EVALUATION OF WILDFLOWER SEED MIXES FOR INTERIOR ALASKA

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ABSTRACT

The germination, establishment, and survival of six wildflower seed mixes was evaluated in relation to two management practices: irrigation and seasonal sowing date. In addition, Alaska Native Wildflower Mix was evaluated for effects of sowing rate. In the spring-sown treatments, Custom Wildflower and Country Meadow® mixes had greatest seedling establishment, and the public preferred Country Meadow® Mix. In the fall-sown plots, Custom Wildflower Mix had the greatest species establishment, and the public preferred Country Meadow® Mix. Fall-sowing and irrigation resulted in increased species establishment. For the second growing season, Experimental Wildflower Mix with grass had the most wildflower species reappear. Addition of grass seed to Alaska Native Wildflower and Experimental Wildflower mixes did not significantly affect species establishment. There was no significant difference in wildflower species establishment between one, two and three times the recommended sowing rate for Alaska Native Wildflower Mix; however the public preferred the higher sowing rates.

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CHAPTER 1

INTRODUCTION

There is a trend in the United States toward an environmental outlook to gardening, landscaping and revegetation. Use of native plant material (i.e., wildflowers) is increasing because of concerns about resource conservation, increased maintenance costs of turf (Airhart and Falls 1984, Diboll 1989, Middelmann *et al.* 1989, Nash 1993, McTavish 1986, United States Department of Agriculture [USDA] 1987, Cox and Klett 1984), preservation and conservation of native plants, insects and wildlife [National Wildflower Research Center (NWRC) 1989, Averett and Northington 1989, Wilson 1992, Flint 1989, Ortho Books 1984, Johnson and Millard 1993] and environmental effects of pesticide and fertilizer use (Ahern *et al.* 1992). Wildflower seed production has been suggested as an alternative crop for otherwise unproductive farm land (Middelmann *et al.* 1989) and cut flower production (Bratcher 1993).

Interest in wildflowers has grown significantly since 1982 with the introduction of a seed packaging concept called Meadow in a Can® by the Clyde Robin Company (SeedWorld 1987). Since then, wildflowers have been used as a landscape alternative by home gardeners (Aimone 1986, Gilbert 1987, Pompei 1986, Orlando 1988, Otteson 1986, Storer 1987, SeedWorld 1987, Corley 1989, Johnson and Millard 1993, Emerson 1990), golf course superintendents (Stroud 1989), state and federal highway departments (NWRC 1989, Dickens *et al.* 1989, D. Brown 1993), National Park Service (U.S. Government 1989) and residential landscape architects (Brown *et al.* 1981).

State highway departments have used wildflowers to minimize costs of mowing, irrigation, application of herbicides, and erosion control [SeedWorld 1987, NWRC

1989, Wilson 1992, D. Kerr Mississippi Department of Transportation (DOT) pers. comm., D. Stark, Wisconsin DOT pers. comm., D. Brown, Ohio DOT pers. comm.]. The Texas DOT has been planting wildflowers for 50 years, and research has shown a 25% saving in annual mowing costs compared to turf maintenance mowing (Corley 1989, USDA 1987). A Massachusetts research project (R5-9) resulted in a recommendation that wildflowers be used in the landscape where possible to control erosion, naturalize the highway in its surroundings, and provide aesthetic relief to motorists along existing roadways (Falls and Airhart 1979).

Because pesticides, oil, gasoline, lead, and sediments contribute to water pollution from the runoff of managed turfed highway rights-of-way (Fabos 1985), wildflowers can be an advantageous alternative (Ahern *et al.* 1992). For instance, some airborne pollutants can be trapped and filtered by the tall foliage of some wildflower species. Once trapped by the vegetation, the pollutants are more likely to be leached into the soil rather than run off into surface waters resulting in less runoff with wildflower vegetation than with turf (Ahern *et al.* 1992, Spirn 1984, Leopold and Dunne 1978).

Federal law (Section 130 of the federal Surface Transportation and Uniform Relocation Assistance Act of 1987) also requires that native wildflowers be planted as part of any landscaping project undertaken on the federal highway system. Twenty-five cents of every one hundred landscaping project dollars must be spent on native wildflowers (Averett and Northington 1989, SeedWorld 1987, Diboll 1992).

In Alaska, the state Department of Transportation and Public Facilities (DOT&PF) had included *Papaver nudicaule* in its roadside revegetation seed mixes, but the practice was discontinued because of concerns by the Bureau of Land Management (BLM) that the use of non-native species could result in an interbreeding with native species. DOT&PF currently uses a combination of two or more grasses (*Festuca* *rubra*, *Poa glauca*, *Lolium multiflorum*, and *Poa pratensis*) in its highway revegetation projects (P. Misterek Alaska Department of Transportation, pers. comm.).

Native plants have been used in Alaskan home landscapes since the gold rush era. In 1993, there were 23 sources of commercially sold native wildflower seed in Alaska (Alaska Department of Natural Resources 1993) The use of wildflower mixes, particularly in establishment of wildflower meadow landscapes, is of more recent interest and has paralleled the national trend begun in the 1980's. In 1992, 17 businesses in the Fairbanks area retailed wildflower seeds or seed mixes (P. Holloway University of Alaska Fairbanks, per. comm). Homeowners and businesses in Alaska have joined the national trend in the use of wildflowers as a landscaping tool. Mixes available for retail sale include several that are "recommended or blended for Alaska" but contain very few indigenous species. Two Alaska companies purchase wildflower mixes in bulk from a "Lower 48" source, repackage them and then sell the mixes as wildflower mixes for Alaska.

The largest commercial source of Alaska wildflower seeds is Baldwin Seed Co. (Kenai, AK) that has sold seeds since 1948. Recently, this business expanded with plans to produce bulk seed of three native species: *Polemonium pulcherrimum*, *Polemonium acutiflorum*, and *Sanguisorba menziesii*. However, due to problems in producing bulk wildflower seed and lack of an established market for locally produced seed, Alaskan wildflower seed is a highly speculative crop (Baldwin 1992).

No business produces a true Alaskan wildflower seed mix. Information on seed germination techniques, field cultivation practices, species composition and competition, and applicable field management practices for Alaska wildflowers are sketchy or nonexistent.

The objectives of this research were to characterize six native and non-native wildflower seed mixes sold in Alaska in terms of seed germination, flowering dates, winter survival, and public acceptability; begin to develop recommendations for a wildflower mix composed exclusively of Alaska native plants; and evaluate two management practices, irrigation and seasonal sowing dates on establishment of wildflower mixes in interior Alaska.

CHAPTER 2

LITERATURE REVIEW

Research on establishment of wildflower meadows should involve studies of seed germination and dormancy, seedling establishment, plant competition, stand maintenance, and environmental factors such as light, moisture, and temperature. The literature on these topics is sketchy because national interest in wildflowers did not begin until the early 1970's with "Operation Wildflower" [National Council of State Garden Clubs, Inc. (NCSGC) 1981]. In addition, much of the information is often extrapolated from research with individual species rather than plant interactions in a meadow environment.

Plant interactions are important in plant community dynamics and can be influenced by propagule arrival time, germination, flowering and dispersal, and the position of the perennating buds. Direct influence or indirect exploitation of shared resources by plants can result in smaller plants and self-thinning of crowded stands, thus increasing inequality among plants over time. Additionally, differences in relative growth rates and relative emergence times can have a major influence on the outcome of competition among species. Competition plays a major role in structuring pasture communities, but only within the limits set by a variety of environmental/biotic constraints (Harper 1977). The following review identifies the major factors influencing wildflower germination and establishment within a meadow environment.

Seed Germination

Under ideal conditions, i.e., adequate moisture, light and temperature, seed dormancy mechanisms can delay or inhibit seed germination (Atwater and Vivrette 1987). These are inherent mechanisms for wild plant species to maintain viable seed populations over time to avoid loss of all seed to extreme fluctuations in temperature and moisture levels (Atwater and Vivrette 1987, Mirov 1936, Hartmann *et al.* 1990). Dormancy mechanisms allow time for seed dispersal from the parent plant that can be of short duration or up to many decades and can influence the timing of seed germination to coincide with optimum environmental conditions for seedling establishment and growth, thus preventing germination during unfavorable conditions and increasing the longevity of the seed (Atwater and Vivrette 1987).

Seed dormancy can take many forms either individually or in combination: seed coverings impermeable to water or gases, immature embryos, chemical inhibitors, and hormonal and chemical inhibitors in the embryo and endosperm (Alderson 1987, Atwater and Vivrette 1987, Hartmann *et al.* 1990). If provided with the correct physical environment, after-ripening can occur (Alderson 1987, Allen and Meyer 1990). However, germination performance can be non-uniform and unpredictable in wild species (Alderson 1987).

Light: Germination and Flowering

Light requirements for seed germination vary by species (Mayer and Poljakoff-Mayber 1982). Light is a germination-controlling factor through both dormancy induction and release, often interacting with temperature (NWRC 1989, Hartmann *et al.* 1990). Seed responses can be divided into four broad categories: seeds that may require continuous illumination, brief illumination, or total darkness. Also, seeds may germinate regardless of the presence or absence of illumination (Mayer and Poljakoff-Mayber 1982). Many seeds are stimulated to germinate when exposed to light depending upon age, storage, harvest processing methods and accompanying temperature (Hartmann *et al.* 1990). This response has been shown to be phytochrome mediated for many species (Toole 1973, Richards and Beardsell 1987, Hartmann *et al.* 1990).

Wildflowers such as *Gilia capitata* (Grant 1949), *Gypsophila* sp. (Rose-Fricker 1991), *Hesperis matronalis* (Association of Official Seed Analysts 1981), *Linaria vulgaris* (Young and Young 1986), *Linum lewisii* (Art 1986), and *Penstemon strictus* (Emery 1988) germinate best with light and alternating temperatures. In contrast, light has no marked effect on percentage germination of *Rudbeckia* sp. (Mitchell 1926), *Achillea* sp. (Emery 1988), or *Aster sibiricus* (Bliss 1958).

Germination that is inhibited by light appears to involve the seed coat or the endosperm, and is temperature-dependent (Hartmann *et al.* 1990). For instance, *Nemophila insignis* (Chen 1968) and *Phacelia tanacetifolia* seed germination is inhibited by light (Schultz and Klein 1963). *Nemophila* requires three days of darkness, proceeding light, and all germination is inhibited by temperatures higher than 27.5C (Chen 1968). In contrast, *Phacelia* requires 48 hours of dark to attain maximum germination (Chen and Thimann 1965, Schultz and Klein 1963). *Phacelia* is most sensitive to light inhibition 13 to 17 hours after the beginning of imbibition. Removing or rupturing the seed coat near the radicle allows complete and normal germination in light (Chen and Thimann 1965, Schultz and Klein 1963, Quick 1947).

In addition to germination, light also affects flowering (Eastin and Sullivan 1984). These effects can be divided into three different components which can also interact to affect flowering: responses to light duration (photoperiod), light quality (wave-length) and irradiance (radiant energy) (Eastin and Sullivan 1984). For instance, the time between appearance of visible buds and anthesis of the first inflorescence in *Gypsophila* is delayed at a low ambient photosynthetic photon flux (450 $mol \cdot s^{-1} \cdot m^{-2}$) and a night temperature less than 20C. For maximum stem height and flowering yield, *Gypsophila* requires long day (LD) conditions until onset of flowering (Hicklenton *et al.* 1993).

Light levels needed by plants to sustain growth is an important factor for wildflower meadow establishment (Hartmann *et al.* 1990). Selection of wildflower species becomes increasingly difficult as light levels are decreased because many meadow species require high levels of light (full-sun) (Preece and Reed 1993). Relatively high intensity light results in sturdy, vigorous plants; whereas, low light intensity results in etoliation, reduced photosynthesis, and poor seedling survival (Hartmann *et al.* 1990). Competition for light between short-growing plants and tall-growing plants can result in the taller growing plants dominating the planting (Harper 1977).

For optimum germination and establishment, site conditions and species requirements must be compatible (Preece and Reed 1993, NWRC 1989). Site conditions for the majority of commercial wildflower mixes include full sun for a minimum of eight hours a day to maintain adequate growth (Wildseed Farms, Inc. 1992, NWRC 1989).

Temperature: Germination and Flowering

Temperature is a major factor in overcoming seed dormancy (Salac and Traeger 1982, Maguire and Overland 1972, Mirov 1936, Nichols 1934, Hartmann *et al.* 1990, Kaspar and McWilliams 1982, Beardsell and Richards 1987, Bratcher *et al.* 1993). Physiologically dormant seeds require a period of after-ripening before germination will occur. This after-ripening period involves subjecting imbibed seeds to cool, moist conditions for a period of times. The most effective temperatures are between 0 and 5C, and duration is typically between 30 and 120 days (Richards and Beardsell 1987).

Iris setosa requires a period of cold stratification ranging from 120 to 150 days at 4C (Holloway 1987). *Penstemon* sp. requires an 8 week period of cold stratification at

15C (Allen and Meyer 1990, Kitchen and Meyer 1990) and *Aquilegia* will have 80% to 90% germination at a relatively low temperature (Davis *et al.* 1993). This is common in species whose seeds mature in autumn and presumably the winter environment provides cold stratification (Allen and Meyer 1990). Many annuals, which typically germinate in summer in arid and temperate regions, may require high temperatures for optimum germination (Mott 1972). Three Alaska native shrub seeds require storage at temperatures just above freezing with two species requiring temperatures between 2C and 15C for two to three months for germination to occur (Densmore 1974). Without specific knowledge of individual native species and germination requirements, natural environmental conditions should be duplicated (Hartmann *et al.* 1990).

