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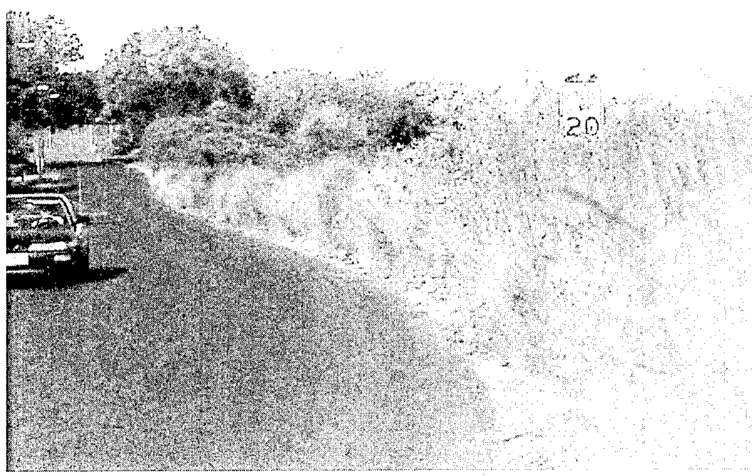

Effects of Seeding Date on Establishment of Prairie Grasses in Minnesota

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16. Abstract (Limit: 200 words)

This research project investigated the effects of seeding date on native prairie grasses. Specific objectives included determining

* the effects of seeding date on first-season establishment
* the effects of seeding date on second-season establishment
* whether dormant seedings are as successful as seedings done during the main growing season
* whether increasing the percentage of cool-season grass seed in a mix improves stand establishment

In 1996 and 1997, native prairie grasses were seeded in field plots at the University of Minnesota's St. Paul campus. Seeding was done 10 times during each growing season, at two- to four-week intervals. Species included Schizachyrium scoparium (little bluestem), Bouteloua curtipendula (sideoats grama), Elymus canadensis (Canada wildrye), and Bromus kalmii (Kalm's brome), a 'cool-season' and a 'warm-season' mix.

Mixes with a higher percentage of cool-season grass seed performed better than mixes containing more warm-season grass seed. However, the cool-season mixes produced very few warm-season grass plants.

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Effects of Seeding Date on Establishment of Prairie Grasses in Minnesota

Final Report

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TABLE OF CONTENTS

LIST OF TABLES

List of Figures

EXECUTIVE SUMMARY

The Minnesota Department of Transportation (Mn/DOT) has been working towards successful establishment of drought-tolerant native prairie plants along roadsides. Techniques for planting prairie species have been refined over the past several years, but one area that has not received much attention is seeding date. In the Upper Midwest, restorationists generally seed prairie species in spring or early summer. Planting early in the season ensures that seedlings have time to mature before winter. Restorationists also do dormant seedings in late fall that do not germinate until the following spring. For Minnesota, Mn/DOT guidelines recommend planting native seed mixes April through July 10, or after September 15. This short planting season often creates scheduling difficulties and landscape managers would like to extend planting dates into August if possible.

The primary goal of this project was to investigate the effects of seeding date on native prairie grasses. Specific objectives included: 1) Determine effects of seeding date on first-season establishment; 2) Determine effects of seeding date on second-season establishment; 3) Determine whether dormant seedings are as successful as seedings done during the main growing season; and 4) Determine whether increasing the percentage of cool-season grass seed in a mix improves stand establishment.

In 1996 and 1997, native prairie grasses were seeded in field plots at the University of Minnesota, St. Paul. Seeding was done ten times during each growing season, at two to four week intervals. On each seeding date, four monocultures and two mixes were broadcast, in three replications. Species included *Schizachyrium scoparium* (little bluestem), *Bouteloua curtipendula* (sideoats grama), *Elymus canadensis* (Canada wildrye), and *Bromus kalmii* (Kalm's brome). One mix was a "cool-season" mix composed of 25% of each of the four species. The second mix was a "warm-season mix" of the same species, but with *S. scoparium* and *B. curtipendula* comprising 81% of the mix. In addition, in 1997 two modified Mn/DOT mixes were planted on four seeding dates.

When moisture was adequate, *S. scoparium* and *B. curtipendula* survived winter if planted by early August. When moisture was adequate, *E. canadensis* and *B. kalmii* survived winter if planted by early September. On sites that are irrigated, planting can be done anytime before these dates. If irrigation is not possible, land managers must weigh the likelihood of receiving adequate rainfall. Early planting provides a longer growing season and, thus, a higher probability of receiving the necessary rainfall for germination and growth.

E. canadensis and *B. kalmii* established well from dormant seedings in at least one of two years. Dormant seedings of *S. scoparium* and *B. curtipendula* never established well in this study. It is possible that dormant seedings of these two species would establish better on lighter, less fertile soil, with different planting methods (e.g. drilling seed, mulching, or using cover crops), or under different weather patterns.

Mixes with a higher percentage of cool-season grass seed performed better than mixes containing more warm-season grass seed. However, the cool-season mixes produced very few warm-season grass plants. Some restorationists suggest that cool-season grasses fade out after five to eight years and are replaced by warm-season grasses. If this is true, cool-season mixes offer several advantages.

CHAPTER 1
INTRODUCTION

1.1 Background

Steep slopes, intense heat, compacted soils, and highway pollutants make the land adjacent to highways a brutal environment for plants. The Minnesota Department of Transportation (Mn/DOT) has been working towards successful establishment of drought-tolerant native prairie plants in these harsh conditions. During the past several decades, the restoration community has refined techniques for planting prairie species. Special seed cleaning equipment and seed drills have been designed. Experiments on seeding rate, seeding depth, and seedbed preparation have been conducted. Burning, mowing, and grazing have all been studied as maintenance practices. Books and nursery catalogs [1, 2,3] document how to plant and manage prairies. *The Mn/DOT Seeding Manual* [4] contains recommendations on seed mixes and planting methods for prairie restoration projects along Minnesota roadsides.

One subject in prairie restoration that has not received much attention is seeding date. In the Upper Midwest, restorationists generally seed prairie species in spring or early summer. Planting early in the season ensures that seedlings have time to mature before winter. Restorationists also do dormant seedings. These are plantings done in late fall that do not germinate until the following season. For Minnesota, Mn/DOT guidelines recommend planting native seed mixes April through July 10 or September 15 through November 15 [4]. More specifically, warm-season grasses can be dormant seeded after September 15 and cool-season grasses after October 20 (Robert Jacobson, personal communication, 1999). The short planting season for native grasses during the growing season often creates scheduling difficulties and landscape managers would like to extend planting dates into August if possible.

Understanding optimal times for planting is crucial for successful stand establishment of prairie grasses. This information can be used to select the best planting time or to adjust seed mixes.

1.2 Literature Review

After the great dust storms of the 1930's, interest grew in establishment methods for rangeland grasses in dry western states. Since then, several seeding date studies have been conducted. However, most of these studies have been on cool-season species and many have been on non-native grasses. Summer drought and heat usually restrict planting to spring or fall, but conclusions vary on which is the best time to plant. In Idaho, a study on two cool-season mixes (*Agropyron spp.* and *Poa secunda*) found fall plantings were more dependable than spring plantings [5]. In Montana, researchers planted *Agropyron desertorum* (crested wheatgrass) and *Bromus inermis* (smooth brome) eight times throughout the growing season for four years. Though several dates produced successful stands, early April was the only seeding date that provided successful establishment every year of the study [6]. In Saskatchewan, Kilcher investigated five cool-season grasses and found best seeding dates differed for each species [7].

Because of the dry conditions and the species used in the western studies, it is difficult to apply them to prairie restorations further east. Very little research has been done on dates for seeding prairie grasses in the Midwest and the Upper Midwest. One Kansas study looked at *Buchloë dactyloides* (buffalo grass). The researchers recorded good first-season establishment when they planted April through July, and poor establishment for August seedings [8]. Note, however, in this study the plots were irrigated and weeded. The researchers recorded a significant date effect *without* moisture stress or weed competition. This suggests that once minimum moisture requirements are met, other factors related to date may play an extremely important part in establishment -- perhaps temperature, day length, or variables such as wind or the life cycles of soil microorganisms.

1.3 Research Objectives

The primary goal of this project was to investigate the effects of planting time on native prairie grasses in Minnesota. Specific objectives included:

1. Determine the effect of planting date on first-season establishment. First-season establishment was defined as the number of seedlings that were alive in September or October of the planting year.

2. Determine the effect of planting date on second-season establishment. Second-season establishment was defined as the number of seedlings that were alive in July, the year following the planting season.
3. Determine whether dormant seedings are successful.
4. Determine whether increasing the percentage of cool-season grass seeds in a mix improves stand establishment.

1.4 Overview of Experiment

In 1996 and 1997, native prairie grasses were seeded in field plots at the University of Minnesota, St. Paul. Seeding was done ten times during each growing season, at two to four week intervals. On each seeding date, four monocultures and two mixes were broadcast, in three replications. Species included:

1. *Schizachyrium scoparium* (little bluestem)
2. *Bouteloua curtipendula* (sideoats grama)
3. *Elymus canadensis* (Canada wildrye)
4. *Bromus kalmii* (Kalm's brome)
5. Warm-season mix of the above grasses (81.25% warm-season grasses, 18.75% cool-season grasses, Table 2-3)
6. Cool-season mix of the above grasses (50.00% warm-season grasses, 50% cool-season grasses, Table 2-3)

In addition, in 1997, two modified Mn/DOT mixes were seeded on four dates. These mixes were variations of Mn/DOT Mix 15A and contained no forbs or cover crops. One was a standard mix weighted towards warm-season grasses. The second mix included the same species but had a higher percentage of cool-season grasses (Table 2-4).

1.5 Organization of Report

Chapter 1 of this report provides a brief overview of the problem and the objectives for the research. Chapter 2 explains the experiment's design and methods. Chapter 3 presents the results. Chapter 4 discusses some of the environmental factors causing the results and the experimental parameters that limit application of the results. And Chapter 5 presents conclusions and recommendations.

CHAPTER 2

EXPERIMENTAL DESIGN AND METHODS

2.1 Location and Dates

This research was conducted in cultivated fields at the University of Minnesota, St. Paul. Soil at this site is Waukegan silt loam, with high fertility and pH 6.6. Two experiments were done. In Number 1, the main experiment, four species and two mixes were planted in 1996 and in 1997. Number 2, the Mn/DOT experiment, tested two Mn/DOT seed mixes planted in 1997. Table 2-1 summarizes the two experiments.

Table 2-1. Summary of experiments.

Experiment	Year of Plantings	Data Collected	No. of Plantings	Monoculture or Mix?	No. of Species	No. of Mixes
1 - Main	1996	Fall 1996 & July 1997	10	Both	4	2
	1997	Fall 1997 & July 1998	10	Both	4	2
2 - Mn/DOT	1997	Fall 1997 & July 1998	4	Mix only	7	2

2.2 Experiment Design and Treatments

The experiment used a split-plot design with three replications to investigate seeding date (main-plot effect) and species or mix (subplot effect). The 1996 and 1997 plantings were on adjacent fields. Each subplot was 3.7 m by 4.0 m (12 ft by 13 ft). Figure 2-1 provides a diagram of the experiment design.

For Experiment 1, ten seedings were done each growing season, at two to four week intervals (see Table 2-2). The Mn/DOT mixes were planted on four dates at approximately four-week intervals from June through September.

Table 2-2. Planting dates for Experiments 1 and 2.

