.150
ERROR	5.680	48	0.118		

DEP VAR: SIMPSON INDEX N: 72 MULTIPLE R: 0.551 SQUARED MULTIPLE R: 0.304

ANALYSIS OF VARIANCE

SOURCE	SUM-OF-SQUARES	DF	MEAN-SQUARE	F-RATIO	P
BLOCK	0.000	1	0.000	0.441	0.510
TILLTRTM	0.000	3	0.000	0.782	0.510
EXCTRTMT	0.000	2	0.000	2.456	0.096
BLOCK* TILLTRTM	0.000	3	0.000	0.293	0.830
BLOCK* EXCTRTMT	0.000	2	0.000	0.856	0.431
TILLTRTM* EXCTRTMT	0.000	6	0.000	0.795	0.579
BLOCK* TILLTRTM* EXCTRTMT	0.001	6	0.000	0.986	0.446
ERROR	0.005	48	0.000		

APPENDIX D

JUNE 2009 ANOVA TABLES

<u>All Native Seedling Establishment 2-way ANOVA tables for data collected in June of 2009. Data was not transformed in any way.</u>

DEP VAR: TOTAL SEEDLING N: 24 MULTIPLE R: 0.621 SQUARED MULTIPLE R: 0.385

ANALYSIS OF VARIANCE

SOURCE	SUM-OF-SQUARES	DF	MEAN-SQUARE	F-RATIO	P
BLOCK	170.667	1	170.667	2.287	0.150
TRTMT	28.833	3	9.611	0.129	0.942
BLOCK* TRTMT	548.333	3	182.778	2.449	0.101
ERROR	1194.000	16	74.625		

DEP VAR: GRASS SEEDLING N: 24 MULTIPLE R: 0.527 SQUARED MULTIPLE R: 0.278

ANALYSIS OF VARIANCE

SOURCE	SUM-OF-SQUARES	DF	MEAN-SQUARE	F-RATIO	P
BLOCK	1.500	1	1.500	0.153	0.701
TRTMT	4.833	3	1.611	0.164	0.919
BLOCK* TRTMT	54.167	3	18.056	1.836	0.181
ERROR	157.333	16	9.833		

DEP VAR: FORB SEEDLING N: 24 MULTIPLE R: 0.630 SQUARED MULTIPLE R: 0.396

ANALYSIS OF VARIANCE

SOURCE	SUM-OF-SQUARES	DF	MEAN-SQUARE	F-RATIO	P
BLOCK	204.167	1	204.167	4.475	0.050

TRTMT	13.333	3	4.444	0.097	0.960
BLOCK* TRTMT	261.833	3	87.278	1.913	0.168
ERROR	730.000	16	45.625		

DEP VAR: TOTAL SPECIES N: 24 MULTIPLE R: 0.493 SQUARED MULTIPLE R: 0.243

ANALYSIS OF VARIANCE

SOURCE	SUM-OF-SQUARES	DF	MEAN-SQUARE	F-RATIO	P
BLOCK	0.000	1	0.000	0.000	1.000
TRTMT	4.167	3	1.389	0.207	0.890
BLOCK* TRTMT	30.333	3	10.111	1.507	0.251
ERROR	107.333	16	6.708		

DEP VAR: GRASS SPECIES N: 24 MULTIPLE R: 0.444 SQUARED MULTIPLE R: 0.197

ANALYSIS OF VARIANCE

SOURCE	SUM-OF-SQUARES	DF	MEAN-SQUARE	F-RATIO	P
BLOCK	0.375	1	0.375	0.643	0.434
TRTMT	0.792	3	0.264	0.452	0.719
BLOCK* TRTMT	1.125	3	0.375	0.643	0.599
ERROR	9.333	16	0.583		

DEP VAR: FORB SPECIES N: 24 MULTIPLE R: 0.459 SQUARED MULTIPLE R: 0.211

ANALYSIS OF VARIANCE

SOURCE	SUM-OF-SQUARES	DF	MEAN-SQUARE	F-RATIO	P
BLOCK	0.375	1	0.375	0.058	0.813
TRTMT	7.458	3	2.486	0.385	0.765
BLOCK* TRTMT	19.792	3	6.597	1.022	0.409
ERROR	103.333	16	6.458		