Fluctuating day-night temperatures affect seed germination and seedling growth (Hartmann *et al.* 1990, Preece and Read 1993). Seedling growth may require different temperature requirements than those of seed germination (Hartmann *et al.* 1990).

Temperature can affect flowering responses. Several days to several weeks of low temperatures (0 to 10C) promotes flowering in many species. There are both qualitative and quantitative plant responses depending upon the species and strain. For instance, biennials need cold treatment or vernalization to promote flowering (Dennis 1984).

Soil Moisture

Adequate moisture is necessary for seed germination and establishment (Hegarty and Ross 1981, Pinnell *et al.* 1985). Poor emergence is not necessarily associated with failure to germinate but with failure to complete the post-germination, pre-emergence stage of growth due to poor soil conditions, primarily adequate moisture (Matthews and Powell 1986).

Little variation exists among germination of plant species in tolerance to low water potential (Mott and Groves 1981). Recommendations for wildflower establishment include supplemental irrigation after planting if there is inadequate rainfall to sustain germination (NWRC 1989, Longland 1989, Ahern 1990, Wildseed Farms, Inc. 1992, Corley 1989, Ferreniea 1988, Trelawney 1983, Johnson and Millard 1993, Wilson 1992). Some wildflowers may adapt to uncertain moisture conditions by germinating in the spring to take advantage of spring rains and melting snow cover (Longland 1989).

For wildflower meadow establishment, an application of 2.5 ml of water per day for 4 to 6 weeks until seedlings are well established is recommended (Corley 1989, Wildseed Farms, Inc. 1992). Keeping the soil moist for the first month allows for good seedling germination, establishment, and better wildflower "color" display (Rose-Fricker 1991, Stroud 1989). A lack of water after initial imbibition and before radicle emergence may result in the death of the developing seedling (Pinnell *et al.* 1985) or development of secondary seed dormancy (Hartmann *et al.* 1990).

Sowing Dates

Seeds germinate best when natural conditions are simulated including seed dormancy conditions, temperature requirements for germination, and the location of the planting site (Salac *et al.* 1978, Mirov 1936, Hartmann *et al.* 1990). The most common conditions needed to promote seed germination in dormant seeds is a prolonged period of low temperatures before germination and adequate moisture (Mirov 1936, Nichols 1934).

Successful seedling emergence, establishment, stand counts, stand heights, and winter survival are influenced significantly by sowing date (Zajicek *et al.* 1986, Hartmann *et al.* 1990, Salac 1977). For instance, a fall-sowing date of Oct. 27 for native species (Nebraska) resulted in seedlings twice as tall as those seedlings emerging from a spring seeding date (Zajicek *et al.* 1986).

A fall-sowing date can result in germination that is early and abundant, essential for most forbs, and advantageous for most grasses (Zajicek *et al.* 1986, Johnson and Millard 1993). State highway maintenance departments report a fall-sowing resulted in more wildflower species germinating compared to a spring sowing (D. Brown Ohio DOT, pers. comm., D. Kerr Mississippi DOT, pers. comm.). However, it is difficult to recommend a diverse wildflower species mix for one seeding date because of the many different seed germination requirements (Zajicek *et al.* 1986). Additionally, a fall-sowing date must be determined for the particular planting site to prevent seed germination from occurring until the following spring.

Soil Preparation

Recommendations for soil preparation focus on the removal of weeds and weed seeds prior to planting wildflower mixes. Elimination of undesirable vegetation allows for the establishment of the desirable plant species (NWRC 1989, Art 1986, Longland 1989, Diboll 1992, Wilson 1992, Rose-Fricker 1991, Salac *et al.* 1978, Ahern *et al.* 1992). For example, seeding on established grass vegetation on Nebraska highway roadsides resulted in complete failure of wildflower species establishment (Salac *et al.* 1978).

Shallow or surface tilling allows for good soil to seed contact and minimizes weed seed disturbance (Ahern *et al.* 1992, Martin 1990, Wildseed Farms, Inc. 1992, Ferreniea 1988, D. Airhart, pers. comm., Wilson 1992, D. Brown Ohio DOT, pers. comm.). Methods include plowing to a depth of 20 cm and treating the soil with a herbicide; tilling several times periodically for one planting season prior to sowing and germinating as many weed seeds as possible; scalping the soil with a lawnmower before seeding; and burning existing vegetation (Livingston and Livingston 1989, Martin 1990, Longland 1989, D. Airhart, pers. comm., NWRC 1989, Johnson and Millard 1993).

The application of a herbicide after tilling on a wildflower planting in a Charleston, South Carolina city park resulted in the maximum germination of wildflower seeds (Livingston and Livingston 1989). State highway maintenance departments report using herbicides as the most effective method for eliminating existing turf and reducing weed competition (D. Brown Ohio DOT, pers. comm., D. Stark Wisconsin DOT, pers. comm.). Fumigation of seed beds with a herbicide can produce excellent results but is expensive (D. Airhart, pers. comm.).

Sowing Methods

Recommendations for sowing method include hand sowing, hydroseeding, and grain drilling or no-till seeding (Johnson and Millard 1993, Salac 1977). The method used is typically dependent upon the size of the planting area and location. For small sites, it is more economical to hand seed (Pennisi 1990, Johnson and Millard 1993). For better seed distribution, seed may be mixed with fine, damp sand, in proportion of four parts sand to one part seed. An adjustable, hand-carried mechanical seeder is effective for many plant species, although even distribution of small seeds with a mechanical seeder is difficult (NWRC 1989).

Highway landscapers often use a drill seeder for wildflower and grass seeding (D. Gray Nebraska DOT, pers. comm., D. Kerr Mississippi DOT, pers. comm., D. Stark Wisconsin DOT, pers. comm., D. Brown Ohio DOT, pers. comm.). In Nebraska 99% of wildflower and grass plantings are drill seeded rather than hydroseeded. One planting that was hydroseeded failed; whereas, plantings drill seeded were flourishing (D. Gray, Nebraska DOT pers. comm.).

Sowing Rates

The optimum seeding rate is dependent on the species as well as commercial objectives. Low densities would be desired if a high percentage of seedlings are to reach a desired size for field planting (Hartmann *et al.* 1990). A field seeding rate of 3x to 4x supplier's recommended rate for each seed species has been advocated for rapid plot coverage (D. Airhart, pers. comm., Airhart *et al.* 1983, Doubrava and Raulston 1978).

Hartmann (*et al.* 1990) suggests the formula to ascertain the seeding rate:

$$\text{Weight of seeds to sow per area} = \frac{\text{density (plants/unit area) desired}}{\text{purity percent}^{1} \times \text{germination percent}^{1} \times \text{field factor}^{1,2} \times \text{number of seeds/unit weight (seed count)}}$$

Annuals and Perennials Selection

Annuals are included in wildflower mixes to provide first year "color" and can act as a "nurse" crop to developing perennials (Ferreniea 1988, Ahern 1990, Martin 1990, Rose-Fricker 1991, Stroud 1989, Johnson and Millard 1993, Wilson 1992, D. Brown Ohio DOT, pers. comm.). Many annuals may germinate more readily than many perennials, which have special requirements for germination (Mirov 1936, Pinnell *et al.* 1985). Though annuals are included in the mix, they rarely persist beyond the second year after seeding (Longland 1989, Ferreniea 1988, Wilson 1992, Crockett

[1] Expressed as a decimal.
[2] Soil texture and moisture level.

1972, Wilson 1992, D. Brown Ohio DOT, pers. comm., D. Kerr Mississippi DOT, pers. comm.) and the cost of replanting annual species yearly prohibit roadside use (Salac *et al.* 1973).

For long term results, perennials are usually included in a mix (Longland 1989, Martin 1990, Diboll 1989, Rose-Fricker 1991). Perennials can be slower to develop and will usually not flower in the first growing season (Stroud 1989). In succeeding years, the hardy perennials will persist (Wilson 1992, D. Kerr Mississippi DOT, pers. comm., D. Brown Ohio DOT, pers. comm.).

One recommended mix is 25% annuals and 75% perennials and biennials (Ferreniea 1988). Nonnative annual flower seeds found in most commercial mixes, rarely self-sow or establish self-sustaining colonies as native annuals might (Ferreniea 1988). However, native annual and perennial species typically return and establish if allowed to reseed (Wildseed Farms, Inc. 1992).

Mixes of Wildflowers and Grasses

Grasses often are a component of a wildflower mix because native grass seed is less costly than wildflower seed, bulks up the wildflower mix for easier application, aids in soil stabilization without becoming competitive depending on the selected grass, decreases annual weed competition (Diboll 1989, Lofts Seed, Inc. 1991, Pompei 1986, NWRC 1989, Wilson 1992, Martin 1990, Johnson and Millard 1993), lends color and texture to the landscape (Ahern *et al.* 1992), provides support and protection for tall flowers, provides an important food source for wildlife, and is a natural component of a wildflower meadow (Cotter *et al.* 1989).

California began a program to reestablish native perennial bunch grasses on roadside revegetation projects because of the high costs associated with the use of herbicides (i.e., potential pollution and health hazards) and roadside ground blading used to control weeds and reduce fire hazards (Swezey 1991). Grass and wildflower mixtures seeded on prepared sites in Nebraska resulted in satisfactorily establishment of all species of grasses selected; however, there was mixed results of the wildflower species establishment (Salac *et al.* 1978). Ahern (*et al.* 1992) found the presence of grasses to be an important factor in the attractiveness of the wildflower planting.

Experts do not agree on a recommended ratio of wildflower and grass seeds. Recommendations for non-competitive grasses range from 20% (Pompei 1986, Rose-Fricker 1991) to 80% of the total mix (NWRC 1989, Johnson and Millard 1993).

Wildflower Maintenance

A maintenance program is required once the site is prepared and planted (McGourty 1979, Johnson and Millard 1993). Recommended methods include hand weeding, mowing and burning (Ahern *et al.* 1992, Ahern 1990, Wildseed Farms, Inc. 1992, McGourty 1979, Lofts 1991). Hand weeding maintains the wildflower plantings but is labor intensive (Corley 1989). A more preferable method is mowing (Ahern *et al.* 1992, Longland 1989, Corley 1989, McGourty 1979, Lofts Seed Inc. 1991, D. Kerr, pers. comm.).

Mowing at the correct time is an economical and effective tool for managing the balance of species as the meadow matures by reducing weed competition (Ahern *et al.* 1992, Ferreniea 1988, D. Kerr Mississippi DOT, pers. comm., Salac *et al.* 1978). Many selected species will grow and bloom more profusely if cut back during the first half of the growing season (Longland 1989, O'Connor 1990, Corley 1989). For instance, mowing delayed and extended bloom for several wildflower species by up to 1 1/2 months on Nebraska wildflower test sites (Salac *et al.* 1973).

CHAPTER 3

SEED GERMINATION TESTS OF SIX WILDFLOWER MIXES

Methods

Successful establishment of wildflower meadows is determined, in part, by rapid and complete seed germination. In order to more effectively evaluate germination response in the field, controlled environment seed germination tests were conducted on all species in six wildflower mixes. Because of time and equipment constraints and the very large number of species being evaluated, germination was conducted under one temperature and light regime. No attempt was made to identify optimum germination conditions for all species.

Two commercial mixes, Country Meadow® Mix and Custom Wildflower Mix, were purchased from vendors in Fairbanks, Alaska just prior to testing. Three subsamples from top, middle, and bottom of the packages[3] were separated by species and weighed to obtain seed weight, percent by weight in the mix, seeds per gram and average number of seeds per sample. Seeds of the Alaska Native Wildflower Mix and the Experimental Wildflower Mix were obtained as individual species from Nauriaq Gardens and Big Dipper Gardens using the same lots as seed used in the field plantings (Appendix A).

Treatments consisted of four replicates of 100 seeds of each species with the exception of four species (*Calendula officinalis, Chrysanthemum leucanthemum, Linum rubrum, Papaver nudicaule*) where there were too few seed to obtain replicates of a hundred. Seeds were placed on 2mm filter paper in sterilized plastic petri dishes and

[3]Average weight of subsamples for Country Meadow® - 7.2g and Custom Wildflower - 5.5g.

moistened with water pretreated by reverse osmosis. Four dishes were enclosed in a plastic bag and then placed 15 - 20 cm beneath 40-W cool-white fluorescent lights for 18 hours per day. Dishes were remoistened as needed.

Temperature was monitored daily with a Hygro Thermograph. Average daily temperature was 21.5C. Germination (radicle emergence) was counted daily for 30 days; and the total percent germination and days to 25%, 50% and total germination were recorded.

Results and Discussion

Both the commercial mixes contained large quantities of "filler" seed in terms of total percent by weight in the mix as well as number of seed per gram (Tables 1 and 2). Two annual species (*Gypsophila muralis* and *Centaurea cyanus*) each comprised more than 9% of Country Meadow® Mix. Three perennial species (*Achillea millefolium*, *Rudbeckia hirta*, and *Papaver rhoeas*) were present in large seed numbers in Custom Wildflower Mix samples and ranged from 1474 (*Achillea millefolium*) to 4076 (*Papaver rhoeas*) seeds. Regional commercial mixes often contain inexpensive, bulky, filler seed (i.e., *Gypsophila muralis* and *Achillea millefolium*) (NWRC 1989, Art 1986).