Experiment	Year planted	1	2	3	4	5	6	7	8	9	10
1- Main	1996	5/22	6/13	7/12	7/30	8/9	8/19	8/29	9/9	9/23	10/21
1 - Main	1997	5/22	6/13	7/15	7/30	8/8	8/19	8/29	9/10	9/23	10/17
2 - Mn/DOT	1997	--	6/13	7/15	--	8/8	--	--	--	9/23	--

Figure 2.1. Design of experiment. 1996 and 1997 plantings were in adjacent fields.

MN/DOT PLOTS

REP 3

1	3	4	2
B	B	A	B
A	A	B	A

REP 2

1	2	3	4
B	A	A	A
A	B	B	B

REP 1

4	2	1	3
A	A	B	B
B	B	A	A

1997 PLOTS

REP 1

7	2	3	5	1	4	6
4	1	2	3	4	5	6
9	5	4	1	2	3	6
2	1	5	6	2	4	3
5	5	3	2	4	1	6
3	5	1	4	6	2	3
1	4	3	5	2	1	6
10	5	1	3	6	2	4
8	1	4	5	6	2	3
6	4	3	1	2	5	6

REP 2

8	5	6	1	2	3	4
2	4	1	6	2	3	5
6	5	2	4	3	6	1
1	1	4	6	2	3	5
10	1	6	4	2	5	3
7	2	3	4	1	6	5
9	1	6	5	4	3	2
5	5	1	6	2	4	3
4	2	3	6	4	1	5
3	2	1	6	5	3	4

REP 3

8	5	1	6	3	2	4
6	6	4	3	5	1	2
3	3	1	6	5	4	2
4	2	4	6	3	1	5
9	5	4	1	2	3	6
1	2	3	6	5	4	1
10	3	6	2	4	5	1
5	1	4	2	6	5	3
7	3	1	6	5	4	2
2	5	1	4	2	6	3

1996 PLOTS

REP 1

4	1	6	4	3	5	2
10	2	4	3	1	6	5
5	5	1	6	4	3	2
9	2	3	1	4	6	5
2	5	2	1	6	4	3
7	5	6	4	3	1	2
1	3	4	5	6	2	1
8	1	6	3	2	5	4
3	3	1	5	2	4	6
6	3	6	2	5	4	1

REP 2

8	2	1	3	6	4	5
1	6	4	1	2	5	3
2	6	4	3	1	5	2
7	1	4	3	5	2	6
3	2	3	5	6	4	1
5	4	1	5	6	2	3
4	5	1	2	4	6	3
6	6	5	1	4	2	3
9	5	2	3	1	4	6
10	5	3	1	4	2	6

REP 3

9	4	1	2	3	5	6
7	6	3	5	4	1	2
3	3	6	4	2	1	5
6	2	3	4	1	5	6
10	4	2	6	3	5	1
2	5	3	6	2	4	1
5	3	6	4	5	2	1
8	5	2	1	4	3	6
4	4	2	6	5	1	3
1	1	3	4	6	5	2

MN/DOT Dates & Mixes
- **1**=June 13
- **2**=July 15
- **3**=Aug 8
- **4**=Sept 23
- A=Mix 15A
- B=Mix 15B

Main Plot Mixes
- 1=little bluestem
- 2=sideoats grama
- 3=Kalm's brome
- 4=Canada wildrye
- 5=Mix 1
- 6=Mix 2

1996 Seeding Dates

1=May 22	**6**=Aug 19
2= June 13	**7**=Aug 29
3=July 12	**8**=Sep 9
4=July 30	**9**=Sep 23
5=Aug 9	**10**=Oct 21

1997 Seeding Dates

1=May 22	**6**=Aug 19
2= June 13	**7**=Aug 29
3=July 15	**8**=Sep 10
4=July 30	**9**=Sep 23
5=Aug 8	**10**=Oct 17

Experiment 1 investigated four prairie grasses in monoculture and two mixes. *Schizachyrium scoparium* and *Bouteloua curtipendula* are warm-season grasses and grow most efficiently at warm temperatures encountered in mid to late summer. *Elymus canadensis* and *Bromus kalmii* are cool-season grasses with most efficient shoot growth at the cooler temperatures seen early and late in the growing season. They flower and produce seeds by early summer and are generally dormant during the hottest mid-summer weeks. The four species studied in monoculture were also combined in two different mixes (see Table 2-3). In a typical prairie mix the ratio of warm-season grasses to cool-season grasses is often approximately 80% to 20% [9]. Mix A in the experiment was a "warm-season" mix, with most of its bulk weight (81.25%) from warm-season grasses. A "cool-season" mix, Mix B, was developed by increasing the cool-season species to 50% of the mix by weight.

Table 2-3. Species and mixes tested in Experiment 1.

Botanical name	Common name	Monocultures	Mix A - warm-season	Mix B - cool-season
Schizachyrium scoparium	little bluestem	100%	50.00%	25.00%
Bouteloua curtipendula	sideoats grama	100%	31.25%	25.00%
Elymus canadensis	Canada wildrye	100%	6.25%	25.00%
Bromus kalmii	Kalm's brome	100%	12.50%	25.00%

Percentage indicates the percentage of bulk seed, by weight.

Experiment 2 tested two mixes and no monocultures. A warm-season mix similar to Mn/DOT's Mix 15A was adapted for the experiment. And a cool-season variation of this mix, Mix 15B, was developed (see Table 2-4). These mixes contained no forbs or cover crops.

Table 2-4. Mixes tested in Experiment 2 -- Mn/DOT Plots.

Botanical Name	Common Name	Mix 15A warm-season	Mix 15B cool-season
Andropogon gerardii	big bluestem	21.33%	11.90%
Sorghastrum nutans	Indian grass	17.70%	10.44%
Bouteloua curtipendula	sideoats grama	18.37%	10.83%
Schizachyrium scoparium	little bluestem	12.29%	7.01%
Panicum virgatum	switch grass	4.71%	3.01%
Elymus canadensis	Canada wildrye	6.35%	28.24%
Elymus trachycaulum	slender wheatgrass	4.17%	18.72%
	Weed seed	0.06%	0.04%
	Inert, etc.	15.03%	9.80%

Percentage indicates the percentage of pure live seed, by weight.

2.3 Seed and Seeding Rate

Prairie Restoration, Inc. of Princeton, MN, donated seed for Experiment 1. Mn/DOT supplied seed for Experiment 2 (purchased from Prairie Restoration, Inc.). Seed was received in April 1996 and April 1997 and placed in a seed storage room at approximately 7.0 °C (44.6 °F). In 1996, seeding rate was 15.7 kg/ha bulk seed (14.0 lbs/acre). For the 1997 planting, these rates were converted to pure live seed (PLS) rates so the 1996 and 1997 plantings could be compared more accurately. Appendix A provides details on the conversion to PLS seeding rate.

2.4 Preparing, Planting, and Maintaining Plots

In May of each planting year, the field was tilled and dragged. Plots were staked and strips of *Lolium perenne* (perennial ryegrass) were seeded to separate the three replications and to separate seeding date treatments. The turf strips were mowed regularly. Weeds that grew before plots were planted were kept short by periodic mowing.

The goal for bed preparation was a tilled, weed-free plot, with friable soil. Since there were few perennial weeds in the experiment fields, tilling was adequate preparation. However, a few plots were subjected to an application of herbicide (see Appendix B for details). On each planting date the process was:

1. Till the plots with tiller pulled by small tractor (two to four passes).
2. Pack the plots with a manual drum roller to create a firm seedbed.
3. Rake the soil to loosen the packed surface.
4. Manually broadcast the seed.
5. Rake the seed into the soil.
6. Pack the plots with a manual drum roller to prevent seed from washing away.

The scale and design of the experiment dictated the above planting methods. They are labor-intensive practices often used on small sites of less than 1 ha. This method differs from many Mn/DOT restorations in the following ways: 1) seed was broadcast by hand, not drilled by machine, 2) no cover crop was planted, and 3) no mulch was used.

Because planting was done on ten different days throughout the growing season, there were several uncontrollable variables in bed preparation and planting. The same equipment was not available for all planting dates. Tilling depth varied from approximately 8 cm to 15 cm. Soil moisture was different each date and tilling at different moistures resulted in different soil structure. Weed cover increased as the season progressed. Different combinations of weed cover and soil moisture meant different number of passes with the tiller. Plots were tilled two, three, or four times.

The plots were maintained by mowing four or five times each year. Equipment used included a tractor with flail mower and a riding mower with the deck raised.

2.5 Collecting Data

Data were collected in September or October of the planting year (first-season establishment), and in the following July (second-season establishment). To collect data a one-meter square frame was placed randomly in each plot and the number of target seedlings/m^2 was counted. Weed seedlings were not tallied.

Identification of grass seedlings is difficult and taxonomists caution that 100% accuracy is impossible [10]. Accuracy in this experiment was very high because the main experiment contained only four species and all were very distinct from each other. In addition, they were distinguishable from most of the weed species encountered. In the Mn/DOT plots, identification was more difficult so plots were clipped and, when necessary, a dissecting scope was used for identification.

Data on precipitation, air temperature, and soil temperature were obtained from the University of Minnesota Weather Station, approximately 100 yards from the experiment plots.

2.6 Analyzing Data

Analysis of variance (ANOVA) for a split-plot design was conducted using SAS software [11]. To stabilize variances data was transformed by the formula: Square root [y] + Square root [y+1]. Each planting year was analyzed individually, resulting in six ANOVA's:

1. 1996 Planting -- 1st season establishment
2. 1996 Planting -- 2nd season establishment
3. 1997 Planting -- 1st season establishment
4. 1997 Planting -- 2st season establishment
5. Mn/DOT Plots, 1997 -- 1st season establishment
6. Mn/DOT Plots, 1997 -- 2st season establishment

Each ANOVA tested the simple effects -- seeding date and mix -- as well as the interactive effect, mix $\subseteq$ seeding date. The error term for seeding date was block $\subseteq$ seeding date. Tukey multiple comparison tests were done on seeding date and on mix for each ANOVA. The mix $\subseteq$ seeding date interaction was explored by graphing seeding date for each individual species or mix.

CHAPTER 3
ANALYSIS OF RESULTS

Establishment patterns differed greatly for the 1996 and 1997 plantings. Overall, the best seeding dates for 1996 were May through mid-July, and the best seeding dates for 1997 were mid-July through early September. However, not all species established well during these periods. The species or mix with the best overall performance was *Elymus canadensis*, followed by the cool-season mixes. To investigate these results in detail six questions are addressed:

1. What were the results of the statistical analysis?
2. What were precipitation and temperature patterns during the study?
3. What was the best time to seed each species or mix?
4. Did dormant seedings establish as well as other seedings?
5. How did establishment compare for warm-season mixes vs. cool-season mixes?
6. Did species composition of the mixes change over time?

3.1 What were the results of the statistical analysis?

Seeding date, mix, and mix $\subseteq$ seeding date interaction significantly affected stand establishment ($p < .05$, Table 3-1). The only exception to this was first-season establishment of the Mn/DOT mixes.

The overall effect of seeding date (all species and mixes combined) is shown by the Tukey multiple comparison tests (Table 3-2). For the 1996 plantings, best first-season establishment occurred from May through August plantings. By the following season, the May through mid-July plantings had distinguished themselves as best. Results differed for the 1997 plantings with best first and second-season establishment occurring from late July through early September seedings.