DEP VAR: WEED SPECIES N: 24 MULTIPLE R: 0.615 SQUARED MULTIPLE R: 0.379

ANALYSIS OF VARIANCE

SOURCE	SUM-OF-SQUARES	DF	MEAN-SQUARE	F-RATIO	P
BLOCK	12.042	1	12.042	8.028	0.012
TRTMT	1.458	3	0.486	0.324	0.808
BLOCK* TRTMT	1.125	3	0.375	0.250	0.860
ERROR	24.000	16	1.500		

DEP VAR: SIMPSON INDEX N: 24 MULTIPLE R: 0.555 SQUARED MULTIPLE R: 0.308

ANALYSIS OF VARIANCE

SOURCE	SUM-OF-SQUARES	DF	MEAN-SQUARE	F-RATIO	P
BLOCK	0.001	1	0.001	0.194	0.666
TRTMT	0.013	3	0.004	1.473	0.259
BLOCK* TRTMT	0.007	3	0.002	0.834	0.494
ERROR	0.045	16	0.003		

<u>All Granivory Exclosure 3- way ANOVA tables for data collected in June of 2009. Data was not transformed in anyway.</u>

DEP VAR: TOTAL SEEDLING N: 72 MULTIPLE R: 0.639 SQUARED MULTIPLE R: 0.408

ANALYSIS OF VARIANCE

SOURCE	SUM-OF-SQUARES	DF	MEAN-SQUARE	F-RATIO	P
BLOCK	17.014	1	17.014	0.192	0.663
TILLTRTM	756.597	3	252.199	2.851	0.047
EXCTRTMT	1329.340	2	664.670	7.514	0.001
BLOCK* TILLTRTM	26.042	3	8.681	0.098	0.961
BLOCK* EXCTRTMT	15.799	2	7.899	0.089	0.915
TILLTRTM* EXCTRTMT	494.965	6	82.494	0.933	0.480
BLOCK* TILLTRTM* EXCTRTMT	284.896	6	47.483	0.537	0.778
ERROR	4245.833	48	88.455		

DEP VAR: GRASS SEEDLING N: 72 MULTIPLE R: 0.727 SQUARED MULTIPLE R: 0.529

ANALYSIS OF VARIANCE

SOURCE	SUM-OF-SQUARES	DF	MEAN-SQUARE	F-RATIO	P
BLOCK	14.670	1	14.670	1.310	0.258
TILLTRTM	169.705	3	56.568	5.052	0.004
EXCTRTMT	175.174	2	87.587	7.822	0.001
BLOCK* TILLTRTM	104.427	3	34.809	3.109	0.035
BLOCK* EXCTRTMT	31.424	2	15.712	1.403	0.256
TILLTRTM* EXCTRTMT	95.660	6	15.943	1.424	0.225

BLOCK* TILLTRTM* EXCTRTMT	13.021	6	2.170	0.194	0.977
ERROR	537.500	48	11.198		

DEP VAR: FORB SEEDLING N: 72 MULTIPLE R: 0.621 SQUARED MULTIPLE R: 0.386

ANALYSIS OF VARIANCE

SOURCE	SUM-OF-SQUARES	DF	MEAN-SQUARE	F-RATIO	P
BLOCK	0.087	1	0.087	0.001	0.971
TILLTRTM	487.066	3	162.355	2.517	0.069
EXCTRTMT	639.583	2	319.792	4.958	0.011
BLOCK* TILLTRTM	84.983	3	28.328	0.439	0.726
BLOCK* EXCTRTMT	75.694	2	37.847	0.587	0.560
TILLTRTM* EXCTRTMT	415.278	6	69.213	1.073	0.392
BLOCK* TILLTRTM* EXCTRTMT	244.444	6	40.741	0.632	0.704
ERROR	3095.833	48	64.497		