Seed numbers by weight in the Alaska Native Wildflower Mix (Table 3) ranged from 3 seeds (*Corydalis sempervirens*) to 110 seeds (*Epilobium angustifolium*). In contrast, the Experimental Wildflower Mix (Table 4) contained equal seed weights of each species; although, the actual numbers of seed ranged from 32 seeds (*Hedysarum Mackenzii*) to 2040 seeds (*Chenopodium capitatum*) per sample average (6.0g).

Seeds began to germinate two days after sowing. Of the twenty-three species evaluated in the Alaska Native Wildflower and Experimental Wildflower mixes, only five species had germination percentages greater than 50% (Table 5). Seeds of two of

Table 1. Species composition in Custom Wildflower Mix.

Species	Average seed weight per sample[z] g	Average species composition by weight %	Estimated seeds per g[y]	Average species composition by number %
Achillea millefolium	.2 ± .1	3.7	7370	18.0
Alyssum saxatile	.2 ± 0	3.7	1060	2.6
Centaurea cyanus	.2 ± .2	4.0	220	6.2
Cheiranthus allionii	.6 ± .1	10.6	1010	7.1
Chrysanthemum maximum	.3 ± .1	5.0	760	2.5
Gilia capitata	.3 ± .1	3.7	1950	7.9
Hesperis matronalis	.5 ± .1	9.8	500	3.2
Linum lewisii	.6 ± .1	10.6	740	5.2
Linum rubrum	.7 ± .1	13.5	370	3.3
Nemophila menziesii	.6 ± .1	11.0	510	3.8
Oenthera lamarckiana	.2 ± 0	3.7	490	1.2
Papaver nudicaule	.2 ± .1	3.7	6730	16.7
Penstemon strictus	.3 ± .1	6.0	1250	5.1
Rudbeckia hirta	.3 ± .1	6.0	4170	17.0
trash/miscellaneous	.1 ± .1	1.3		

[z]Average of 3 samples (5.5g sample size): top, middle, bottom of packaged mix
[y]Estimated from one seed sample.

Table 2. Species composition in Country Meadow® Mix.

Species	Average seed weight per sample[z] g	Average species composition by weight %	Estimated seeds per g[y]	Average species composition by number %
Alyssum maritimum	.3 ± .1	3.7	1980	5.6
Aquilegia sp.	.3 ± .1	3.7	690	1.7
Calendula officinalis	.3 ± .2	4.5	230	.7
Centaurea cyanus	.7 ± .1	9.2	300	1.9
Cheiranthus allionii	.5 ± .1	6.4	590	2.6
Chrysanthemum coronarium	.3 ± 0	4.0	440	1.2
Chrysanthemum leucanthemum	.1 ± .1	1.8	1510	1.8
Cynoglossum amabile	.5 ± .1	7.3	330	1.6
Eschscholtzia californica	.4 ± .1	5.5	1060	3.9
Godetia amoena	.4 ± .2	5.9	1060	4.2
Gypsophila muralis	.9 ± .3	11.9	680	5.5
Hesperis matronalis	.5 ± .1	6.4	500	2.2
Linaria maroccana	.3 ± .1	3.7	6080	15.2
Linum lewisii	.3 ± .1	4.5	740	2.3
Linum rubrum	.4 ± .1	5.9	370	1.5
Lychnis chalcedonica	.2 ± .1	2.3	2520	4.0
Nemophila menziesii	.3 ± .1	3.7	510	1.3
Papaver nudicaule	.1 ± 0	1.4	6080	5.6
Papaver rhoeas	.4 ± .1	5.5	10190	10.0
Phacelia tanacetifolia	.1 ± .1	1.0	350	.2
trash/miscellaneous	.1 ± .1	1.4		

[z]Average of 3 samples (7.2g sample size): top, middle, bottom of packaged mix
[y]Estimated from one seed sample.

Table 3. Species composition in Alaska Native Wildflower Mix.

Species	Average seed weight per sample^{z} g	Average species composition by weight %	Estimated seeds per g^{y}	Average species composition by number %
Achillea ptarmica	❖	+	7500	11.9
Arnica alpina	❖	+	1200	1.9
Aster sibiricus	❖	+	2000	3.2
Centaurea cyanus	.1 ± 0	9.0	250	3.4
Chenopodium capitatum	❖	+	5100	8.1
Corydalis sempervirens	❖	+	330	.5
Epilobium angustifolium	❖	+	11000	17.5
Epilobium latifolium	❖	+	11000	17.5
Eschscholtzia californica	❖	+	1060	1.8
Galium boreale	❖	+	NS^{x}	NS
Hedysarum Mackenzii	.2 ± 0	18.0	80	2.2
Hieraceum scabriusculum	❖	+	2750	4.5
Iris setosa	.2 ± 0	18.0	120	3.5
Linaria vulgaris	❖	+	6000	9.6
Linum lewisii	❖	+	740	1.1
Lupinus arcticus	.3 ± .2	27.0	50	2.2
Nemophila menziesii	❖	+	570	1.0
Oxytropis campestris	❖	+	900	1.4
Parnassia palustris	❖	+	NS	NS
Polemonium acutiflorum	❖	+	NS	NS
Sanguisorba officinalis	❖	+	800	1.3
Solidago multiradiata	❖	+	2000	3.2
Tripleurospermum inodoratum	❖	+	2500	4.0

^{z}Average of 3 samples (1.1g sample size): 3 prepackaged seed packets 1.2g.
^{y}Estimated from one seed sample.
^{x}NS - insufficient number of seed to measure.
❖ Indicates amount of seed < 0.1g.
+ Indicates percent $\leq 1\%$.

Table 4. Species composition in the Experimental Wildflower Mix.

Species	Average seed weight per sample[z] g	Average species composition by weight %	Estimated seeds per g[y]	Average species composition by number %
Arnica alpina	.4 ± 0	6.7	1200	6.1
Aster sibiricus	.4 ± 0	6.7	2000	10.1
Bupleurium triradiatum	.4 ± 0	6.7	700	3.5
Chenopodium capitatum	.4 ± 0	6.7	5100	25.8
Delphinium glaucum	.4 ± 0	6.7	1050	5.3
Erigeron glabellus	.4 ± 0	6.7	2100	10.6
Galium boreale	.4 ± 0	6.7	NS[x]	NS
Hedysarum Mackenzii	.4 ± 0	6.7	80	.4
Melandrum affine	.4 ± 0	6.7	NS	NS
Oxytropis campestris	.4 ± 0	6.7	900	4.6
Polemonium acutifolium	.4 ± 0	6.7	1300	6.6
Rhinanthus minor	.4 ± 0	6.7	NS	NS
Sanguisorba officinalis	.4 ± 0	6.7	800	4.1
Solidago multiradiata	.4 ± 0	6.7	2000	10.1
Tripleurospermum inodorata	.4 ± 0	6.7	2500	12.7

[z]Average of 3 samples, each 6.0 g.
[y]Estimated from one seed sample.
[x]NS - insufficient number of seed to measure.

Table 5. Germination of wildflower species in the Alaska Native Wildflower and Experimental Wildflower mixes.

Species	Average time to first germination (days)	Average time to specified germination (days)		Germination[z] (%)
		(25%)	(50%)	
Achillea ptarmica	5	7.3		34.8
Arnica alpina	3	6.3		30.0
Aster sibiricus	4	11.0		28.5
Bupleurium triradiatum	14			12.3
Centaurea cyanus	2	2.0	2.0	94.8
Chenopodium capitatum	2.5	12.8	17.3	71.8
Corydalis sempervirens	7			21.5
Delphinium glaucum	0			0
Epilobium angustifolium	5	6.8		47.8
Epilobium latifolium	6			20.0
Eschscholtzia californica	3	4.0	6.0	77.3
Galium boreale	10	24.5		30.8
Hedysarum Mackenzii	6			24.8
Hieraceum scabriusculum	2.5			2.0
Iris setosa	0			0
Linaria vulgaris	5			5.5
Linum lewisii	4	11.8	22.0	53.3
Lupinus arcticus	6			7.8
Melandrum affine	0			0
Nemophila menziesii	1	7.0		9.5
Oxytropis campestris	5			6.0
Parnassia palustris	0			0
Polemonium acutifolium	6.5			4.0
Sanguisorba officinalis	5	10.0	19.8	60.3
Solidago multiradiata	12.8			4.0
Tripleurospermum inodoratum	9.5			3.0

[z]Total germination after 31 days

these species (*Centaurea cyanus* and *Eschscholzia californica*) were purchased from commercial nurseries, while the remainder were wild-collected. Three species did not germinate under the controlled conditions (*Delphinium glaucum*, *Iris setosa*, and *Parnassia palustris*). *Iris setosa* requires cold stratification (Holloway 1987). Poor germination of other species could be attributed to poor viability of seed lots, seed dormancy effects, or other germination requirements such as cooler temperatures or illumination. *Nemophila menziesii* germinates best after a 3 day dark treatment (Emery 1988). *Lupinus arcticus* (Baldwin Seed Co. 1987) and *Oxytropis campestris* (Klebesadel 1971) require scarification of the seed coat to induce germination.

All species in the commercial mixes except *Aquilegia* sp. germinated rapidly with radicle emergence beginning within the first week of sowing (Tables 6 & 7). *Aquilegia* sp. requires stratification because of thermodormancy inhibition (Finnerty *et al.* 1992). Seventy percent of the species had germination percentages greater than 50%.

Table 6. Germination of wildflower species in the Country Meadow® Mix.

Species[z]	Average time to first germination (days)	Average time to specified germination (days)		Germination[y] (%)
		(25%)	(50%)	
Alyssum amabile	1.8	2.0	2.0	85.5
Aquilegia sp.				0.0
Calendula officinalis[x]	5.7			21.0
Centaurea cyanus	1.3	1.3	2.0	87.0
Cheiranthus allionii	2.5	4.3	6.0	71.8
Chrysanthemum coronarium	2.0	4.0	11.5	69.0
Chrysanthemum leucanthemum[x]	3.0	4.3	6.3	87.3
Cynoglossum amabile	2.0	2.3	3.5	71.3
Eschscholzia californica	2.3	4.3	12.0	54.0
Godetia amoena	1.3	2.0	2.0	95.0
Gypsophila muralis	1.3	2.3	2.8	89.5
Hesperis matronalis	3.8	10.8		32.3
Linaria maroccana	3.0	2.3	3.3	72.5
Linum lewisii	5.7	11.0	17.8	64.8
Linum rubrum[x]	2.0	2.0	5.7	92.7
Lychnis chalcedonica	2.3	4.5	5.5	89.3
Nemophila menziesii	1.0	7.0		29.8
Papaver nudicaule[x]	3.0	9.0		30.0
Papaver rhoeas	2.0	3.0	5.8	56.8
Phacelia tanacetifolia[x]	2.0			24.0

[z]4 replicates, n=100
[y]Total germination after 30 days
[x]*C. officinalis* 3 replicates, n=47; *P. tanacetifolia* 3 replicates, n=35; *C. leucanthemum* 3 replicates, n=100; *L. rubrum* 3 replicates, n=100 due to limited seed.

Table 7. Germination of wildflower species in the Custom Wildflower Mix.

Species[z]	Average time to first germination (days)	Average time to specified germination (days)		Germination[y] (%)
		(25%)	(50%)	
Achillea millefolium	2.3	5.3		37.4
Alyssum saxatile	2.0	2.3	3.0	88.3
Centaurea cyanus[x]	1.0	1.0	1.0	99.0
Cheiranthus allionii	2.0	2.0	3.0	92.0
Chrysanthemum maximum	1.5	2.0	3.0	95.5
Globe gilia	1.3	7.8		35.3
Hesperis matronalis	2.8	5.0		44.3
Linum lewisii	2.5	13.5		52.8
Linum rubrum	2.0	3.0	3.0	86.0
Nemophila menziesii	1.0	6.5		30.0
Oenthera lamarkiana	4.0	5.5	8.0	71.5
Papaver nudicaule	4.0	5.3	6.0	89.3
Penstemon strictus	3.5			8.8
Rudbeckia hirta	2.0	2.0	3.0	92.3

[z]4 replicates, n=100
[y]Total germination after 30 days
[x]*C. cyanus* 3 replicates, n=50 due to limited seed.

CHAPTER 4

SOWING RATE AND NUMBER OF SPECIES PER PLOT FOR ALASKA NATIVE WILDFLOWER MIX

Methods

Unfertilized, Tanana silt-loam soil, located at the University of Alaska Fairbanks Agricultural and Forestry Experiment Station Fairbanks Experiment Farm, was tilled to a depth of 15-20cm. Plots 1x3m in size were fumigated with methyl bromide on June 8, 1992 (Great Lakes Chemical Corporation, Ind.) to minimize weed competition. Periodic rototilling between plots and hand weeding within the plots were used to control weeds as needed.