Tukey tests for the overall effect of mix (all seeding dates combined) are summarized in Table 3-3. In 1996, *Elymus canadensis* was the most successful species, followed by the cool-season mix. In 1997, *E. canadensis, Bromus kalmii* and the cool-season mix performed better than *Schizachyrium scoparium, Bouteloua curtipendula*, and the warm-season mix.

The interaction effect, mix $\subseteq$ seeding date, is considered in Section 3.3.

Table 3-1. Results of split-plot analysis of variance showing effects of seeding date and mix treatments on stand establishment of prairie grasses.

No.	Experiment	Data for	Year	R^2	Effects	F Ratio	*p*
1	Main	1st season establishment	1996	.94	mix	168.64	.0001
					seeddate	19.42	.0001
					mix $\subseteq$ seeddate	10.49	.0001
2	Main	2nd season establishment	1996	.92	mix	59.69	.0001
					seeddate	24.55	.0001
					mix $\subseteq$ seeddate	5.74	.0001
3	Main	1st season establishment	1997	.96	mix	18.94	.0001
					seeddate	43.62	.0001
					mix $\subseteq$ seeddate	3.45	.0001
4	Main	2nd season establishment	1996	.92	mix	96.92	.0001
					seeddate	12.32	.0001
					mix $\subseteq$ seeddate	3.58	.0001
5	Mn/DOT	1st season establishment	1997	.98	mix	3.55	.0963
					seeddate	287.26	.0001
					mix $\subseteq$ seeddate	1.54	.2768
6	Mn/DOT	2nd season establishment	1997	.96	mix	47.86	.0001
					seeddate	18.86	.0019
					mix $\subseteq$ seeddate	5.73	.0216

Table 3-2. Effects of seeding date treatments on stand establishment of prairie grasses.

Year	Data from	5/22	6/13	7/12	7/30	8/9	8/19	8/29	9/9	9/23	10/21
1996	1st season	8.8ab	10.4a	11.0a	10.1ab	8.3abc	9.3ab	7.8abc	6.8bc	4.9c	1.0d
1996	2nd season	5.6ab	7.2a	4.2bc	3.2cd	2.0d	1.9d	1.9d	1.9d	1.5d	1.4d
1997	1st season	1.9e	2.4de	8.0cd	16.3a	20.1a	15.7ab	18.3a	10.2bc	1.0e	1.0e
1997	2nd season	2.0b	2.1b	6.5ab	10.5a	11.5a	9.8a	9.8a	9.8a	7.0ab	4.6b
1997	Mn/DOT 1st season	--	3.2c	15.7b	--	21.9a	--	--	--	1.0c	--
1997	Mn/DOT 2nd season	--	5.9b	12.2a	--	14.9a	--	--	--	11.2a	--

Values represent the mean number of seedlings/m^2 transformed by (SQRT[y] + SQRT[y+1]). Within a given row, values with the same letter do not differ significantly ($p < 0.05$).

Table 3-3. Effects of species or mix treatments on stand establishment of prairie grasses.

Year Planted	Data from	Schizachy-rium	Bouteloua	Bromus	Elymus	Warm Mix	Cool Mix
1996	1st season	4.8d	4.7d	3.6d	17.7a	6.6c	9.6b
1996	2nd season	1.9d	2.1cd	1.8d	5.9a	2.8c	4.0b
1997	1st season	7.8cd	7.3d	10.4ab	11.8a	9.2bc	10.5ab
1997	2nd season	2.1d	2.9d	10.0b	12.2a	6.9c	10.1b
1997	Mn/DOT 1st season	--	--	--	--	9.7a	11.2a
1997	Mn/DOT 2nd season	--	--	--	--	9.2b	13.0a

Values represent the mean number of seedlings/m^2 transformed by (SQRT[y] + SQRT[y+1]). Within a given row, values followed by the same letter do not differ significantly ($p < 0.05$).

3.2 What were precipitation and temperature patterns during the study?

Rainfall differed greatly for 1996 and 1997, providing the opportunity to observe establishment during conditions of drought and abundant moisture. Figure 3-1 graphs precipitation for all three years of the study and for the 30-year norm. In general, 1996 had normal spring precipitation followed by summer drought. 1997, on the other hand, saw spring drought and above average summer rainfall. In 1998, the plots received fairly normal April and May rainfall and above average June precipitation. Average monthly air and soil temperatures are shown in Figures 3-2 and 3-3.

Figure 3-1. Monthly precipitation. Data for 1996, 1997, and 1998 were collected at University of Minnesota weather station. Data for 30-year norm are from Minneapolis-St. Paul International Airport.

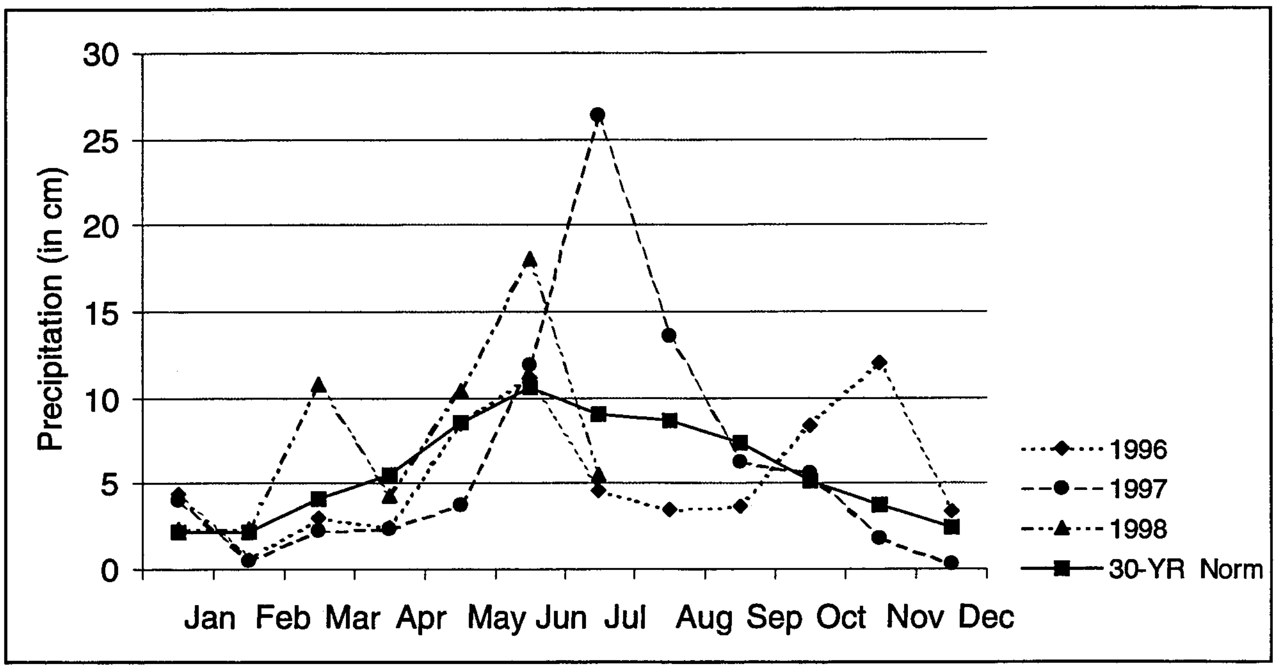


Figure 3.2. Mean monthly air temperature. Data is from University of Minnesota Weather Station, which is located approximately 100 yards from the experiment site.

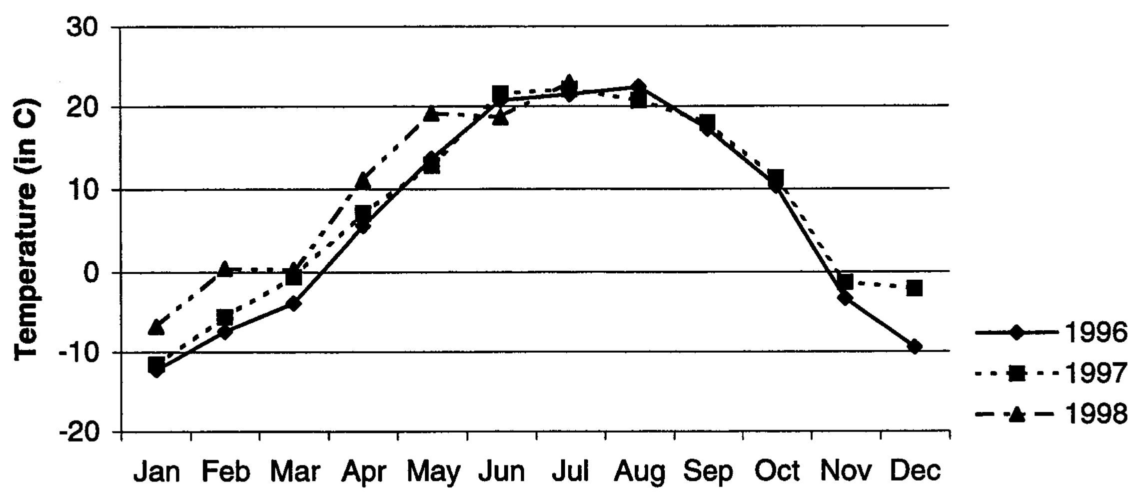
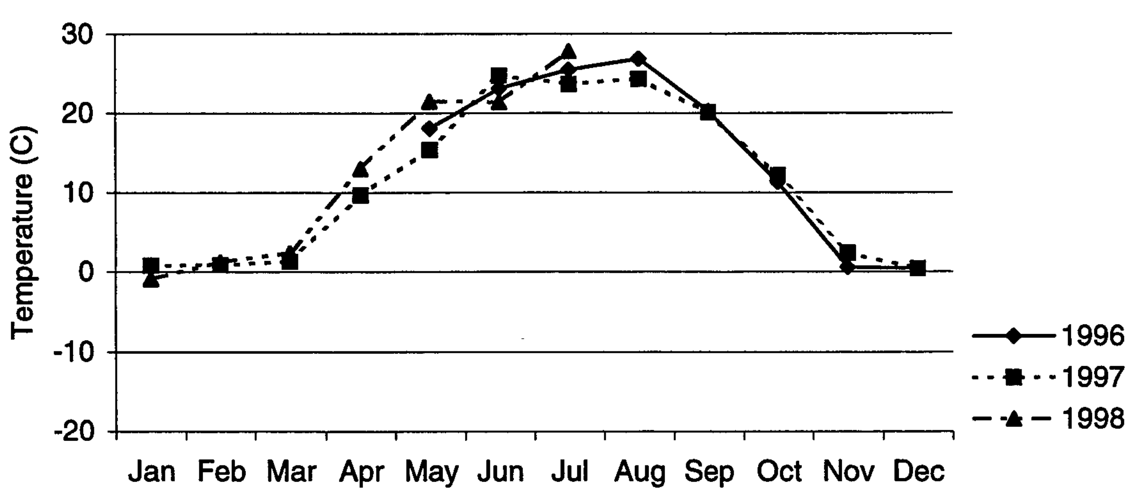


Figure 3.3. Mean monthly soil temperature at 5 cm below soil surface. Data is from the University of Minnesota Weather Station, which is located approximately 100 yards from the experiment site.



3.3 What was the best time to seed each species or mix?

As seen earlier, there was a significant mix ⊆ seeding date effect in this experiment. To understand this effect it is helpful to consider each species individually. Two establishment patterns emerged. The warm-season grasses established well if planted by early August and the cool-season grasses established well if planted by early September, or as dormant seedings.