DEP VAR: TOTAL SPECIES N: 72 MULTIPLE R: 0.645 SQUARED MULTIPLE R: 0.416

ANALYSIS OF VARIANCE

SOURCE	SUM-OF-SQUARES	DF	MEAN-SQUARE	F-RATIO	P
BLOCK	0.125	1	0.125	0.044	0.835
TILLTRTM	16.486	3	5.495	1.921	0.139
EXCTRTMT	8.361	2	4.181	1.461	0.242
BLOCK* TILLTRTM	16.375	3	5.458	1.908	0.141

BLOCK* EXCTRTMT	1.750	2	0.875	0.306	0.738
TILLTRTM* EXCTRTMT	29.639	6	4.940	1.727	0.135
BLOCK* TILLTRTM* EXCTRTMT	24.917	6	4.153	1.451	0.215
ERROR	137.333	48	2.861		

DEP VAR: GRASS SPECIES N: 72 MULTIPLE R: 0.469 SQUARED MULTIPLE R: 0.220

ANALYSIS OF VARIANCE

SOURCE	SUM-OF-SQUARES	DF	MEAN-SQUARE	F-RATIO	P
BLOCK	0.000	1	0.000	0.000	1.000
TILLTRTM	0.611	3	0.204	0.698	0.558
EXCTRTMT	0.778	2	0.389	1.333	0.273
BLOCK* TILLTRTM	0.667	3	0.222	0.762	0.521
BLOCK* EXCTRTMT	1.000	2	0.500	1.714	0.191
TILLTRTM* EXCTRTMT	0.222	6	0.037	0.127	0.992
BLOCK* TILLTRTM* EXCTRTMT	0.667	6	0.111	0.381	0.888
ERROR	14.000	48	0.292		

DEP VAR: FORB SPECIES N: 72 MULTIPLE R: 0.680 SQUARED MULTIPLE R: 0.462

ANALYSIS OF VARIANCE

SOURCE	SUM-OF-SQUARES	DF	MEAN-SQUARE	F-RATIO	P
BLOCK	0.125	1	0.125	0.048	0.828

TILLTRTM	19.819	3	6.606	2.530	0.068
EXCTRTMT	5.583	2	2.792	1.069	0.351
BLOCK* TILLTRTM	18.264	3	6.088	2.332	0.086
BLOCK* EXCTRTMT	0.250	2	0.125	0.048	0.953
TILLTRTM* EXCTRTMT	33.306	6	5.551	2.126	0.067
BLOCK* TILLTRTM* EXCTRTMT	30.194	6	5.032	1.927	0.095
ERROR	125.333	48	2.611		

DEP VAR: WEED SPECIES N: 72 MULTIPLE R: 0.505 SQUARED MULTIPLE R: 0.255

ANALYSIS OF VARIANCE

SOURCE	SUM-OF-SQUARES	DF	MEAN-SQUARE	F-RATIO	P
BLOCK	8.000	1	8.000	4.299	0.044
TILLTRTM	5.611	3	1.870	1.005	0.399
EXCTRTMT	0.361	2	0.181	0.097	0.908
BLOCK* TILLTRTM	1.889	3	0.630	0.338	0.798
BLOCK* EXCTRTMT	0.083	2	0.042	0.022	0.978
TILLTRTM* EXCTRTMT	11.306	6	1.884	1.012	0.429
BLOCK* TILLTRTM* EXCTRTMT	3.361	6	0.560	0.301	0.933
ERROR	89.333	48	1.861		

DEP VAR: SIMPSON INDEX N: 72 MULTIPLE R: 0.466 SQUARED MULTIPLE R: 0.217

ANALYSIS OF VARIANCE

SOURCE	SUM-OF-SQUARES	DF	MEAN-SQUARE	F-RATIO	P
BLOCK	0.000	1	0.000	0.035	0.852
TILLTRTM	0.000	3	0.000	0.250	0.861
EXCTRTMT	0.000	2	0.000	0.453	0.639
BLOCK* TILLTRTM	0.002	3	0.001	1.715	0.176
BLOCK* EXCTRTMT	0.001	2	0.001	1.649	0.203
TILLTRTM* EXCTRTMT	0.001	6	0.000	0.323	0.922
BLOCK* TILLTRTM* EXCTRTMT	0.000	6	0.000	0.205	0.974
ERROR	0.016	48	0.000		