Nine plots were sown on June 12, 1992 with Alaskan Native Wildflower Mix. Treatments included one, two and three times the recommended sowing rate (1.0g per 3.6 m^2) in a completely randomized design with three replicates of each treatment. To achieve even coverage, seeds were combined with sand (1:10 by volume, respectively), divided in half, broadcast by hand in two directions, and then lightly raked into the soil. Plots received 11 - 13 mm water daily by overhead sprinkler irrigation until seedling establishment on July 13, 1992 and thereafter, natural rainfall was the source of water (Appendix B). Soil moisture was monitored weekly with two tensiometers evenly spaced within the nine plots at a 7 - 9 cm depth.

In 1992, data were gathered twice weekly after seedling emergence on June 23 until August 12 and then weekly until September 10. In 1993, data were gathered weekly from May 14 until September 16. Data included first flowering date of all species, seedling establishment (number of species per plot) and density (number of plants per species per plot) in a randomly-selected 1/8m^2 sample. Data from September 10 were analyzed by analysis of variance (ANOVA) and mean separation by Tukey's HSD at $P \leq .05$ (SAS GLM version 6.07).

Public opinion surveys were conducted from mid season (July 20, 1992 and July 23, 1993) to end of season (Sept. 10, 1992 and Aug. 29, 1993) to determine preference for the different sowing rates. Volunteers (50 people in 1992 and 29 people in 1993) ranked the nine plots from one (most preferred) to nine (least preferred). Data were tested for significant differences at $P \leq .05$ by comparing the rank totals between all possible pairs of samples using Friedman Test and Statistical Tables.

Results and Discussion

The 1992 growing season. Tensiometer values were recorded for additional information on soil moisture within the plots to possibly help explain the results of species establishment and flowering. The second growing season was drier than the first growing season (Figures 1 and 2).

During the first growing season, average number of species per plot in the Alaska Native Wildflower mix did not differ significantly among plots sown at one, two and three times the recommended sowing rate (Table 8). By September 5, the number of wildflower species per plot ranged from 8 to 12 species. Three of these wildflowers were annuals not native to Alaska (*Eschscholtzia californica, Nemophia menziesii, Centaurea cyanus*), two were native annuals (*Chenopodium capitatum, Tripleurospermum inodoratum*), and the remaining species were native perennials (Table 9).

The public was capable of distinguishing between the recommended rate and the higher rates (Table 10) but not between the two highest seeding rates. Most respondents had difficulty ranking the nine plots at the end of the season (Sept. 5, 1992) because

Figure 1. Plot tensiometer readings for 1992.

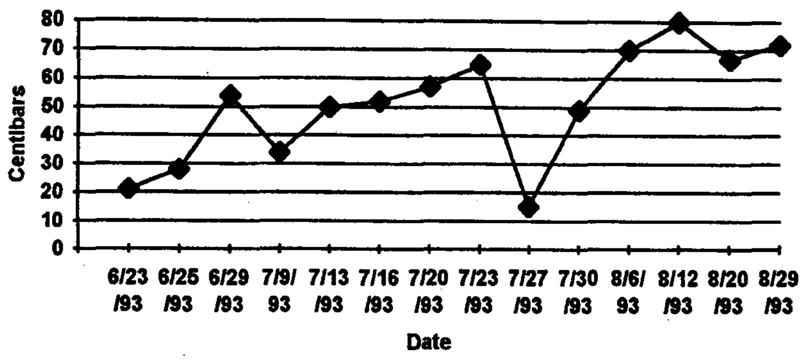


Figure 2. Plot tensiometer readings for 1993.

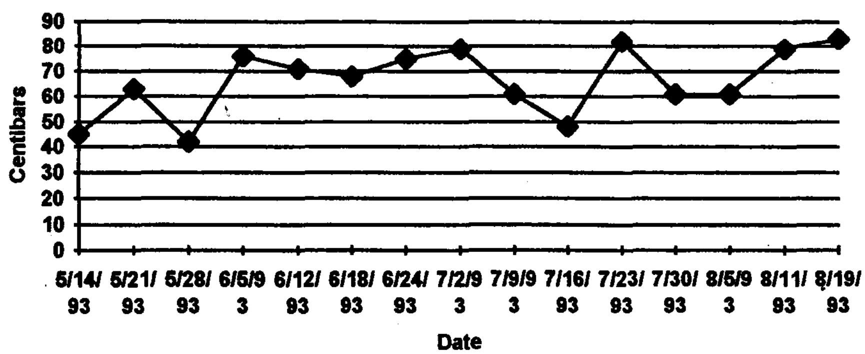


Table 8. Average number of wildflower species per plot in the Alaska Native Wildflower Mix at three sowing rates in 1992.

	Average number of wildflower species per plot		
Rate of sowing[z]	July 2	July 30	Sept. 5
1.0[z]	3.0a[y]	7.5b	8.0b
2.0	2.5a	7.5b	9.0b
3.0	3.7a	8.0b	12.3b

[z]g per $3.6m^2$ plots
[y]means separation within rows by Tukey's HSD at $P \leq .05$. Means did not differ significantly among rate treatments within collection data.

Table 9. Dates of first emergence and flowering for Alaska Native Wildflower Mix species sown on June 12 regardless of sowing rate in 1992.

Species	Date of first emergence	Date of first flowering
Achillea ptarmica	July 16	
Arnica alpina	July 16	
Aster sibiricus	July 16	
Centaurea cyanus	June 23	July 27
Chenopodium capitatum	June 23	August 12
Corydalis sempervirens	July 16	
Epilobium angustifolium		
Epilobium latifolium		
Epilobium species	July 16	August 6
Eschscholtzia californica	August 23	July 27
Galium boreale		
Hedysarum Mackenzii	July 9	
Hieraceum scabruisculum	July 9	
Iris setosa		
Linum lewisii	July 13	July 30
Linaria vulgaris[y]	July 16	September 5
Lupinus arcticus		
Nemophia menziesii	June 23	August 23
Oxytropis campestris		
Parnassus palustris		
Polemonium acutiflorum	July 13	
Sanguisorba officinalis		
Solidago species		
Tripleurospermum inodoratum	July 13	July 30

[z] Species emerged in at least one of the nine plots.

[y] Considered invasive, noxious weed in Canada (Nadeau *et al.* 1992) and Alaska (Alaska, Division of Agriculture 1987).

Table 10. Public preference[z] for three sowing rates of Alaska Native Wildflower Mix during the first growing season (1991).

Comparison of Sowing Rate Treatment Pairs	Rank Total
1.0 - 2.0[y] =	47a[x]
1.0 - 3.0 =	102b
2.0 - 3.0 =	149b

[z]Lowest rank = 6 = least preferred rate.
[y]Grams per 3.6 m2 plot.
[x]Tabulated critical values for $P \leq .05$, 50 panelists and 3 treatments, from Friedman Test and Statistical tables is 90. Only differences between 1.0 and 3.0, and 2.0 and 3.0 were significant.

nearly every plot was covered with *Eschscholtzia californica* and other non-native annuals. However, appearance of the higher sowing rate plots was more uniform in plot coverage.

Most native and non-native annuals may establish and flower in the first year (Rose-Fricker 1991). Several native perennial species present in the Alaska Native Wildflower Mix did not establish for the first growing season. Perennial species can take several years to germinate and establish primarily due to complex germination requirements (Pinnell *et al.* 1985, Salac *et al.* 1975, Mirov 1936, Hartmann *et al.* 1990). For instance, *Iris setosa* (Holloway 1987), *Linaria vulgaris* (Steffek 1983, Nadeau and King 1991, Nadeau et al. 1992), and *Lupinus arcticus* (Baldwin Seed Co. 1987, Young and Young 1986, Klebesadel 1971) require stratification to overcome seed dormancy. It is interesting to note that *Polemonium acutiflorum* occurred in all nine plots and bloomed in several plots. *Polemonium acutiflorum* requires no pregermination treatment, and adequate moisture results in satisfactory emergence and establishment (Baldwin Seed Co. 1987).

Although germination percentages of non-native species ranged from 30% - 95% under controlled conditions (Table 5), frequency of these species in the field plots ranged from 1 - 3 plants per plot. Field seeding of non-commercial wildflower species generally results in lower germination percentages than may occur in a controlled germination environment (Christiansen and Landers 1966). Low sowing seed density can result in low soil seed reserves and thus poor seedling establishment (Reader and Buck 1990).

The 1993 growing season. During the second growing season, there was no significant difference ($P \leq .05$) in the numbers of species per plot (average species per plot was 6 - 12 species) among the three sowing treatments. The public preference for the three sowing rate treatments in year two was similar to the previous growing season (Tables 10 and 11). Respondents preferred the higher seeding rates, although the same difficulties in ranking the plots occurred in the second year as in the first year.

Ninety percent of the native species in the mix occurred in at least one of the nine plots and of those, 14 species flowered in 1993 (Table 12). Two native annuals returned and flowered (*Chenopodium capitatum* and *Tripleurospermum inodoratum*). The non-natives, *Eschscholtzia californica*, *Centaurea cyanus* and *Nemophila menziesii*, did not return for the second growing season. Non-native annuals rarely self-sow and persist in subsequent years after initial sowing (Ferrenia 1988, D. Brown per.comm., D. Stark per. comm.).

Only two of the 18 perennial species failed to occur in the second growing season: *Galium boreale* and *Parnassia palustris*. *Galium boreale* seeds averaged 30.8% germination under controlled conditions (Table 5) but field environmental conditions apparently were not appropriate for seed germination or seedling establishment in the field. The field was relatively dry (Figure 2 and Appendix B) and *Parnassia palustris* is typically found in a marsh-type environment (Pratt 1989). *Parnassia palustris* did not germinate in the controlled germination test (Table 5) indicating possibly poor seed viability or improper environmental conditions for germination. Bliss (1958) reported 86% germination in light at 22C after prolonged cold storage.

Only four native species flowered in 1992 (Table 9) compared to 14 species in 1993 Table 12). This could be attributed to some species requiring more than one season to germinate and establish (Hartmann *et al.* 1990) or environmental conditions may not have been conducive to establishment and flowering for the first season (Atwater and Vivrette 1987, Eastin and Sullivan 1984, Preece and Reed 1993, Dennis 1984)

Table 11. Public preference[z] of Alaska Native Wildflower Mix for the three sowing rates during the second growing season, 1993.

Comparison of Sowing Rate Treatment Pairs	Rank Total
1.0 - 2.0[y] =	20a[x]
1.0 - 3.0 =	230b
2.0 - 3.0 =	210b

[z]Lowest rank = 6 least preferred rate.
[y]Grams per 3.6 m2 plot.
[x]Tabulated critical values for $P \leq .05$, 25 panelists and 3 treatments, from Friedman Test and Statistical tables is 61. Only differences between 1.0 and 3.0, and 2.0 and 3.0 were significant.

Table 12. Dates of first emergence and flowering during the second growing season (1993) for Alaska Native Wildflower Mix regardless of sowing rate.

Species	Date of first emergence	Date of first flowering
Achillea ptarmica	May 21	July 23
Arnica alpina	May 21	June 5
Aster sibiricus	May 14	June 16
Chenopodium capitatum	May 21	July 23
Corydalis sempervirens	May 14	July 2
Epilobium angustifolium	May 14	June 24
Galium boreale		
Hedysarum Mackenzii	May 14	June 18
Hieraceum scabruisculum	June 5	July 9
Iris setosa	June 5	
Linaria vulgaris [z]	May 21	June 18
Linum lewisii	June 5	June 18
Lupinus arcticus	May 14	June 5
Oxytropis campestris	June 24	
Parnassia palustris		
Polemonium acutiflorum	May 14	June 5
Sanguisorba officinalis	July 23	
Solidago species	May 14	July 16
Tripleurospermum inodoratum	May 21	June 5

[z]Considered invasive, noxious weed in Canada (Nadeau *et al.* 1992) and Alaska (Alaska Division of Agriculture 1987).

Linaria vulgaris proved to be quite invasive during the second growing season. In one plot, *Linaria vulgaris* covered one-fourth the plot area. Nadeau (*et al.* 1992) reported severe infestations by vegetative spread of the species in agricultural situations where the soil was frequently tilled.

All species except *Lupinus arcticus* and *Polemonium acutiflorum* established in 1993 with the same density in each treatment (Tables 13 and 14). Complex germination requirements may promote germination over several years - a few seeds each year - and thus, regardless of numbers of seeds sown, very few germinate in any one year. Optimum conditions for seed germination of some species may have not been present. Plant competition during the first year may have had a subsequent effect on seed germination, occurrence, establishment and development (Harper 1977). For example, the explosive growth of *Eschscholtzia californica* in the first growing season may have influenced subsequent seed germination of other species through competition for moisture, nutrients and light.

Table 13. *Lupinus arcticus* density at three sowing rate treatments.

Sowing rate[z]	Average number per plot
1.0[y]	.67a[x]
2.0	1.0b
3.0	2.0b

[z]3 replicates
[y]g/m^2
[x]Means separation by Tukey's HSD at $P \leq .05$.

Table 14. *Polemonium acutiflorum* denstiy at three sowing rate treatments.

Sowing rate[z]	Average number per plot
1.0[y]	0.0a[x]
2.0	1.0b
3.0	3.0c

[z]3 replicates
[y]g/m^2
[x]Means separation by Tukey's HSD at $P \leq .05$.