3.3.1 Warm-season grasses: S. scoparium and B. curtipendula

Figure 3-4 presents establishment results for *S. scoparium*. In 1996, the best planting dates for this species were May, June and mid-July. Winter survival was poor for all dates except the June planting. Results were quite different in 1997, with August plantings giving the best first-season establishment, and the August 8th planting providing best second-year establishment.

Establishment of *B. curtipendula* was fairly similar to that of *S. scoparium*, as shown in Figure 3-5. For the 1996 plantings, May, June and July plantings had the best first-season establishment, with the June seeding showing best survival the second season. In 1997, on the other hand, July and August plantings were best, with the late July and early August plantings having best second-season establishment.

The establishment pattern for these two warm-season grasses seems to follow rainfall for the planting years, with poor establishment during the summer drought of 1996 and the spring drought of 1997.

3.3.2 Cool-season grasses: E. canadensis and B. kalmii

Establishment results for *E. canadensis* are shown in Figure 3-6. In 1996, first-season establishment was excellent for all plantings (except the dormant seedings). It is important to note, however, *E. canadensis* seedlings that established from late July through September plantings did not germinate until rainfall events in late September 1996. Thus, these seedlings were only a few weeks old entering the cold season. Most did not survive the winter. By the second season, May, June, and early July had distinguished themselves as the best seeding times for 1996. For the 1997 plantings, best first and second-establishment of *E. canadensis* came from July through early September seedings. The September and October dormant plantings also did well.

Figure 3-7 shows establishment for *B. kalmii*. Poor establishment from the 1996 plantings is attributed to seed with low viability. (Seeds from the same lot had very poor germination when grown in a greenhouse.) For 1997 plantings, establishment patterns were similar to *E. canadensis* with good second-season establishment from July through early September plantings. The September dormant seeding was relatively successful but the October dormant seeding was not.

As with the warm-season grasses, establishment patterns for *E. canadensis* and *B. kalmii* seem to follow rainfall for the planting year.

3.3.3 Mixes

Establishment patterns for the mixes followed those of the monocultures, with poor establishment from plantings done during drought. All mixes tolerated later plantings better than the warm-season monocultures. However, if planted after mid-August the mixes had predominantly cool-season grasses. Best seeding dates for each mix are shown in Figures 3-8, 3-9, 3-10, and 3-11. For a comparison of warm-season and cool-season mixes, see Section 3.5.

3.4 Did dormant seedings establish as well as other seedings?

Establishment results for the dormant seedings were indicated in Figures 3-4 through 3-11 above (Section 3.3). For the 1996 plantings, no dormant seedings established well. *S. scoparium* and *B. curtipendula* never established well from dormant seedings. *E. canadensis* had good establishment from both the September and October 1997 dormant plantings. And *B. kalmii* performed well in the September 1997 dormant seeding, but not the October seeding.

3.5 How did establishment compare for warm-season vs. cool-season mixes?

Analyses of variance showed that establishment almost always differed significantly for cool-season mixes and for warm-season mixes (Table 3-3). However, those analyses combined all seeding dates. If each seeding date is evaluated separately, the cool-season mixes outperform the warm-season mixes, except on a few dates (Figures 3-12, 3-13). Tukey multiple comparison tests for the Mn/DOT experiment indicated that, for each seeding date, the cool-season mix had better establishment or there was no significant difference between the mixes.

3.6 Did species composition of the mixes change over time?

For both the warm-season and cool-season mixes there was a shift in species percentage over time. Table 3-4 shows that from the first season to the second season there was a greater loss of the warm-season grasses than of the cool-season grasses in the mixes. By the second-season, cool-season grasses dominated all the mixes. However, there is no reason to assume that this trend will continue as the planting mature.

Table 3-4. Change in species composition for the mixes. Values indicate the percentage of seedlings present in the mix for each species. For example, for the 1996 planting, at the end of the first season 33.6% of the seedlings present in Mix A were *S. scoparium*. By the end of the 2nd season *S. scoparium* decreased to 18.5% of the total seedlings present. (Values are based on mean number seedlings/m^2 for all ten plantings done in a year.)

Experiment 1 - Main Mixes		**Mix A - Warm**		**Mix B - Cool**	
Planting Year	Species	% of mix 1st season	% of mix 2nd season	% of mix 1st season	% of mix 2nd season
1996	*Schizachyrium scoparium*	33.6	18.5	7.9	2.2
	Bouteloua curtipendula	28.3	8.6	10.4	2.2
	Elymus canadensis	37.1	65.4	77.9	89.4
	Bromus kalmii	0.9	7.4	3.8	6.1
	Total	100.0	100.0	100.0	100.0
1997	*Schizachyrium scoparium*	51.7	1.9	19.4	0.4
	Bouteloua curtipendula	17.6	3.5	10.1	0.5
	Elymus canadensis	19.0	47.4	31.4	32.6
	Bromus kalmii	11.7	47.2	39.0	66.4
	Total	100.0	100.0	100.0	100.0

Experiment 2 - Mn/DOT Mixes		**Mix 15A - Warm**		**Mix 15B - Cool**	
Planting Year	Species	% of mix 1st season	% of mix 2nd season	% of mix 1st season	% of mix 2nd season
1997	*Andropogon gerardii*	3.8	24.3	2.7	3.8
	Sorghastrum nutans	6.9	3.9	1.2	0.5
	Bouteloua curtipendula	16.9	8.6	4.7	0.2
	Schizachyrium scoparium	28.3	3.6	12.0	0.5
	Panicum virgatum	28.1	0.4	11.4	0.0
	Elymus canadensis	1.7	11.4	9.9	18.5
	Agropyron trachycaulum	14.2	47.9	58.2	76.4
	Total	99.9	100.1	100.1	99.9

Figure 3.4. Establishment for *Schizachyrium scoparium.*

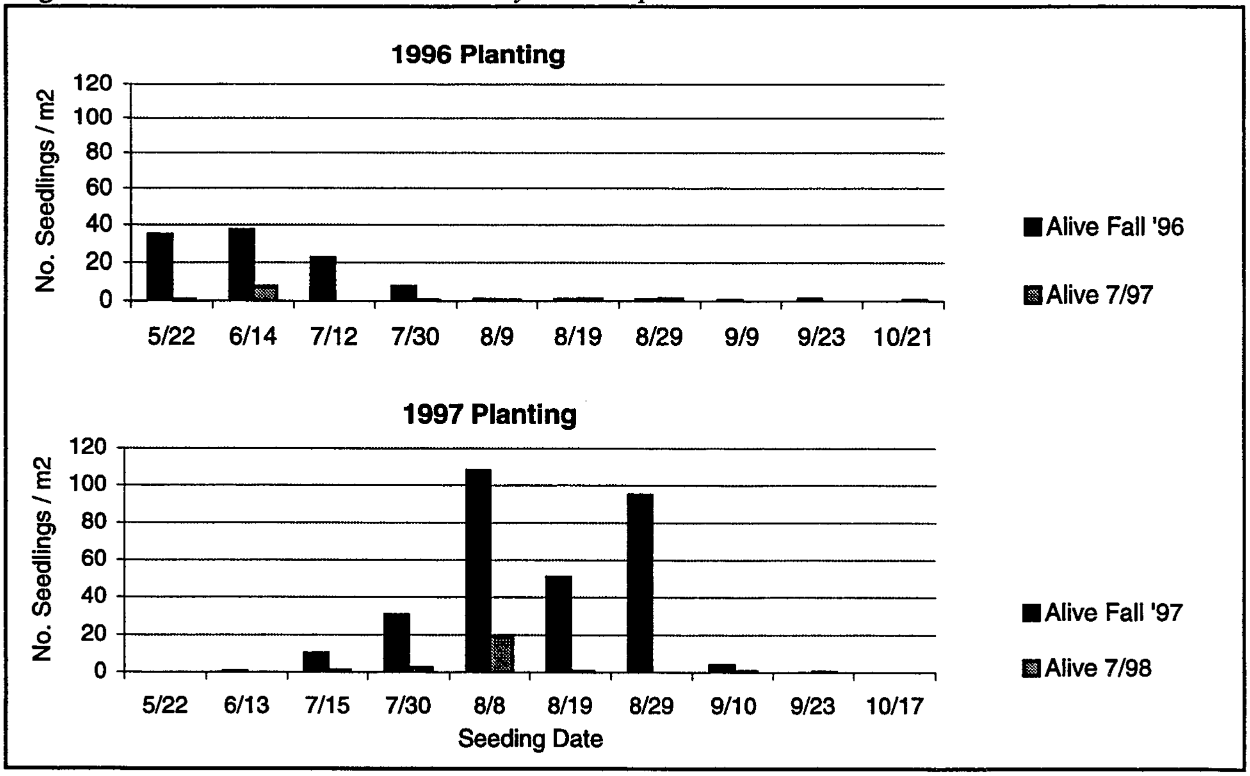


Figure 3.5. Establishment for *Bouteloua curtipendula* .