<u>All Weed Biomass 2- way ANOVA tables for data collected in September of 2008. Data was not transformed in anyway.</u>

DEP VAR: GRASS MEAN N: 24 MULTIPLE R: 0.546 SQUARED MULTIPLE R: 0.298

ANALYSIS OF VARIANCE

SOURCE	SUM-OF-SQUARES	DF	MEAN-SQUARE	F-RATIO	P
BLOCK	330.042	1	330.042	0.166	0.689
TREATMEN	12489.765	3	4163.255	2.091	0.142
BLOCK* TREATMEN	700.685	3	233.562	0.117	0.949
ERROR	31854.613	16	1990.913		

DEP VAR: FORB MEAN N: 24 MULTIPLE R: 0.610 SQUARED MULTIPLE R: 0.373

ANALYSIS OF VARIANCE

SOURCE	SUM-OF-SQUARES	DF	MEAN-SQUARE	F-RATIO	P
BLOCK	5388.007	1	5388.007	5.271	0.036
TREATMEN	2739.773	3	913.258	0.893	0.466
BLOCK* TREATMEN	1589.927	3	529.976	0.518	0.676
ERROR	16356.187	16	1022.262		

APPENDIX E

SEED INCORPORATION AND PRELIMINARY EXPERIMENT ANOVA TABLES

Seed incorporation seed count 2-way ANOVA tables for data collected in November of 2007. Data was not transformed in any way.

DEP VAR: INITIAL SEED COUNTS N: 24 MULTIPLE R: 0.985 SQUARED MULTIPLE R: 0.970

ANALYSIS OF VARIANCE

SOURCE	SUM-OF-SQUARES	DF	MEAN-SQUARE	F-RATIO	P
BLOCK	3174.000	1	3174.000	2.756	0.116
TRMNT	583816.000	3	194605.333	168.953	0.000
BLOCK*TRMNT	3954.000	3	1318.000	1.144	0.361
ERROR	18429.333	16	1151.833		

DEP VAR: ONE WEEK LATER SEED COUNTS N: 24 MULTIPL R: 0.943 SQUARED MULTIPLE R: 0.889

ANALYSIS OF VARIANCE

SOURCE	SUM-OF-SQUARES	DF	MEAN-SQUARE	F-RATIO	P
BLOCK	1837.500	1	1837.500	0.776	0.392
TRMNT	297403.167	3	99134.389	41.847	0.000
BLOCK*TRMNT	3405.833	3	1135.278	0.479	0.701
ERROR	37904.000	16	2369.000		

Preliminary test of the effect of fluorescent powder on seedling emergence 2- way ANOVA table for data collected in a greenhouse. Data was not transformed in any way.

DEP VAR: NATIVE SPECIES N: 24 MULTIPLE R: 0.363 SQUARED MULTIPLE R: 0.132

ANALYSIS OF VARIANCE

SOURCE	SUM –OF-SQUARES	DF	MEAN-SQUARE	F-RATIO	P

POWDER	3.375	1	3.375	0.316	0.582
TREATMENT	22.458	3	7.486	0.702	0.565
POWDER* TREATMENT	0.125	3	0.042	0.004	1.000
ERROR	170.667	16	10.667		

Preliminary test of powder on granivory 2-way ANOVA table for data collected in May of 2008. Data was not transformed in any way.

DEP VAR: SPECIES MORTALITY N: 50 MULTIPLE R: 0.628 SQUARED MULTIPLE R: 0.394

ANALYSIS OF VARIANCE

SOURCE	SUM-OF-SQUARES	DF	MEAN-SQUARE	F-RATIO	P
TRTMT	0.020	1	0.020	0.617	0.437
SPECIES	0.584	4	0.146	4.506	0.004
TRTMT* SPECIES	0.240	4	0.060	1.852	0.138
ERROR	1.296	40	0.032		