CHAPTER 5

EFFECTS OF SOWING DATE AND IRRIGATION ON SPECIES ESTABLISHMENT FOR SIX WILDFLOWER SEED MIXES

Methods

Six wildflower seed mixes were sown in field plots at the University of Alaska Fairbanks and Forestry Experiment Station Fairbanks Experiment Farm, (Appendix B). Three mixes were purchased from commercial sources: Country Meadow® Mix, Custom Wildflower Mix and Alaska Native Wildflower Mix. In addition, an Experimental Wildflower Mix was formulated entirely of Alaska native species that were hand harvested from wild stands in interior Alaska. Both Alaska Native Wildflower Mix and the Experimental Mix were sown with and without 'Tundra' glaucous bluegrass seed (*Poa glauca* cv. Tundra) (Appendix C).

Unfertilized, Tanana silt-loam soil was tilled to a depth of 15-20 cm. Seventy-two, 1.2x3 m plots were arranged in a randomized split/split block design with three replicates of three treatments: wildflower mix, irrigated or non irrigated plots, and fall or spring sowing dates. Spring-planted plots were fumigated with methyl bromide (Great Lakes Chemical Corporation, Ind.) to minimize weeds competition (June 8, 1992). Periodic rototilling between the plots and hand weeding within the plots were done as needed.

Unexpectedly, plots for the fall-sown seeds had to be shoveled to remove an unseasonably early snow fall. Because soil temperature was too cold for methyl bromide to be applied, fall sown-plots were intensively hand weeded beginning with seedling emergence on May 14, 1993 until mid-July 1993.

Seeds were mixed with sand (1:10 by volume, respectively), broadcast by hand, then lightly raked into the soil on June 12, 1992 for spring-sown seeds and September

25, 1992 for fall-sown seeds. Supplier recommended seeding rates for the six seed mixes and the grass seed for a 1.2x3m plot were:

Alaska Native Wildflower Mix	1.0g
Country Meadow®Mix	9.1g
Custom Wildflower Mix	5.7g
Experimental Wildflower Mix	6.0g
Poa glauca cultivar Tundra	2.3g

Spring-sown irrigated plots received 3.4ml of water daily (overhead sprinkler irrigation) from the date of sowing (June 12, 1992) until seedling establishment on July 13, 1992. Fall-sown irrigated plots received 11 - 13 mm water daily (overhead sprinkler irrigation) beginning May 14, 1993 until seedling establishment on July 9, 1993. All plots thereafter received natural rainfall. Soil moisture was monitored weekly with two tensiometers evenly spaced within each block at a 7 - 9 cm depth. Air temperature records were obtained from the Agricultural and Forestry Experiment Station, Fairbanks Experiment Farm weather station one kilometer north of the research site (Appendix D).

The experiment was designed to evaluate effects of irrigation and both spring and fall sowing dates on six wildflower mixes. Data included species establishment (number of species per plot and date of establishment) and density (number of plants per species per plot) in a randomly-selected $1/8m^2$ sample. Dates of species emergence and flowering were recorded at the first observation of these events in any replicate plot. Sample data for 1992 were gathered twice weekly from June 23 until August 12 and then weekly until a hard freeze on September 10. Data for 1993 were gathered weekly from May 14 until a hard freeze on September 17. Data gathered on September 10 were analyzed by analysis of variance (ANOVA) at $P \leq .05$ and mean separation by Tukey's HSD (SAS GLM version 6.07).

A public opinion survey was conducted to determine preference for different seed mixes on irrigated and non irrigated plots. Respondents ranked the six mixes in order of preference from one (most preferred) to six (least preferred). Data (50 people completed surveys for 1992, 29 people completed surveys for 1993) were analyzed by ANOVA and mean separation by Duncan's multiple range test at $P \leq .05$.

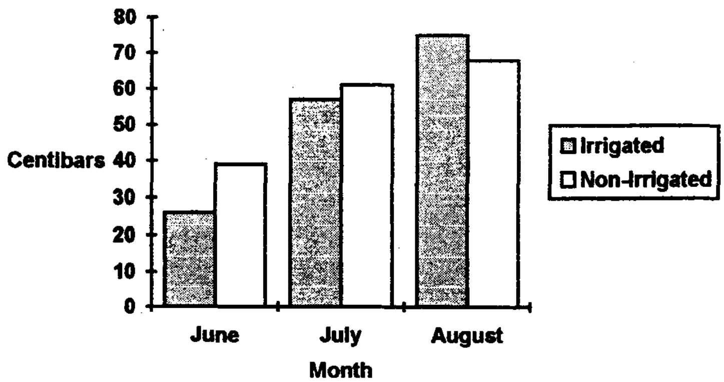
Results and Discussion

Evaluation of spring-sown wildflower mixes 1992. Tensiometer values were recorded for additional information on soil moisture within the plots and to possibly help explain the results of species establishment and flowering. The second growing season was drier than the first growing season (Figures 3 and 4).

The Custom Wildflower and Country Meadow® mixes had significantly higher numbers of species per plot than the other mixes on both irrigated and non irrigated plots (Table 15). The greater number of species per plot may be related to a higher germination percentage of field-cultivated as opposed to wild-collected seeds (Rose-Fricker 1991, Stroud 1989, Martin 1990) and complex seed germination requirements that may have delayed or prevented germination during the first season (Young and Young 1986, Bliss 1958, North Carolina Wild Flower Preservation Society, Inc. 1977).

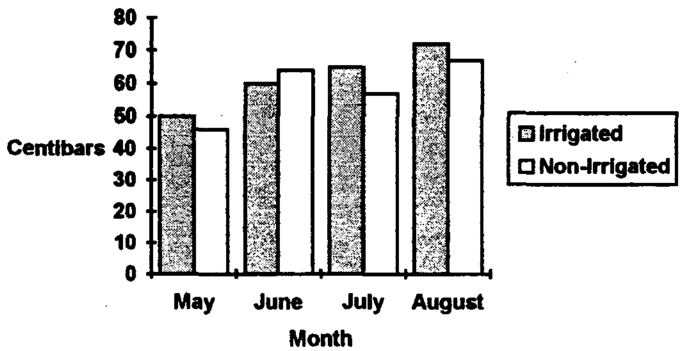
Country Meadow® and Custom Wildflower mixes averaged greater seeding rates per plot (9.1 and 5.7g, respectively) than the Alaska Native Wildflower and Experimental Wildflower mixes (1.0 and 6.0g, respectively); therefore, plant competition might have been a greater factor in plant establishment in the commercial mix plots when compared to the other mixes. Short-statured annuals such as, *Linaria maroccana*, *Alyssum maritimum* and *Nemophila menziesii* dominated these mixes early in the season. Later, the tall-statured annual plants such as *Chrysanthemum*

Figure 3. Average monthly soil moisture by tensiometer^z in irrigated and non-irrigated plots for 1992.



^{z}Mean of 3 replicates for irrigated and non-irrigated plots. No readings for May or Sept. due to frozen soils.

Figure 4. Average monthly soil moisture by tensiometer^z in irrigated and non-irrigated plots for 1993.



^{z}Mean of 3 replicates for irrigated and non-irrigated plots. No readings for Sept. due to frozen soils.

Table 15. Percent species establishment of six spring-sown wildflower mixes regardless of irrigation treatment.

Wildflower Mix[z]	Average species establishment[y] (%)
Country Meadow Mix	68a[x]
Custom Wildflower® Mix	67a
Experimental Mix	46b
Experimental Mix with grass	43b
Alaska Native Wildflower Mix with grass	30bc
Alaska Native Wildflower Mix	23c

[z]3 replicates of non-irrigation and irrigation
[y]Based upon number of species that established in relation to total number of species per mix.
[x]Means separation by Tukey's HSD at $P = .05$.

leucanthemum, *Papaver rhoeas* and *Gilia capitatum*, matured and began to crowd or shade the short-statured plants. Competition between species can directly or indirectly influence plant growth and result in mean size per plant reduction (Harper 1977). However, most of the short-statured plants had set seed before the tall-statured plants had matured. Despite the apparent crowding by the taller species, the short species reappeared in the plots during the second season; however, appearance was limited to the edges of the test plots.

Eleven wildflower species in Alaska Native Wildflower and Experimental Wildflower mixes and four wildflower species in the commercial mixes did not occur during the first growing season (Tables 16, 17 and 18). This could be attributed to several factors: physiological dormancy may have prevented seed germination (Hartmann *et al.* 1990); and plant competitive stresses such as moisture and light may have prevented establishment (Harper 1977).

For instance, *Iris setosa* has a physiological dormancy and seeds were not expected to germinate in the first year since steps were not taken to overcome this dormancy (Holloway 1987). *Lupinus arcticus* seeds require scarification for optimum germination (Baldwin Seed Co. 1987). Only 8% of the seeds germinated in the controlled environment tests, and no seeds germinated on either irrigated or non irrigated plots. Despite a germination percent of 89%, *Papaver nudicaule* did not occur for the first growing season in the commercial mixes. *Papaver nudicaule* is considered a perennial and does best when planted in the fall (Martin 1990).

Table 16. Dates of first emergence and flowering for spring-sown Alaska Native Wildflower Mix and Experimental Wildflower Mix, 1992.

		Irrigated plots		Non-irrigated plots	
Species	Germination[z] (%)	Date of first emergence	Date of first flowering	Date of first emergence	Date of first flowering
Achillea ptarmica	34.8	July 20			
Arnica alpina	30.0	July 9		July 9	
Aster sibiricus	28.5	June 29		June 29	
Bupleurium triradiatum	12.3				
Centaurea cyanus	94.8	June 23	July 27	June 23	July 29
Chenopodium capitatum	71.8	June 23	July 27	June 23	July 27
Corydalis sempervirens	21.5	July 16		July 9	
Epilobium angustifolium	47.8				
Epilobium latifolium	20.0				
Eschscholtzia californica	77.3	June 23	July 27	July 2	July 27
Erigeron glabellus	20.0	June 29		July 2	
Delphinium glaucum	0.0				
Galium boreale	30.8				
Hedysarum Mackenzii	24.8	June 29		July 30	
Hieracium scabriusculum	02.0	June 29		July 27	
Iris setosa	0.0				
Linaria vulgaris	05.5	July 23	Aug. 29		
Linum lewisii	53.3	July 9		July 13	
Lupinus arcticus	07.8				
Melandrum affine	0.0				
Nemophila menziesii	0.0	June 23	Aug. 12	June 29	Aug. 12
Oxytropis campestris	06.0				
Parnassia palustris	0.0				
Poa glauca cultivar *Tundra*		July 2	Aug. 12	July 2	Aug. 12
Polemonium acutiflorum	4.0	July 9	Aug. 29	July 20	
Sanguisorba officinalis	60.3				
Solidago multiradiata	04.0				
Tripleurospermum inodoratum	03.0	June 29	July 30	June29	July 30

[z]Average germination percentage of 4 replicates of 100 seeds in a controlled environment seed germination test.

Table 17. Dates of first emergence and flowering for spring-sown Country Meadow® Mix, 1992.

		Irrigated plots		Non-irrigated plots	
Species	Germination[Z] (%)	Date of first emergence	Date of first flowering	Date of first emergence	Date of first flowering
Alyssum maritimum	85.5	June 23	July 23	June 23	July 23
Aquilegia sp.	0.0				
Calendula officinalis	21.0	June 29	Aug. 12	July 9	
Centaurea cyanus	87.0	June 23	July 27	June 23	July 27
Cheiranthus allionii	71.8	June 29	Aug. 12	July 20	Aug. 12
Chrysanthemum coronarium	69.0	June 26	Aug. 6	July 2	Aug. 6
Chrysanthemum leucanthemum	87.3	June 26		June 26	
Cynoglossum amabile	71.3	June 29	Sept. 5	July 13	
Eschscholtzia californica	54.0	June 26	July 27	July 2	July 27
Godetia amoena	95.0	June 23		June 23	
Gypsophila muralis	89.5	June 23	July 30	June 23	July 30
Hesperis matronalis	32.3	June 23		June 23	
Linaria maroccana	72.5	June 23	July 23	June 23	July 23
Linum lewisii	64.8	July 9	July 30	July 9	July 30
Linum rubrum	92.7				
Lychnis chalcedonica	89.3				
Nemophila menziesii	29.8	July 6	Aug. 12		
Papaver nudicaule	30.0				
Papaver rhoeas	56.8	June 26	July 30	June 26	July 30
Phacelia tanacetifolia	24.0	July 2	July 30	July 9	July 30

[Z]Average germination percentages of 4 replicates of 100 seeds in a controlled environment seed germination test.

Table 18. Dates of first emergence and flowering for spring-sown Custom Wildflower Mix, 1992.