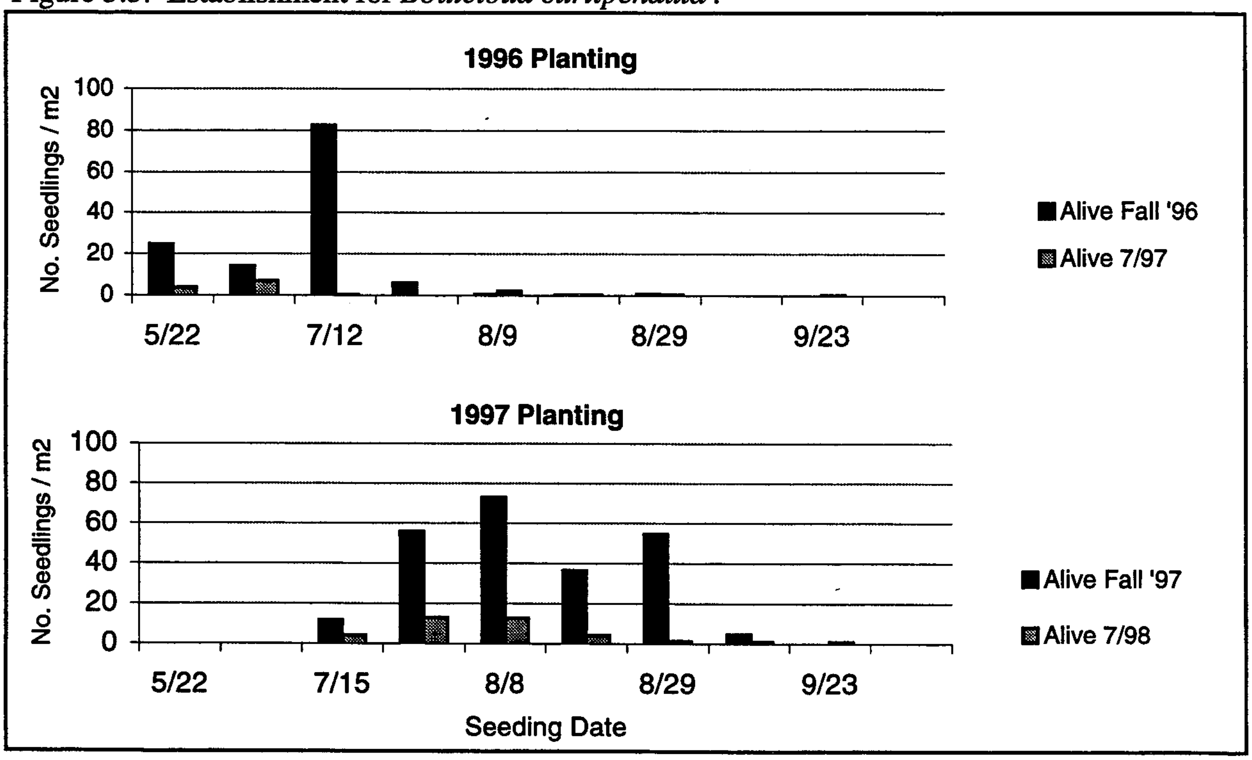


Figure 3.6. Establishment for *Elymus canadensis.*

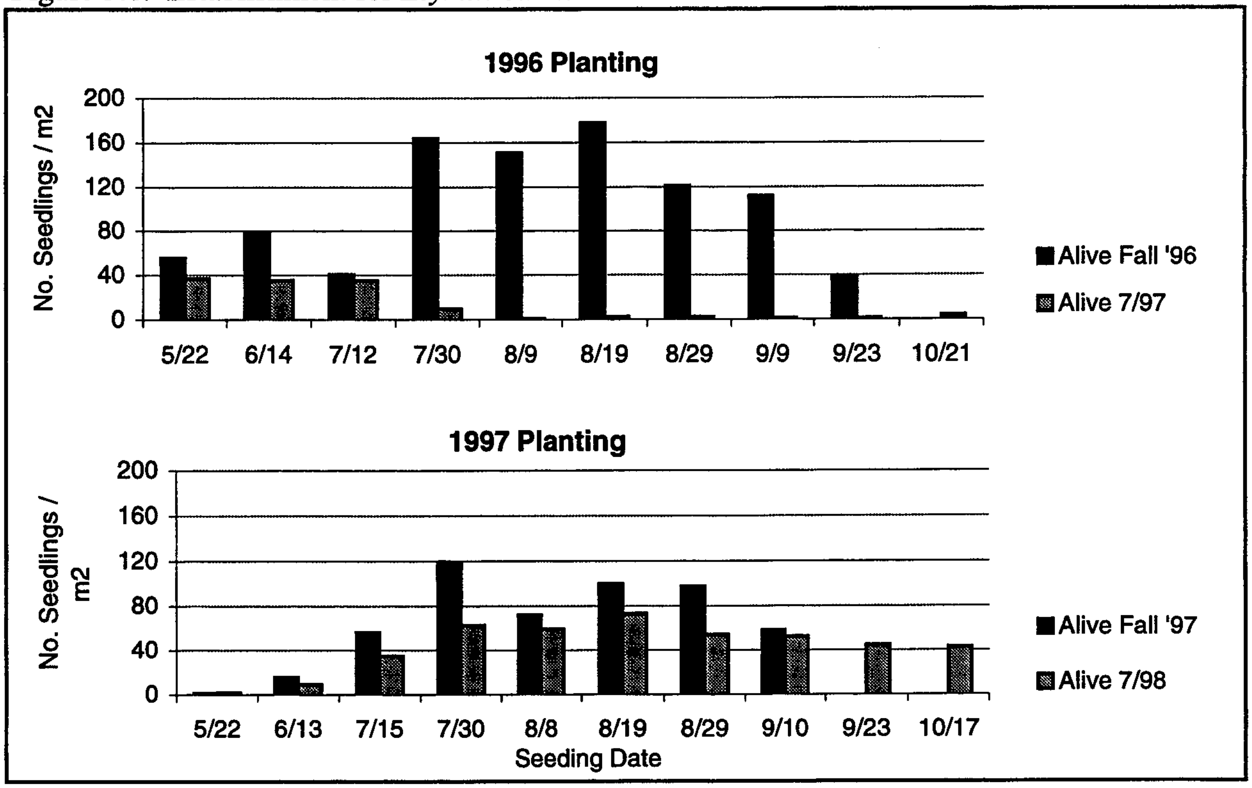


Figure 3.7. Establishment for *Bromus kalmii.* Note that scales differ on the two graphs.

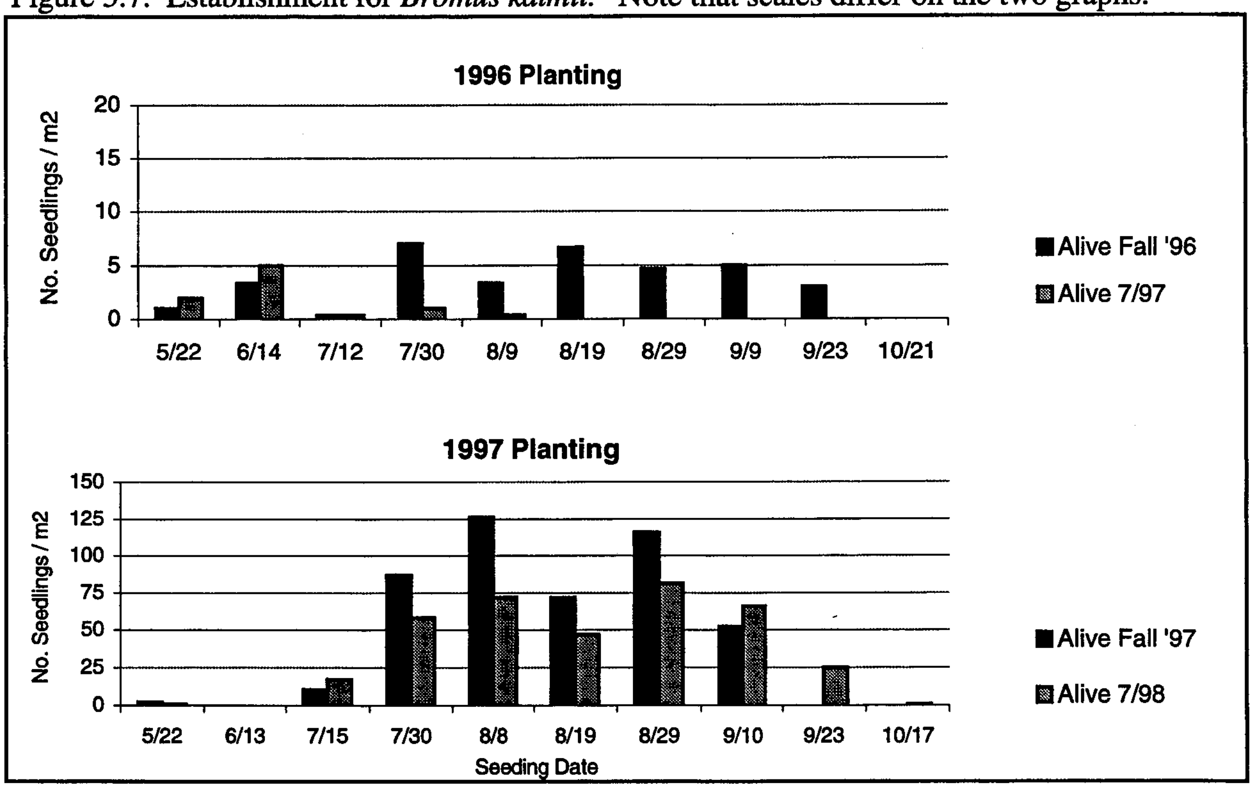


Figure 3.8. Establishment for main experiment Mix A (warm-season mix).

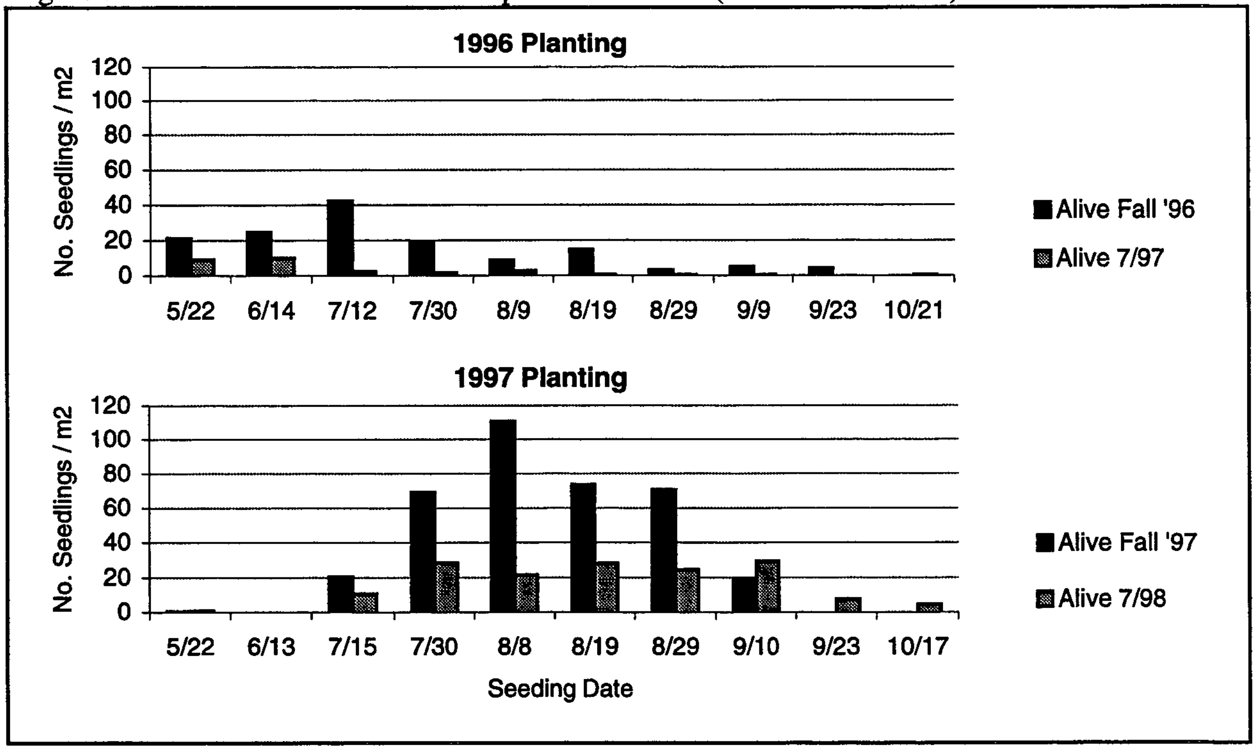


Figure 3.9. Establishment for main experiment Mix B (cool-season mix).

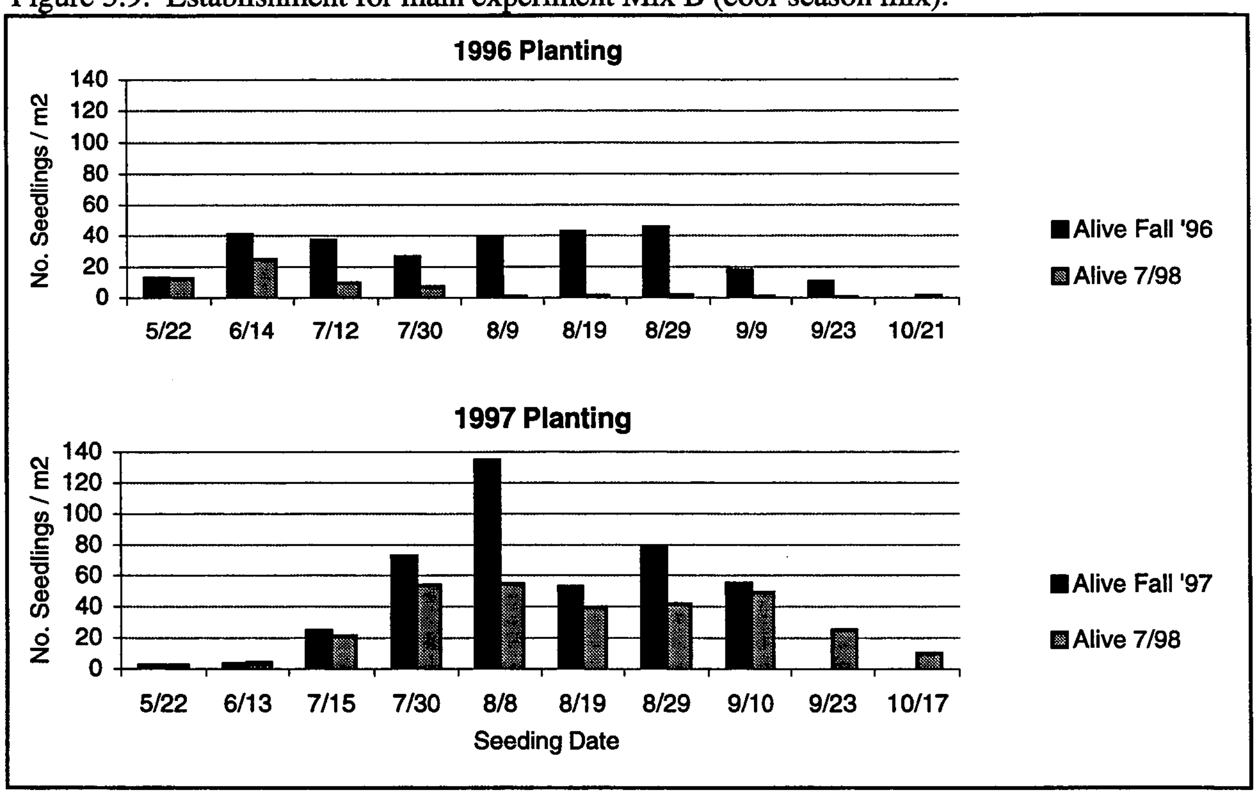


Figure 3.10. Establishment for MN/DOT Mix 15A (warm-season mix), planted 1997.

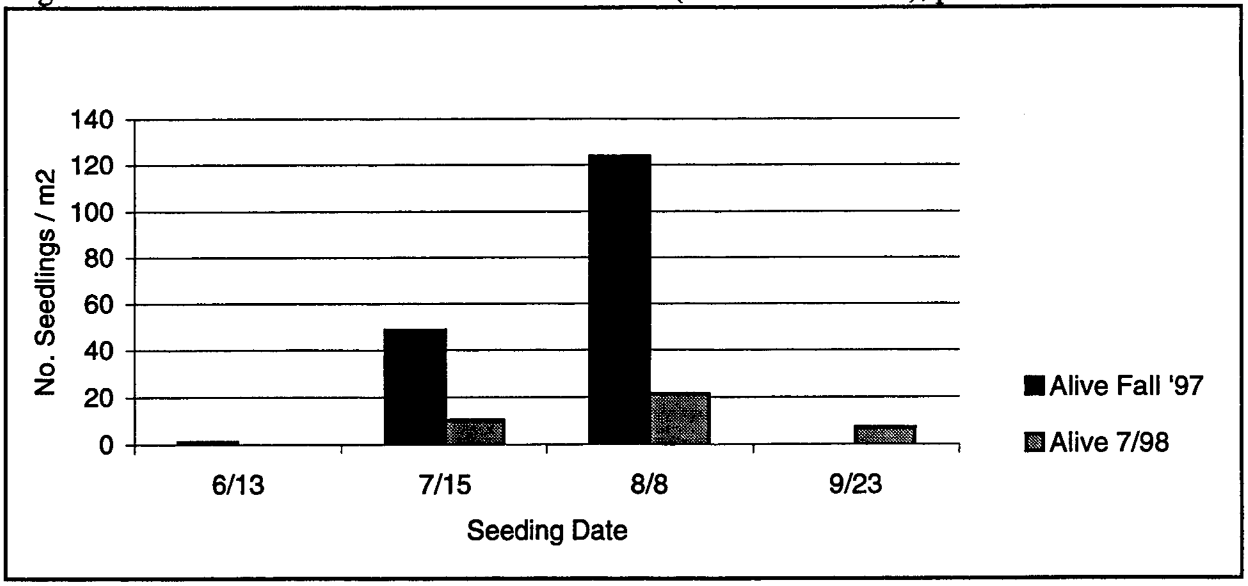


Figure 3.11. Establishment for MN/DOT Mix 15B (cool-season mix), planted 1997.

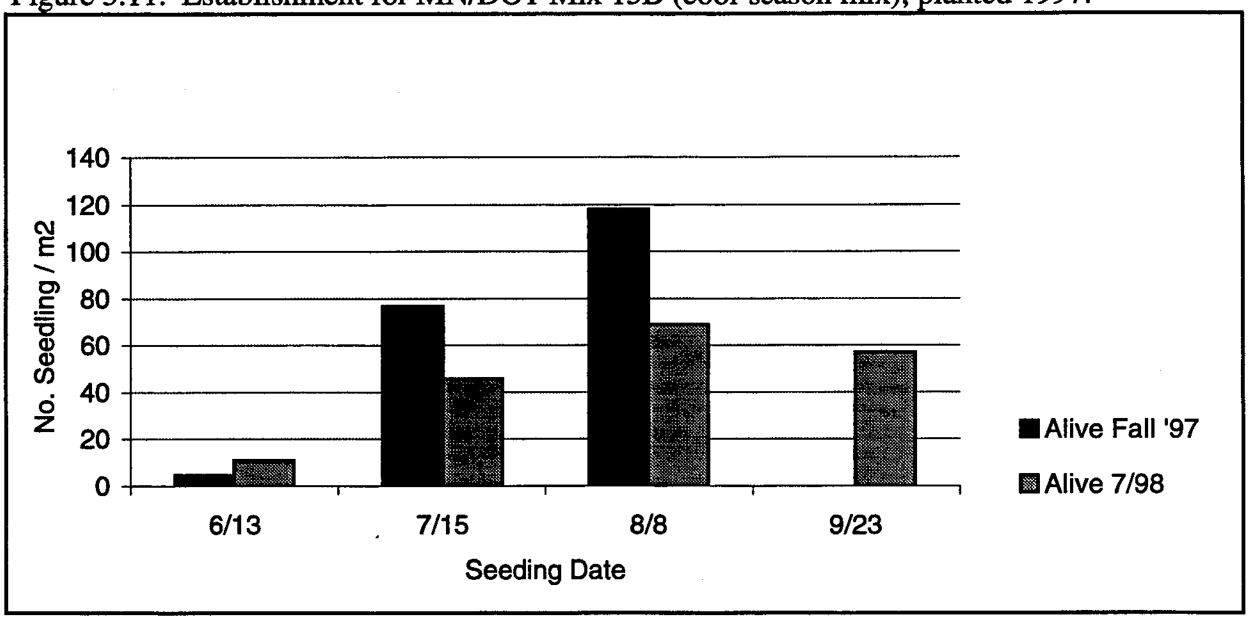


Figure 3-12. Comparison of establishment for Mix A (warm-season) and Mix B (cool-season). Only second-season establishment is shown.

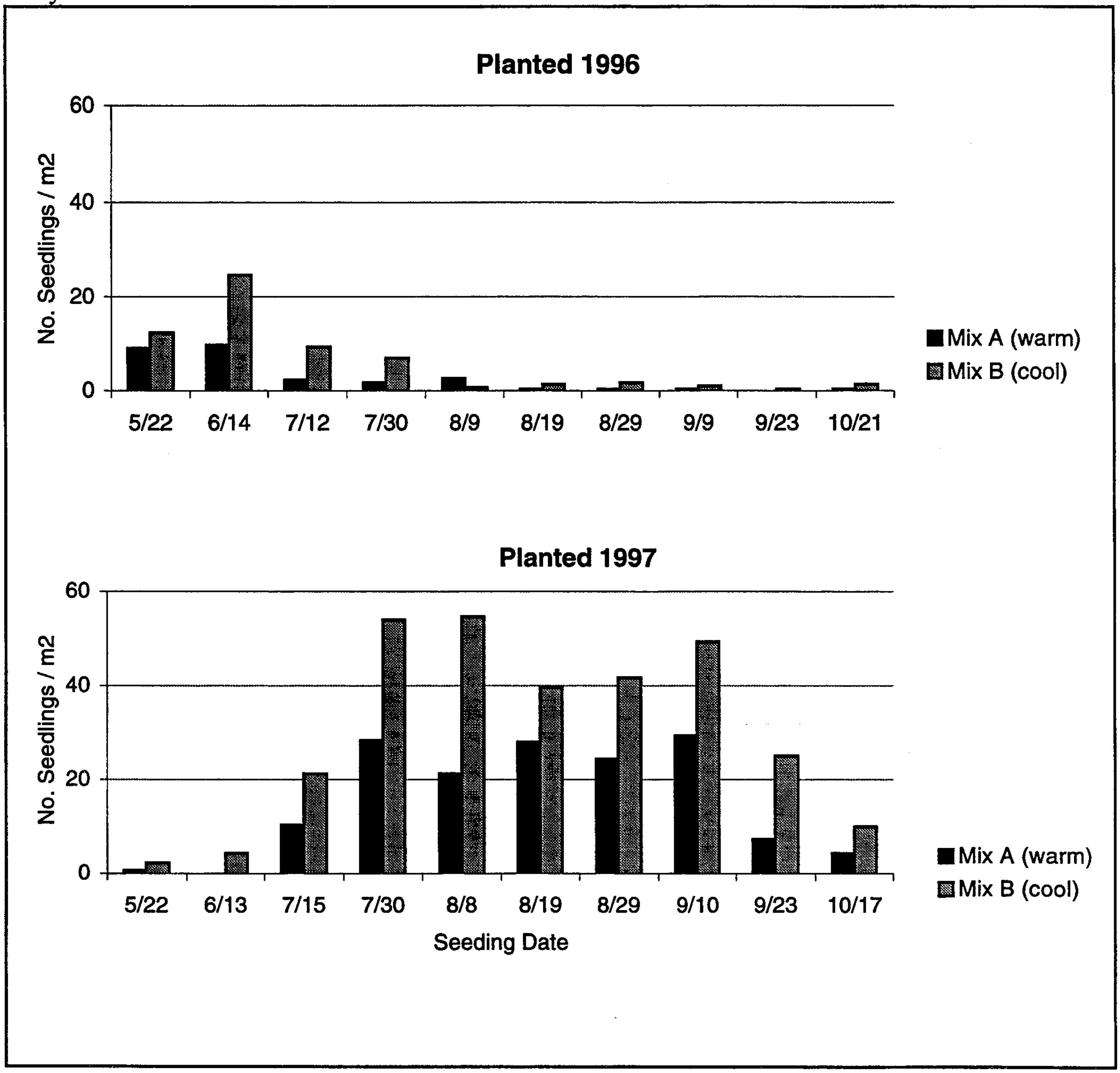
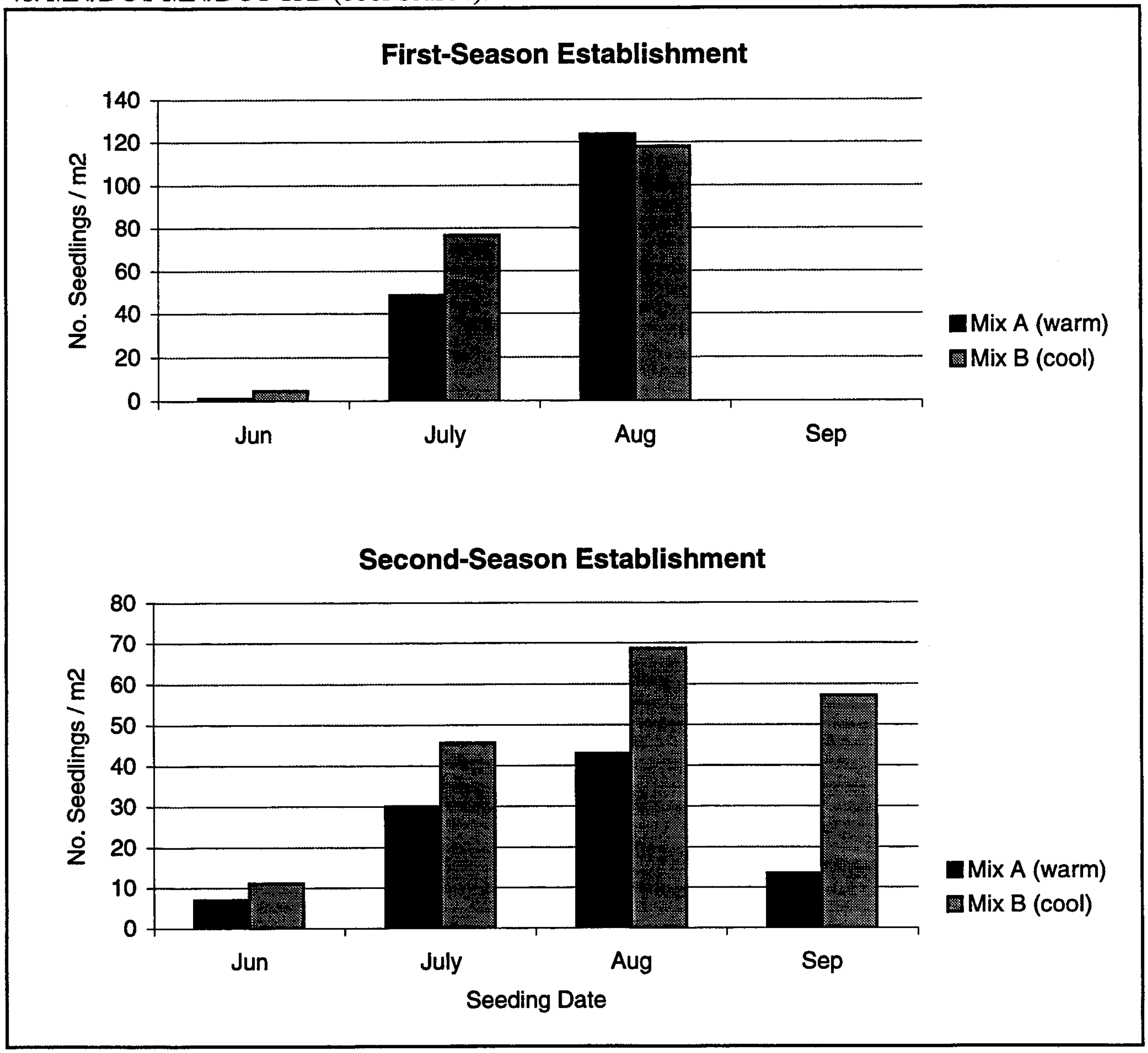