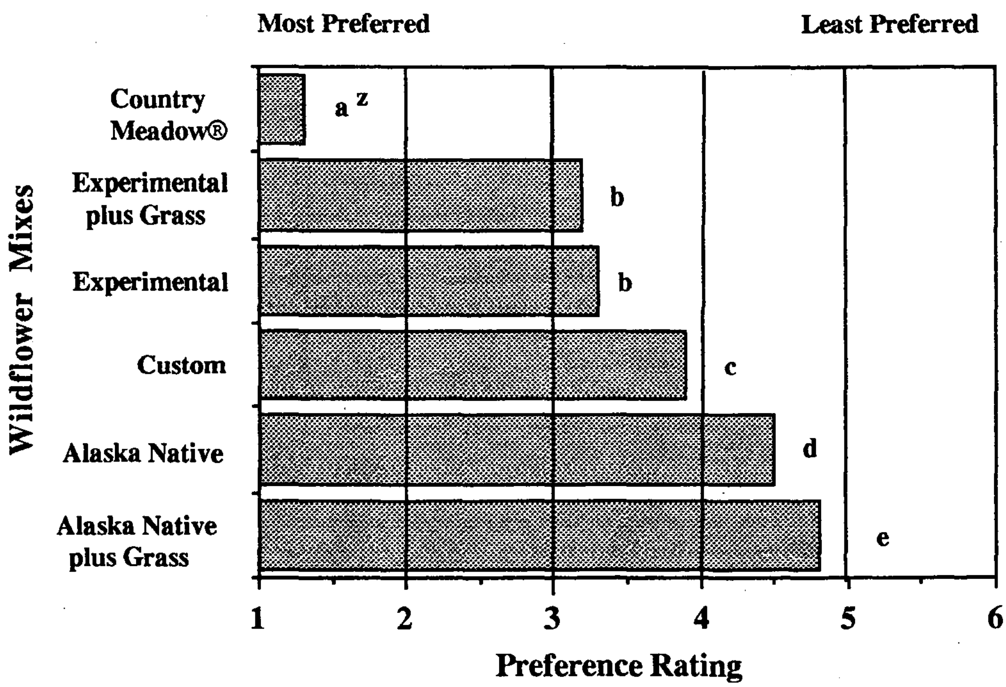
Species	Germination[z] (%)	Irrigated plots		Non-irrigated plots	
		Date of first emergence	Date of first flowering	Date of first emergence	Date of first flowering
Achillea millefolium	37.4	June 20			
Ayssum saxatile	88.3				
Centaurea cyanus	99.0	June 23	July 27	June 23	July 27
Cheiranthus allionii	92.0	July 2	Aug. 12	June 29	Aug. 12
Chrysanthemum maximum	95.5	June 26		July 2	
Gilia capitatum	35.3	June 23	Aug. 3	June 23	Aug. 3
Hesperis matronalis	44.3	June 23		June 23	
Linum lewisii	52.8	July 2	July 30	July 9	July 30
Linum rubrum	86.0	June 23	Aug. 3	July 2	Aug. 3
Nemophila menziesii	30.0	July 9	Aug. 12	July 16	Aug. 12
Oenthera lamarkiana	71.5				
Papaver nudicauli	89.3				
Penstemon strictus	08.8	July 20			
Rudbeckia hirta	92.3				

[z]Average germination percentage of 4 replicates of 100 seeds in a controlled environment seed germination test.

The Country Meadow® Mix was the preferred mix in the public opinion survey (Figure 5). The most important aspects of these mixes were the long flowering season and the multi-colored flowers. The Alaska Native Wildflower Mix and the Custom Wildflower Mix were dominated by a single flower color: the orange-yellow of *Eschscholtzia californica* and the blue of *Gila capitatum* respectively. The Experimental Wildflower Mix had some mixed flower colors but not nearly the intensity and showiness of the Country Meadow® Mix. Some respondents chose the Experimental Wildflower Mix specifically because they identified all the components as Alaska wildflowers. However, the majority of respondents preferred the showy, colorful display of the non native mix.

Evaluation of fall-sown wildflower mixes 1993. The percent of species in each mix that established ranged from 44% to 85% (Table 19). Fall-sown Custom Wildflower Mix had the greatest percent of species establishing of all the mixes. Interestingly, the Experimental Wildflower Mix had a significantly greater percent species establishment per plot than Country Meadow® Mix, possibly due to Experimental Wildflower Mix composition of only native species. Native wildflower species are particularly well adapted to their own region's climactic environment (NWRC 1989) and a fall sowing presumably fulfills requirements of cold stratification for overcoming seed dormancy mechanisms of many wildflower species (Johnson and Millard 1993, Hartmann *et al.* 1990, Smreciu *et al.* 1988, Zajicek *et al.* 1986, Salac *et al.* 1975, Mirov 1936, Nichols 1934). Also, Country Meadow Mix annuals may have not been hardy. Non-locally acquired seed may result in a reduction of cold hardiness, heat and drought tolerance, and general adaptability (Martin 1990).

Figure 5. Public preference during the first growing season for six spring-sown wildflower mixes.



[z]Means separation by Duncan's multiple test range at $P \leq .05$. Means differed significantly among mix treatment. No significant difference between Experimental w/ grass and Experimental mixes.

Table 19. Percent species establishment for fall-sown[z] mixes regardless of irrigation treatment.

Wildflower Mix	Average species establishment[y] (%)
Custom Wildflower Mix	85a[x]
Experimental Mix	73b
Country Meadow® Mix	67c
Experimental Mix with grass	63c
Alaska Native Wildflower Mix	46d
Alaska Native Wildflower Mix with grass	44d

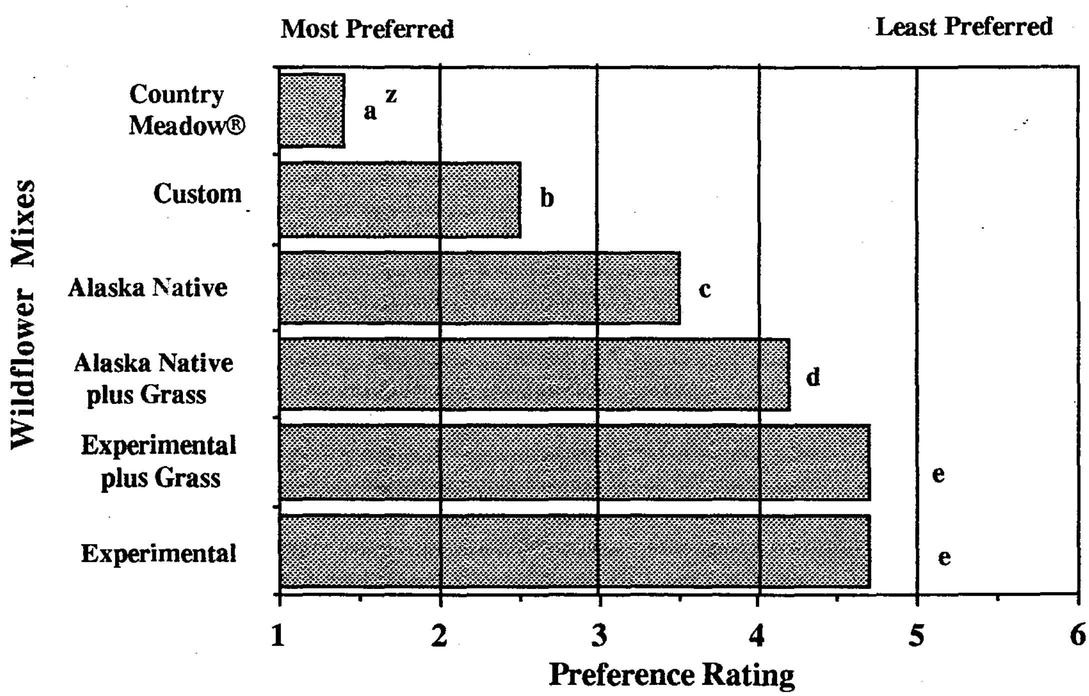
[z]Mixes sown Sept. 25, 1993.
[y]Based upon number of species that established in relation to total number of species per mix.
[x]Mean separation by Tukey's HSD at $P \leq .05$.

The respondents of the public opinion survey preferred Country Meadow® Mix over the other fall-sown mixes (Figure 6). The most important factor used in choosing between the mixes was the "color" display of a mix. Country Meadow® and Custom Wildflower mixes had vivid displays of red, white, orange and blue wildflowers; whereas, Alaska Native Wildflower Mix with and without 'Tundra' bluegrass and the Experimental Wildflower Mix with and without 'Tundra' bluegrass lacked the vivid multicolored wildflowers. However, several respondents commented on the texture and attractiveness of 'Tundra' bluegrass in the wildflower plots.

Of the 16 Alaska native species that established, 9 flowered (Table 20) in both irrigated and non-irrigated fall-sown plots. Presumably, the overwintering process provided the requirements for breaking seed dormancy (Baldwin Seed Co. 1987). Five species failed to establish in Country Meadow® and Custom Wildflower mixes: *Linum rubrum*, *Cynoglossum amabile*, *Aquilegia* sp., *Lychnis chalcedonica*, and *Oenothera lamarkiana* (Tables 21 and 22). This failure may be attributed to chilling injury (Woodstock 1988), inadequate environmental field conditions conducive to germination, or poor environmental field conditions for establishment (Hartmann et al., Harper 1977). For instance, *Cynoglossum amabile* requires absence of light for germination (Lilly Co. 1992), and the process of raking the seeds might not have been enough to bury *Cynoglossum amabile* seeds deep enough to completely block light.

Effects of sowing date. Significantly greater species establishment (63%) was recorded on all fall-sown plots in contrast to 46% species establishment on all spring-sown plots ($P \leq .05$). These results compare favorably with several state highway department studies that found a fall-sowing date of wildflower mixes resulted in a greater number of species establishing and persisting (D. Brown, Ohio Department of

Figure 6. Public preference during the first growing season for six fall-sown wildflower mixes.



[z]Means separation by Duncan's multiple test range at $P \leq .05$. Means differed significantly among mix treatment. No significant difference between Experimental Mix and Experimental Mix with grass.

Table 20. Dates of first emergence and flowering of fall-sown Experimental Wildflower and Alaska Native Wildflower mixes species, 1993.

		Irrigated plots		Non-irrigated plots	
Species	Germination[z] (%)	Date of first emergence	Date of first flowering	Date of first emergence	Date of first flowering
Achillea ptarmica	34.8	June 12	Aug. 27	June 24	
Arnica alpina	30.0	June 5		June 8	
Aster sibiricus	28.5	June12		June 12	
Bupleurium triradiatum	12.3				
Centaurea cyanus				May 14	
Chenopodium capitatum	71.8	May 28	July 23	May 28	July 23
Corydalis sempervirens	21.5	May 28		May 28	
Delphinium glaucum	0.0				
Epilobium angustifolium	47.8	May 21	June 24	June 18	
Epilobium latifolium	20.0				
Erigeron glabellus	20.0	June 5		May 28	
Eschscholtzia californica	77.3	May 28	Aug. 18	May 14	June 18
Galium boreale	30.8				
Hedysarum Mackenzii	24.8	May 28	July 23	May 28	Aug. 5
Heiracium scabriusculum	2.0	June 5	July 9	May 28	June 9
Iris setosa	0.0				
Linaria vulgaris	5.5	May 28	Aug. 5	July 2	July 23
Linum lewisii	53.3				
Lupinus arcticus	7.8	May 28	July 30	May 28	
Melandrum affine	0.0				
Nemophila menziesii	29.5	May 14	June 18	May 28	
Oxytropis campestris	6.0	June 5		June 5	
Parnassia palustris	0.0				
Poa glauca cultivar *Tundra*		May 14	July 16	May 14	July 16
Polemonium acutiflorum	4.0	June 5	July 2	June 12	July 30
Sanguisorba officinalis	60.3	June 12		June 12	
Solidago multiradiata	4.0	Aug.12		Aug. 11	
Tripleurospermum inodoratum	3.0	May 28	June 18	May 28	June 18

[z]Environmental controlled germination conditions.

Table 21. Dates of first emergence and flowering for fall-sown Country Meadow® Mix, 1993.

		Irrigated plots		Non-irrigated plots	
Species	Germination[z] (%)	Date of first emergence	Date of first flowering	Date of first emergence	Date of first flowering
Alyssum maritimum	85.5	June 5	July 2	June 5	July 2
Aquilegia	0.0				
Calendula officinalis	21.0	May 21	July 16	June 12	July 16
Centaurea cyanus	87.0	May 28	July 2	June 18	July 2
Cheiranthus allionii	71.8	June 5	June 24	June 5	June 24
Chrysanthemum coronarium	69.0	May 28	Aug. 5	May 28	Aug. 5
Chrysanthemum leucanthemum	87.3	May 28	July 30	June 24	July 30
Cynoglossum amabile	71.3				
Eschscholtzia californica	54.0	May 28	June 12	May 28	June 12
Godetia amoena	95.0	May 14	July 2	May 14	July 2
Gypsophila muralis	89.5	May 28	June 18	May 14	June 18
Hesperis matronalis	32.3	June 18		May 28	
Linaria maroccana	72.5	May 14	May 28	May 14	May 28
Linum lewisii	64.8	June 12			
Linum rubrum	92.7				
Lychnis chalcedonica	89.3				
Nemophila menziesii	29.8	May14	June 12	May 21	June 12
Papaver nudicaule	30.0	June 12	July 2	June 12	July 2
Papaver rhoeas	56.8	June 5	July 2	June 12	July 2
Phacelia tanacetifolia [y]	24.0	May 21	June 18		

[z]Environmental controlled germiantion conditions.
[y]Only one plant germinated, established and bloomed.

Table 22. Dates of first emergence and flowering for fall-sown Custom Wildflower Mix, 1993.

		Irrigation		Non-irrigation	
Species	Germination[z] (%)	Date of first emergence	Date of first flowering	Date of first emergence	Date of first flowering
Achillea millefolium	37.4	June 18	July 23	June 12	July 30
Alyssum saxatile	88.3	June 5	Aug. 19	June 24	
Centaurea cyanus	99.0	May 14	July 2	May 14	July 2
Cheiranthus allionii	92.0	May 28	June 18	June 24	Aug. 18
Chrysanthemum maximum	95.5	June 5	July 30	May 28	
Gilia capitatum	35.3	May 14	June 18	May 14	Aug. 5
Hesperis matronalis	44.3	May 21	July 30	May 21	
Linum lewisii	52.8	May 28	Aug. 5	June 24	
Linum rubrum	86.0				
Nemophila menziesii	30.0	May 28	Aug. 12	May 28	Aug. 12
Oenthera lamarkiana	71.5				
Papaver nudicauli	89.3	June 12	July 2	June 18	July 2
Penstemon strictus	08.8	June 5	July 30	July 30	
Rudbeckia hirta	92.3	June 5	Aug. 11	June 18	Aug. 12

[z]Environmental controlled germination conditions.

Transportation pers. comm., D. Kerr, Mississippi Department of Transportation pers. comm.).

Twelve native wildflower species established and four flowered in spring-sown plots in the first season (Table 16). In fall-sown plots, 16 Alaska native wildflower species established and 9 flowered in the first season. For instance, fall-sown *Lupinus arcticus* occurred and flowered in both irrigated and non irrigated plots, whereas spring-sown *Lupinus arcticus* did not occur in any plots.

Two wildflower species in the commercial mixes did not establish when spring-sown but did establish and flower when fall-sown: *Papaver nudicaule* and *Alyssum saxatile.* A recommended sowing time for *Papaver nudicaule* is a fall sowing (Wildseed Farms, Inc. 1992). Improved establishment of many wildflower species with fall planting could be attributed to the higher soil moisture content because of melting snow and cold stratification necessary for some wildflower species to overcome dormancy and subsequently germinate and establish (Mirov 1936, Nichols 1934, Hartmann *et al.* 1990, Hegarty and Ross 1981, Pinnell *et al.* 1985).

Two annual species, *Gypsophila muralis* and *Alyssum maritimum*, that established in spring-sown plots had poor field germination and establishment in fall-sown plots despite controlled environment germination percentages of 85% - 89% (Tables 21 and 22). Poor establishment of these species could be attributed to freezing injury after imbibition (Woodstock 1988).

Five native species failed to occur for both spring and fall sowing dates: *Bupleurium triradiatum*, *Delphinium glaucum*, *Galium boreale*, *Melandrum affine*, and *Parnassia palustris.* Germination percentages for these species ranged from 0% to 31% (Table 1). When compared to the controlled germination test percentages of the commercial mixes, these percentages are fairly low. However, if germination test were to be conducted over all temperature and light ranges these germination percentages may change. Also, *Parnassia palustris* may establish better on wet to boggy soils, and irrigation may have not been sufficient for establishment (NCSGC, Inc. 1981). Two species in the Country Meadow® Mix failed to germinate for both sowing dates: *Aquilegia* sp. and *Lychnis chalcedonica*. *Aquilegia* sp. failed to germinate in the controlled germination test (Table 1) and can exhibit erratic seed germination (Davis *et al.* 1993).

Custom Wildflower, Country Meadow® and Alaska Native Wildflower with grass mixes species establishment did not differ significantly between spring and fall-sowing dates ($P \leq .05$). Fall-sowing improved wildflower species establishment for Experimental Wildflower Mix (73% fall, 67% spring), Experimental Wildflower Mix with grass (63% fall, 46% spring) and Alaska Native Wildflower Mix (46% fall, 24% spring). Fall-sowing may be beneficial to many species because dormancy may be overcome through the overwintering process (Mirov 1936, Nichols 1934).

Evaluation of spring-sown mixes second growing season. During the second growing season, establishment of spring-sown species ranged from 34% for Country Meadow® Mix to 70% for Experimental Wildflower Mix (Table 23), and the public preferred Alaska Native Wildflower Mix with grass (Figure 7). In contrast, County Meadow® and Custom Wildflower mixes did not favor as well with respondents. Alaska Native Wildflower Mix had a variety of color from yellows such as *Linaria vulgaris* and *Solidago multiradiata* to pink of *Hedysarum Mackenzii*. Many respondents liked the texture that the 'Tundra' bluegrass added to the Alaska Native Wildflower Mix plots.

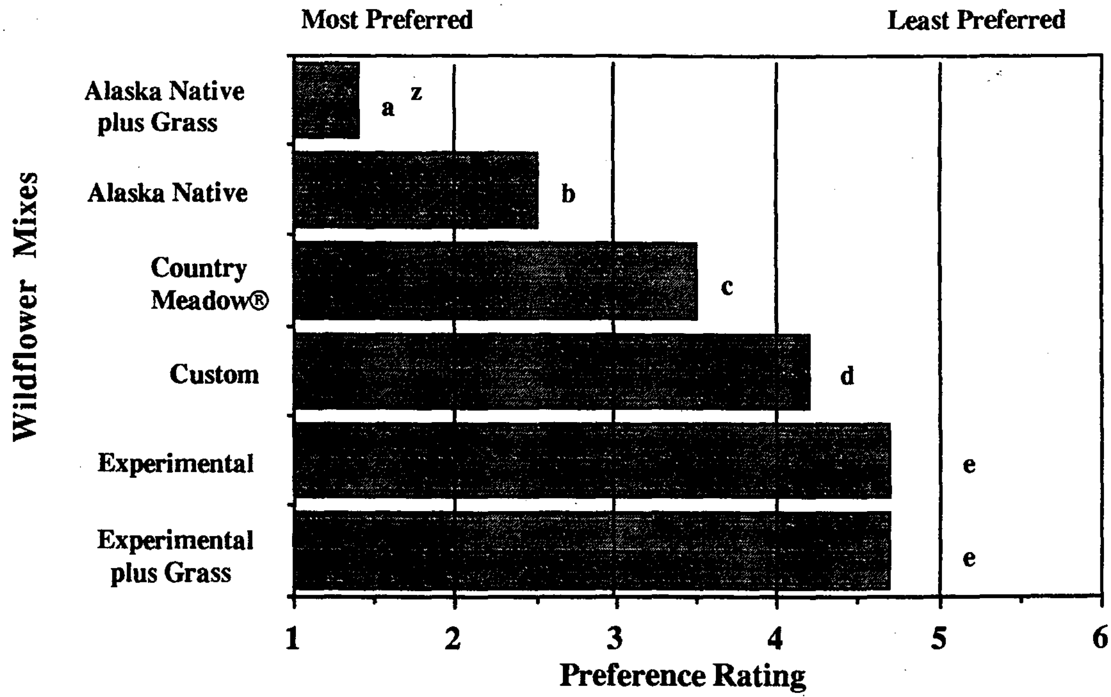
The commercial mixes had considerably fewer species blooming, and the predominant colors were lavender of *Hesperis matronalis* and white of *Achillea*

Table 23. Percent species establishment of six spring-sown wildflower mixes for the second growing season, 1993.

Wildflower Mix[z]	Average species establishment[y] (%)	Change from first growing season (%)
Experimental Mix with Tundra glaucus bluegrass	70a[x]	+27
Experimental Mix	65a	+19
Custom Wildflower Mix	44b	−23
Alaska Native Wildflower Mix with Tundra glaucus bluegrass	38bc	+ 8
Alaska Native Wildflower Mix	37bc	+14
Country Meadow® Mix	34c	−34

[z]3 replicates of both non-irrigation and irrigation.
[y]1992 spring sowing of six mixes. Data gathered 1993 season.
[x]Mean separation by Tukey's HSD at $P \leq .05$.

Figure 7. Public preference during the second growing season for six spring-sown wildflower mixes.



ᶻMean separation by Duncan's multiple range test at $P \leq .05$. Means differed significantly among mix treatments.

millefolium and *Chrysanthemum maximum*. There was little rainfall in July (Appendix B) which may have contributed to a decrease in species and poor flowering in the commercial non-native wildflower mix plots. The lack of color variety in the other mixes may have led many respondents to prefer Alaska Native Wildflower Mix.

For Experimental Mix with and without 'Tundra' bluegrass, 17 native species appeared and 16 bloomed. In contrast, 11 wildflower species established and flowered in the Country Meadow® Mix (Tables 24-26). Between 23% and 34% fewer species reappeared during the second growing season in the two commercial mixes (Table 23). This reduction is not surprising considering the high proportion of annuals in the two commercial mixes (Appendix E). For instance, some annuals that failed to reappear in the commercial mixes during the second growing season were *Centaurea cyanus*, *Cheiranthus allionii*, *Gilia capitatum* and *Godetia amoena*(Table 27). Studies indicate that non-indigenous annuals found in most commercial mixes will rarely self-sow or establish self-sustaining colonies (Longland 1989, Ferreniea 1988, Wilson 1992, Crockett 1972, Sanford 1991). This effect could be due in part to the increased vegetative coverage by perennial wildflowers making it more difficult for annual species to reseed (Harper 1977, Sanford 1991). Some of the species may have established the prior season and overwintered to flower in the second growing season. Replanting annuals yearly is cost prohibitive, thus only a few annuals are included in roadside wildflower mixes for first year color (NWRC 1989, D. Kerr Mississippi Department of Transportation, pers. comm., D. Stark Wisconsin Department of Transportation, pers. comm.).

Table 24. Dates of first emergence and flowering of spring-sown Alaska Native Wildflower and Experimental Wildflower mixes for the second growing season, 1993.

		Irrigated		Non-irrigated	
Species	Germination[z] (%)	Date of first emergence	Date of first flowering	Date of first emergence	Date of first flowering
Achillea ptarmica	34.8	May 28	June 18		
Arnica alpina	30.0	May 14	June 5	May 14	
Aster sibiricus	28.5	May 14	Aug. 11	May 14	Aug. 8
Bupleurium triradiatum	12.3				
Chenopodium capitatum	71.8	May 14	June 12	May 14	July 23
Corydalis sempervirens	21.5	May 14	July 9	May 28	July 9
Delphinium glaucum	0.0				
Epilobium angustifolium	47.8	May 28	July 9	May 28	July 9
Epilobium latifolium	20.0				
Erigeron glabellus	20.0	May 28	June 5	May 28	June 18
Galium boreale	30.8				
Hedysarum Mackenzii	24.8	May 21	July 23	May 21	June 24
Hieracium scabriusculum	02.0	May 14	July 9	June 12	July 9
Iris setosa	0.0	June 5			
Linaria vulgaris	05.5	May 14	June 5		
Linum lewisii	53.3	May 14	Aug. 5		
Lupinus arcticus	07.8	May 14	June 5	May 28	June 5
Melandrum affine	0.0				
Oxytropis campestris	06.0	June 23		June 12	
Parnassia palustris	0.0				
Poa glauca cultivar *Tundra*		May 14	July 16	May 14	July 16
Polemonium acutiflorum	04.0	May 14	June 5	May 14	June 5
Sanguisorba officinalis	60.3			June 18	
Solidago multiradiata	04.0	May 14	July 16	July 30	
Tripleurospermum inodoratum	03.0	May 21	June 5	May 28	July 2

[z]Environmental controlled germination conditions.

Table 25. Dates of first emergence and flowering of spring-sown Custom Wildflower Mix for the second growing season, 1993.

		Irrigated		Non-irrigated	
Species	Germination[z] (%)	Date of first emergence	Date of first flowering	Date of first emergence	Date of first flowering
Achillea millefolium	37.4	May 21	July 23	May 28	Aug. 11
Alyssum saxatile	88.3				
Centaurea cyanus	99.0				
Cheiranthus allionii	92.0				
Chrysanthemum maximum	95.5	May 14	June 18	May 14	
Gilia capitatum	35.3				
Hesperis matronalis	44.3	May 14	June 5	May 21	June 5
Linum lewisii	52.8	July 16	Aug. 5	May 14	May 21
Linum rubrum	86.0				
Nemophila menzeisii	30.0			May 14	July 16
Oenthera lamarkiana [y]	71.5			July 9	Aug. 5
Papaver nudicauli	89.3	May 28	June 18		
Penstemon strictus	08.8	May141	July 30	May 21	Aug. 19
Rudbeckia hirta	92.3	May 21	July 9	May 21	July 30

[z]Environmental controlled germination conditions.

[y]One plant germinated, established and bloomed for all plots.

Table 26. Dates of first emergence and flowering of spring-sown Country Meadow® Mix for the second growing season, 1993.

		Irrigated		Non-irrigated	
Species	Germination[z] (%)	Date of first emergence	Date of first flowering	Date of first emergence	Date of first flowering
Alyssum maritimum	85.5	May 28	July 23	May 28	July 23
Aquilegia sp.	0.0				
Calendula officinalis	21.0	May 28	July 2		
Centaurea cyanus	87.0				
Cheiranthus allionii	71.8				
Chrysanthemum coronarium	69.0			June 5	July 16
Chrysanthemum leucanthemum	87.3	May 21	June 18	June 5	June 18
Cynoglossum amabile	71.3	May 14	July 23	June 5	July 23
Eschscholtzia californica	54.0	June 12	July 2	May 28	June 12
Godetia amoena	95.0				
Gypsophila muralis	89.5	May 28	June 24	May 28	June 18
Hesperis matronalis	32.3	May 14	June 12	May 14	June 12
Linaria maroccana	72.5	May 14	May 28	May 14	May 28
Linum lewisii	64.8	May 14	May 28	May 14	5/28/93
Linum rubrum	92.7				
Lychnis chalcedonica	89.3				
Nemophila menziesii	29.8	June 5	June 24	June 12	July 2
Papaver nudicaule	30.0	June 5	July 2		
Papaver rhoeas	56.8				
Phacelia tanacetifolia	24.0				

[z]Environmental controlled germination conditions.