Figure 3.13. Comparison of establishment for MN/DOT Mix 15A (warm-season mix) vs. MN/DOT MN/DOT 15B (cool-season).



CHAPTER 4
DISCUSSION

It is important to consider the environmental factors that contributed to stand establishment, as well as the experimental factors that limit application of the results. This chapter addresses five questions:

1. Why were establishment patterns so different for the 1996 and 1997 plantings?
2. What are the experimental parameters that limit application of the results?
3. How should seeding dates be selected?
4. Should prairie grasses be planted as dormant seedings?
5. Should cool-season mixes be planted?

This chapter is not intended to provide a thorough discussion of the literature related to these questions. A more exhaustive review of the literature can be found in one of the authors' master's thesis (thesis by Gaynor, to be completed early 1999).

4.1 Why were establishment patterns so different for the 1996 and 1997 plantings?

One of the most notable results in this experiment was that establishment for the 1996 and 1997 plantings differed greatly. This is not surprising since weather patterns were so different the two years. Rainfall and temperature directly affect germination and growth of native seedlings. They also affect factors such as weed cover that can strongly influence establishment of native species. In addition, seed quality may have contributed to differences in the 1996 and 1997 plantings.

4.1.1 Rainfall

Moisture is often regarded as the most limiting factor in establishing grasses. But research is not conclusive on whether increasing moisture actually increases establishment [12,13]. Less debated is the fact that the pattern of rainfall is just as important as amount of rainfall. A study conducted on moisture requirements for *Bouteloua gracilis* (blue grama) helps explain the dynamics between moisture patterns and seedling establishment [14]. Researchers observed that *B. gracilis* germinated within one to two days of receiving moisture and each seedling produced a single root. In order to survive, a seedling had to develop adventitious roots before it was six weeks old. Two to four days of surface moisture were required for development of adventitious roots. It was found that this moisture had to occur some time between the second and sixth week after germination. Though this study looked at only one species, it demonstrates the importance of moisture patterns.

In the experiment there were three particularly striking patterns related to precipitation: 1) Plantings done during drought weeks had reduced establishment; 2) If seedlings had adequate growth early in the season, they could survive summer drought the first year; and 3) Seeds planted during drought but receiving good subsequent rainfall did not always establish well.

Patterns (1) and (2) were not unexpected. The third pattern, however, was somewhat surprising. In 1996, seeds planted during summer drought remained dormant and did not germinate. Late September rains triggered germination of summer-planted *Elymus canadensis,* but seedlings were too young to survive the winter. In 1997, plantings done during the drought of May and June had poor establishment, despite the fact that there was adequate summer rainfall. If the native seeds had remained dormant and not germinated, one would expect to see increased establishment the second season, but this did not occur. One explanation for this poor establishment is that seeds germinated in summer when it rained but the young native seedlings but were quickly outcompeted by weeds. Weed cover is discussed in Section 4.1.3.

4.1.2 Temperature

In the experiment, temperatures during the growing season were relatively normal and were sufficient for germination and growth of the species planted. For germination, cool-season grass species tend to have lower optimum germination temperatures than warm-season grasses [15]. When mature, cool-season grasses generally have optimal growth at cool temperatures and go dormant during the hottest weeks of summer. Warm-season grasses, on the other hand, grow most efficiently at high temperatures. These relationships between temperature, germination, and growth are broad generalizations and it is essential to investigate each species individually. *Schizachyrium scoparium*, for example, germinates at a wide range of temperatures, temperatures that overlap with preferences for some cool-season grasses [16]. It is also important to note that, for a given species, optimal temperature may differ for percentage of germination and speed of germination. Quick germination can offer competitive advantages.

In a field setting, temperature cannot be isolated. It acts in concert with environmental factors such as moisture. This was clearly demonstrated in the experiment. In 1996, mid-summer temperatures might have favored germination and growth of warm-season grasses, but moisture was insufficient for germination. Best establishment that year was produced by spring and early summer plantings, when temperatures were lower but moisture requirements were met. In addition, temperature effects on germination often depend on seed and dormancy issues such as ecotype, age of seed, year of harvest, and storage conditions.

An ability to survive low winter temperatures is also essential for good stand establishment of native grasses in the Upper Midwest. Research has shown mature plants of *Bouteloua curtipendula* and *S. scoparium* can survive temperatures as low as -35 °C (-31 °F) and -27 °C (-17°F), respectively [17]. But little research has been done on winter kill of prairie seedlings. One study of *Agropyron spp.* (wheatgrass) suggested that seedlings needed at least three leaves prior to winter dormancy in order to survive winter and grow well the second season [18]. In our experiment, daily winter soil temperatures were generally near 0.0 °C during December, January, and February and were not cause for concern.

During the winter of 1996-1997 there was a great loss of turf grass throughout the Twin Cities region (Donald White, personal communication, 1997). It is unclear, however, whether that loss was primarily due to a build-up of ice causing crown hydration or to a drop in April temperatures. During the first week of April, average daily soil temperatures rose to 12.1 °C (53.8 °F). Soil temperature then dropped abruptly to below 0.0 °C (32.0 °F) for two days before beginning to rise. Cool-season grasses that had emerged in the experiment plots and started growing during the week of warm temperatures would likely have been killed.

4.1.3 Weed cover

In this experiment, vigorous weed growth often coincided with good establishment of native grasses. Data were not collected on weeds, but casual observation in 1996 found most vigorous weed growth was in May, June, and early July, a time of normal rainfall. This was also the best time for growth of the native seedlings. In 1997, weed growth was heaviest during the weeks of summer rain, from late June into August. July and August of that year were times of best native grass establishment. Despite tremendous weed competition, the native grasses were able to get a foothold.

It is generally believed that annual species such as *Setaria spp.* (foxtail), *Amaranthus spp.* (pigweed), and *Brassica spp.* (mustard) do not pose serious problems for prairie restorations, even if they are heavy the first year [19]. But perennial weeds such as *Phalaris arundinacea* (reed canary grass), *Bromus inermis* (smooth brome), *Centaurea maculosa* (spotted knapweed), *Coronilla varia* (crown vetch), and *Lotus corniculatus* (birdsfoot trefoil) are notoriously troublesome. In the experiment, the fields planted in 1996 and 1997 were side-by-side. The 1996 planting had primarily annual broadleaf weeds, while the 1997 planting had a severe infestation of annual weedy grasses. The grass weeds seemed to cover more of the soil surface. *Digitaria sanguinalis* (crabgrass) was particularly aggressive in some of the 1997 plots. When the rains finally came in late June, temperatures were ideal for germination of this weed. Its sprawling habit seemed well adapted to choking out the slower growing prairie species. How morphological and allelopathic characteristics of specific of weeds affect establishment of native grasses is a question worthy of further study.

4.1.4 Seed quality

Seed quality and viability may have contributed to differences in the 1996 and 1997 plantings. Seed used in 1996 was harvested in 1995; seed for 1997 was harvested in 1996. To diminish the effect of harvest year, PLS rates were used (Appendix A). In the experiment all seed testing was handled by the seed producer. For future projects, it is recommended that the researcher conduct seed viability tests prior to planting.

4.2 What are the experimental parameters that limit application of the results?

This experiment records what happened over 2-1/2 years at one particular location. Before applying these results to other situations, it is important to clearly understand the parameters of the experiment.

4.2.1 Location

The experiment took place in St. Paul, Minnesota. It is impossible to know how far beyond St. Paul the results might extend. Though exact dates may differ, the patterns established are likely to apply to areas that have similar or more rainfall than St. Paul, and that have similar or cooler temperatures during the growing season.

4.2.2 Year

The experiment was conducted over a 2-1/2 year period. Weather patterns and establishment results were unique to these two years, but extremes of drought and moisture were experienced during this time period. Therefore, a wide spectrum of environmental conditions was studied.

4.2.3 Soil

The experiment was conducted on a silt loam soil with high fertility. Results probably would have differed on a sandier, less fertile soil. Rich soils are often associated with more severe weed problems [20] and this could reduce establishment. Heavy soils are usually more prone to heaving from freeze-thaw cycles and this could lead to poor winter survival of seedlings. It is also possible that seeds are more likely to rot in heavy soil than in sandy soil; poor winter survival of seeds would mean poor dormant seedings.

Soil moisture limits the species that are appropriate for a site. In this experiment, the only species that was questionable on the mesic site was *B. curtipendula*, which is generally restricted to dry and dry mesic prairies [21]. Nevertheless, *B. curtipendula* had slightly better winter survival than *S. scoparium*, which was better adapted to the site. *S. scoparium*, although often associated with dry sites, is found on dry, dry mesic, mesic, and wet mesic sites [21].

4.2.4 Sowing method

The most common methods for planting prairie seed are to hand broadcast, machine broadcast, or machine drill. The scale and design of this experiment dictated that seed be hand broadcast and raked into the soil. This method is appropriate for small restorations less than one or two hectares. Many Mn/DOT plantings are drilled. Drilling will generally plant seed deeper than broadcasting, which may be advantageous. In addition, drill rows may create microsite conditions that help retain moisture.

It was interesting to note seedling morphology of *S. scoparium* in this experiment. For some seedlings, the shoot, crown, and 1/2" of the root lay exposed on the soil surface. If the seed had been planted deeper, the root and crown would not have been exposed and winter survival might have been better. It is likely that establishment would have been higher if seed had been drilled instead of broadcast.

4.2.5 Cover crops and mulch

All Mn/DOT plantings use cover crops and sites with bare soil are mulched. The plots in this experiment had neither mulch nor cover crop. It is likely that the results would have differed had these been used. Cover crops establish quickly and, therefore, help conserve soil moisture, reduce erosion, and outcompete annual weeds. However, there is currently no consensus that cover crops improve stand establishment of native prairie species [19]. Because they compete for resources, they may in fact reduce establishment. Some restorationists suggest that annual weeds function as cover crops [19]. Mulches help conserve soil moisture and reduce erosion. In addition they reduce temperatures near the soil surface, which may benefit young seedlings.

4.2.6 Irrigation and weeding

The irrigating and weeding protocols in this experiment replicated those of most large-scale prairie plantings: no irrigation, no weeding. Weeds were controlled by mowing. Though scientific studies have shown mowing weeds improves early stand establishment of prairie species [22], mowing is not done in all restorations. However, most restorationists would probably agree that mowing is necessary on heavy soils that are tilled.

4.3 How should seeding dates be selected?

Seeding dates are generally dictated by work schedules, not by optimal planting times for particular species. On roadside projects, for example, planting often occurs after months of construction work and contractors may have little choice in when to plant. In these situations it is crucial to understand how species are likely to perform and to tailor seed mixes accordingly. For example, if a seeding had to be done in late August, it would be inadvisable to plant only warm-season grasses.

When a project schedule is flexible, seeding date can be used as a restoration tool. In selecting seeding dates, it is important to keep in mind the limitations discussed. The seeding dates recommended below are most appropriate for: 1) the species studied, 2) plantings on heavy soils, 3) restorations with broadcasted seed, and 4) plantings which did not use mulch or cover crops.

The experiment showed that, in a year with adequate rainfall, *S. scoparium* and *B. curtipendula* matured enough to survive the winter if planted by early August (August 8). For *E. canadensis* and *Bromus kalmii*, successful plantings were done into early September. However, these dates are only appropriate for years with adequate moisture. It is impossible to know if rainfall patterns after planting will be adequate. Since most restorations are not irrigated, landscape managers must balance the likelihood of rain with these data on the latest possible planting dates. If irrigation is possible, the later dates are acceptable and may be superior because weed competition usually declines as the season progresses.

4.4 Should prairie grasses be dormant seeded?

One of the most important findings in this experiment was that restorationists need to re-evaluate dormant seeding of prairie grasses. In the 1996 plantings, none of the planted species or mixes established well by dormant seeding. The warm-season grasses studied never had good establishment from fall plantings. There are several possible reasons for this poor establishment.

First, it may be necessary to wait longer before evaluating dormant seedings of warm-season grasses. In this experiment they were evaluated in July, nine or ten months after they were planted. Some restorationists would suggest waiting an additional year. Note, however, that the 1996 dormant seedings were observed in late 1998, nearly two years after seeding. They had still not established; therefore a more thorough sampling was not conducted.

Other reasons for the poor establishment of warm-season grasses may be that the seed is rotting over winter, or that it needs to be planted deeper. It is possible that dormant seedings of these warm-season grasses would have fared better on lighter soil or if they had been planted with mulch or a cover crop.

The Tallgrass Restoration Handbook [9] indicates that *E. canadensis* can be planted anytime during the season, but its list of plants to dormant seed includes no warm-season grasses. Some Minnesota restorationists have reported successful establishment of warm-season prairie grasses from dormant seedings (personal communication with Robert Jacobson and Ronald Bowen, 1998). It is thought that vigorous warm-season species, such as *Andropogon gerardii*, may do especially well. *A. gerardii* was included in the Mn/DOT mixes in this study and was planted in 1997. Though one cannot draw conclusions from a single planting year, *A. gerardii* did not establish well that year as a dormant seeding. If restorationists are observing a diverse selection of warm-season grasses from dormant seedings, it is likely that soil texture or planting techniques (broadcast vs. drill, use of mulch and cover crops) differed from those in this experiment. It would be very worthwhile to investigate this issue further.

4.5 Should cool-season prairie mixes be planted?

Cool-season species usually establish more easily than warm-season species. *E. canadensis*, in fact, is sometimes used as a short-lived perennial cover crop [19]. To determine if one could take advantage of this quick growth, the experiment compared cool-season mixes and warm-season mixes. The cool-season mixes had significantly better establishment. However, warm-season grasses were poorly represented in the plots with cool-season mixes. By the end of the second season they comprised only 1% to 5% of the native plants present. Since warm-season grasses dominate the tallgrass prairie, a planting with predominantly cool-season grasses is rarely the desired outcome of restorations using the tallgrass prairie as a model. This two-year-old prairie planting, however, is very young and its species composition is certain to change.

It has been suggested that, after five to eight years, cool-season grasses such as *E. canadensis* will die out of a restoration and be replaced by other native species [19]. If this is correct, planting cool-season mixes will have several advantages. The cool-season grasses establish more quickly and therefore they compete well with weed seedlings, they help prevent erosion sooner, and they are quicker to produce a stand that is aesthetically acceptable. Also, as seen in this study, they have a longer planting season. It would be beneficial to evaluate several older restorations to document whether the percentage of cool-season grasses had indeed declined and been replaced by warm-season grasses.

CHAPTER 5
CONCLUSIONS AND RECOMMENDATIONS

The experiment was conducted in one location, over 2-1/2 years, on silt loam soil, and employed specific planting and management methods. Keeping these parameters in mind, the following conclusions and recommendations are offered.

1. Recommendations are valid for St. Paul, Minnesota. They probably also extend to areas that are not significantly hotter or drier than St. Paul, including much of the Upper Midwest.

2. If moisture is adequate, *Schizachyrium scoparium* and *Bouteloua curtipendula* can mature enough to survive winter when planted by early August (August 8 in this experiment).

3. If moisture is adequate, *Elymus canadensis* and *Bromus kalmii* can mature enough to survive winter when planted by early September (September 9 in this experiment).

4. If irrigation is possible, planting can be done any time before August 8 (for *S. scoparium* and *B. curtipendula*) or September 9 (for *E. canadensis* and *B. kalmii*). Because weed competition is generally less severe later in the season, late plantings may be advantageous. If irrigation is not possible, earlier planting is advised. Land managers must weigh the likelihood of precipitation. Early planting provides a longer growing season and will have a higher probably of receiving adequate rainfall.

5. *E. canadensis* and *B. kalmii* will establish well from dormant seedings some years. Dormant seedings of *S. scoparium* and *B. curtipendula* did not establish well in this experiment. However, it is possible that on some sites and with certain planting methods (drilling seed, mulching, or using cover crops) dormant seedings may work for these two warm-season grasses. In addition, the dormant seedings were evaluated after one winter and one growing season. It is probably necessary to wait at least two winters before declaring a dormant seeding unsuccessful.

6. Mixes with a high percentage of cool-season grasses had better stand establishment than mixes with a high percentage of warm-season grasses. However, cool-season mixes may produce very few warm-season grass plants and this must be considered. Restorationists suggest that warm-season grasses will eventually dominate these plantings. If this is true, cool-season mixes have several advantages and only a few disadvantages.

This research has raised many interesting questions that are worthy of further study. Two of the most important are the issues of dormant seeding and the use of cool-season mixes.

Dormant seeded warm-season grasses established poorly in this experiment. It is critical to determine whether results would have differed if soil had been lighter or if other methods had been employed (i.e. drilling seed, mulching or using cover crops). Regarding cool-season mixes, it would be worthwhile to evaluate several older restorations, comparing their current species composition with composition of the original mix. This would help document restorationists' observation that cool-season grasses die out after five or ten years and are replaced by warm-season grasses.

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APPENDEX A

SEEDING RATE

APPENDIX A

SEEDING RATE

Seeding rates for prairie restorations vary tremendously. They generally depend on seed availability, quality of seed, budget, planting method (broadcast or drill), and whether a cover crop is used.

For the 1996 plantings, a bulk rate of 35.38 g/plot was used. Pure live seed (PLS) is a more precise description of the amount of seed, thus, rates were converted to PLS for the 1997 plantings. To do this, approximate PLS rates were obtained from the seed producer for seed planted in 1996 and those PLS rates were used for the 1997 plantings.

For a given species, the same PLS rate was used each planting year. Thus, it is valid to compare the 1996 and 1997 plantings for individual species. However, between species there were differences in the amount of seed planted per plot. These differences were negligible between three of the species. Mn/DOT plots were only seeded in 1997 and PLS rates were used.

Table A-1. Conversion of bulk seeding rates to PLS rates for the main experiment.

Mix	Species	Bulk seed rate Broadcast in 1996 (g/plot)	Equivalent PLS rate broadcast in 1997 (g/plot)
Monocultures	*Schizachyrium scoparium*	35.38	16.27
	Bouteloua curtipendula.	35.38	16.36
	Elymus canadensis	35.38	24.77
	Bromus kalmii	35.38	14.98
		% of species in mix broadcast in 1996	Equivalent PLS % broadcast in 1997
Mix A (warm)	*Schizachyrium scoparium*	50.00	53.63
	Bouteloua curtipendula	31.25	27.63
	Elymus canadensis	6.25	8.45
	Bromus kalmii	12.50	10.29
Mix B (cool)	*Schizachyrium scoparium*	25.00%	25.53
	Bouteloua curtipendula	25.00%	20.66
	Elymus canadensis	25.00%	31.47
	Bromus kalmii	25.00%	22.44

APPLENDEX B

HERBICIDE USE

APPENDIX B
HERBICIDE USE

The initial methods called for applying an herbicide before tilling, if a plot had significant weed cover. In 1996, no herbicide was used for the May planting. The June 13 and July 12 plots received an application of Glyphosate prior to tilling. This procedure was then re-evaluated and herbicide use was discontinued. Timing the herbicide treatments was difficult because the planting schedule was very precise and wind-free days were required for applying the herbicide. In addition, the seeding date treatments were separated by only a 1/2 m turf strip and herbicide drift was likely.

The experiment fields had very few perennial weeds and tilling was adequate preparation. Since the goal of seedbed preparation was a tilled, weed-free bed, and because there were very few perennial weeds in the plots, the authors believe that using herbicide for only the June 13 and July 12, 1996 plantings does not affect the experiment results.