Table 27. Native and non native spring-sown wildflower species that did not establish or reappear in the second growing season regardless of irrigation treatment.

Native Species		Non Native Species	
Did not establish	Did not reappear for second growing season	Did not establish	Did not reappear for second growing season
Bupleurium triradiatum		*Aquilegia* sp.	*Centaurea cyanus*
Delphinium glaucum		*Alyssum saxatile*	*Gilia capitatum*
Epilobium latifolium		*Lychnis chalcedonica*	*Linum rubrum*
Galium boreale			*Godetia amoena*
Melandrum affine			*Papaver rhoeas*
Parnassia palustris			*Phacelia tanacetifolia*
			Oenthera lamarkiana [z]
			Cheiranthus allionii [y]

[z]One plant occurred for all plots.

[y]Did not reappear in Country Meadow® Mix. Reappeared in non-irrigated Custom Wildflower Mix plots.

Effects of irrigation. Percent of species that established on all spring-sown mixes was significantly greater on irrigated plots (81%) than on non-irrigated plots (67%) ($P \leq .05$). These results compare with research from many locations at lower latitudes. Nearly all studies recommend irrigation to improve seed germination, greater seedling establishment and improved, prolonged "color" displays (Salac and Traeger 1982, Rose-Fricker 1991, Sanford 1991, Airhart *et al.* 1983, NWRC 1989, Ahern 1990, Longland 1989, Crockett 1972, Ferreniea 1988, Stroud 1989).

An average of 75% to 80% of the wildflower species in the Country Meadow® Mix and 57% to 71% of the wildflower species in Custom Wildflower Mix established and flowered in both irrigated and non-irrigated plots (Tables 17 and 18). Three species occurred only on the irrigated plots: *Nemophila menziesii*, *Achillea millefolium* and *Penstemon strictus*, with only *N. menziesii* blooming. Six of the remaining species did not occur on any plot despite germination percentages under controlled conditions of greater than 70%. This result is probably related to inappropriate field germination conditions. For instance, *Alyssum saxatile* and *Papaver nudicaule* require light for germination (Hartmann *et al.* 1990). The process of raking the seeds into the surface at planting may have excluded light and prevented germination.

In contrast, 58% of the native species in Alaska Native Wildflower Mix and Experimental Wildflower Mix established and flowered on the irrigated plots. Two species established only on the irrigated plots: *Achillea ptarmica* and *Linaria vulgaris*. Drier soil conditions may have exacerbated this poor germinability during the first year. Also, seeds of *Linaria vulgaris* germinated poorly (6%) even under controlled environment conditions. On the non-irrigated plots, 50% of the native species established but only 8% bloomed (*Chenopodium capitatum* and *Tripleurospermum* *inodoratum*) (Table 16). Soil moisture may be more critical to the flowering of many wildflower species.

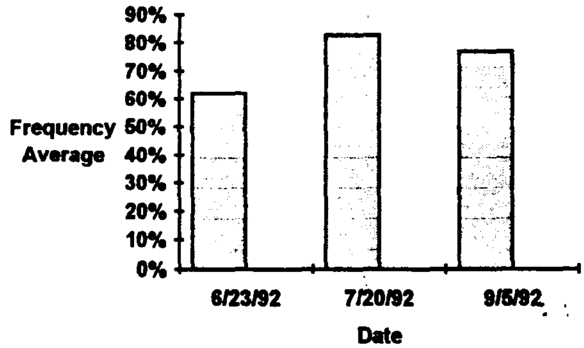
There was no significant difference in the percent of wildflower species in the mixes that established between irrigated and non-irrigated treatments for fall-sown plots. This could be attributed to the moisture from melting snow cover and warm temperatures (Appendix D) in May for seed germination of many species. Additionally, the over-wintering process may have met the requirements for many species to overcome dormancy (Hartmann *et al.* 1990).

Wildflower and grass seed mixes. There was no significant effect of the addition of grass to the wildflower mixes on the percent of wildflower species establishing for spring-sown and fall-sown, and irrigated and non-irrigated plots. The plot frequency of the spring-sown 'Tundra' bluegrass reached an average 83% by July 20, 1992 in both Experimental Wildflower and Alaska Native Wildflower mixes but declined to 77% by Sept. 5, 1992 (Figure 11). The decline in frequency was probably due to grasshopper damage. Fall sowing resulted in 90% frequency of grass in all plots by mid-season.

Non-competitive native grasses included in a wildflower seed mixture may be less costly than a mix composed entirely of wildflower seed (Diboll 1989). Non-competitive native grasses also will add bulk to the mix for easier application, aid in soil stabilization, and tend to decrease annual weed competition (Cotter *et al.* 1989, Martin 1990, Pompei 1986, Rose-Fricker 1991).

Dry weight collection end of season 1993. The analysis of the total above-ground biomass of each mix treatment and by individual species showed no significant differences among irrigation and sowing date treatments. This may be due to inappropriate sampling or plots that were small.

Figure 8. Frequency of occurrence^z of *Poa glauca* 'Tundra' in Experimental Wildflower Mix and Alaska Native Wildflower Mix plots.



^zMeans separation by Tukey's HDS at $P \leq .05$. Percent frequency means differed significantly among the three dates.

CHAPTER 6

CONCLUSIONS

The two commercial mixes, Country Meadow® Mix and Custom Wildflower Mix, had significantly greater proportion of species establishing with both spring and fall planting in irrigated and non-irrigated plots than the other mixes. Fall-sowing increased the proportion of wildflower species that established in the Experimental Wildflower Mix and Alaska Native Wildflower Mix plots. In the first year, the public preferred the multi-colored Country Meadow® Mix over the other five mixes for both spring and fall sowing.

In the second growing season, significantly more species established in the spring-sown Experimental Wildflower Mix than the other mixes; Country Meadow® and Custom Wildflower mixes had significantly fewer species reappearing; and the public preferred Alaska Native Wildflower Mix with grass. Irrigation improved the proportion of wildflower species that established and flowered in spring-sown plots but had no effect on fall-sown plots. Addition of grass to the Experimental and Alaska Native Wildflower mixes had no effect on the proportion of wildflower species that established in those mixes. Above-ground biomass of species in each mix was not influenced by irrigation and sowing date treatments.

There was no significant difference in establishment of wildflower species between sowing rate treatments of spring-sown Alaska Native Wildflower Mix for both growing seasons. However, the public preferred the higher sowing rates for both growing seasons. During the second growing season, plant density increased significantly for *Polemonium acutiflorum* and *Lupinus arcticus* as the sowing rate increased.

CHAPTER 7

RECOMMENDATIONS

Germination. A complex system of mechanisms acting in conjunction or individually are involved in maintenance of dormancy. The control of dormancy and its release is of importance in the establishment of species included in wildflower mixes. A basic knowledge of dormancy mechanisms of native wild-collected seed is necessary for successful germination and eventual commercial production of native wildflower seed species.

Further germination studies should be done on native species to ascertain germination requirements for inclusion in a commercial mix. Germination instructions for numerous species can be found in the Rules for Testing Seeds by the Association of Official Seed Analysts (1981) and the International Rules for Seed Testing by the International Seed Testing Association (1985).

Alaska Native Wildflower Mix sowing rate study. Because there was no significant difference in Alaska Native Wildflower mix species establishment between the three sowing rates, further studies should be conducted to ascertain the optimum seeding rate for Alaska Native Wildflower Mix, perhaps using one, five, ten, and twenty times recommended rate. The public evaluating the plots found the higher sowing rates were visually more appealing. The addition of the non-native annual *Eschscholtzia californica* appeared to be the impetus for this favorable response. Therefore, inclusion of several non-native annuals and perennials for first year color in the Alaska Native Wildflower Mix may be necessary until colorful native species are identified for future inclusion.

Alaska Native Wildflower Mix should be fall-sown and irrigated for best results. If this mix is fall-sown and first year color is desired, the following non-native annuals and perennials could be selected for inclusion: *Papaver nudicaule*, *Hesperis matronalis*, *Calendula officinalis*, and *Papaver rhoeas*. *Linaria vulgaris* is considered a noxious weed in Alaska and should be removed from the mix.

Six wildflower seed mixes study. The commercial wildflower mixes featuring non-native species performed the best of six wildflower seed mixes when evaluated for proportion of species establishment, first-year flowering, and public opinion. These results emphasize the importance of choosing wildflower species that provide a multi-colored mix of flowers in the first year in a successful native wildflower mix.

Fall-sowing these six mixes should result in more species establishing than a spring-sowing. Irrigation should result in a greater proportion of species establishing, and an earlier, longer-lasting flowering period. For spring-sown wildflower mixes, more native wildflower species appeared in the second growing season and fewer non-native wildflower species appeared. Native perennial species show the best potential for long term success of a wildflower planting. Several Alaska wildflowers, *Chenopodium capitatum*, *Tripleurospermum inodoratum*, *Polemonium acutiflorum*, and *Hedysarum Mackenzii*, flowered even under non irrigated conditions when fall-sown and could be important for establishing first-year color for an all-native wildflower mix.

Glaucous bluegrass added to the Experimental Wildflower and Alaska Native Wildflower mixes had no effect on wildflower species establishment both for spring and fall-sowings. Use of a non-competitive native grass in a wildflower mix should aid in lowering production costs associated with expensive wildflower seeds and could enhance a wildflower meadow appearance without sacrificing wildflower visual appeal.

Further studies should be conducted to find an optimum sowing rate of glaucous bluegrass for a fall-sown wildflower mix..

It may be difficult to find visually appealing native annual species to use in a mix to fulfill public preference for multicolors in the first year. However, educating the public about the use and results of native wildflowers and grasses, instead of incorporating non-natives into a mix to satisfy a need for instant color, may be the solution.

For long-term commercial production of Alaska native wildflower species further studies are recommended. For example, few studies have been conducted on identifying wildflowers that would be successful in a commercial enterprise. Wildflower species from this study that look promising are *Polemonium acutiflorum, Lupinus arcticus, Hedysarum Mackenzii, Arnica alpina*, and *Aster sibiricus* . These species should be studied further to identify germination, field cultivation and harvesting requirements to aid commercial production of these wildflower species to be used in an all Alaska native wildflower mix.

APPENDIX A

Alaska Feed Custom Wildflower Mix		
Achillea millefolium	Yarrow	P[z]
Alyssum saxatile		P
Centaurea cyanus	Dwarf cornflower	A
Cheiranthus allionii	Siberian wallflower	A
Chrysanthemum maximum	Dwarf shasta daisy	P
Gilia capitatum	Globe gilia	A
Hesperis matronalis	Dame's rocket	P
Linum lewisii	Blue flax	P
Linum rubrum	Scarlet flax	A
Nemophila menziesii	Baby blue eyes	A
Oenthera lamarckiana	Evening primrose	A
Papaver nudicaule	Iceland poppy	P
Penstemon strictus	Rocky mountain penstemon	P
Rudbekia hirta	Black-eyed susan	P
Denali Seed Company Country Meadow® Wildflower Mix		
Alyssum maritimum	Alyssum	A
Aquilegia ssp.	Columbine	P
Calendula officinalis	Calendula, single	A
Centaurea cyanus	Dwarf cornflower	A
Cheiranthus allionii	Siberian wallflower	A
Chrysanthemum coronarium	Coronarium	A
Chrysanthemum leucanthemum	Ox-eye daisy	P
Cynoglossum amabile	Chinese Forget-me-not	A
Eschscholzia californica	California poppy	A
Godetia amoena	Godetia	A
Gypsophila muralis	Baby's breath	A
Hesperis matronalis	Dame's rocket	P
Linaria maroccana	Toadflax	A
Linum lewisii	Blue flax	P
Linum rubrum	Scarlet flax	A
Lychnis chalcedonica	Maltese cross	P
Nemophila menziesii	Baby blue eyes	A
Papaver nudicaule	Iceland poppy	P
Papaver rhoeas	Corn poppy	A
Phacelia tanacetifolia	Tansy bluebells	A

[z]P - perennial, A - annual, B - biennial.

Experimental Mix

Arnica alpina	Arnica	P[z]
Aster sibiricus	Siberian aster	P
Bupleurium triradiatum	Thoroughwax	P
Chenopodium capitatum	Strawberry spinach	A
Delphinium glaucum	Larkspur	P
Erigeron glabellus	Fleabane	P
Galium boreale	Northern bedstraw	P
Hedysarum Mackenzii	Wild sweet pea	P
Melandrium affine		P
Oxytropis campestris	Yellow oxytrope	P
Polemonium acutiflorum	Tall Jacob's ladder	P
Rhinanthus minor	Rattlebox	A
Sanguisorba officianalis	Burnet	P
Solidago multiradiata	Goldenrod	P
Tripleurospermum inodoratum	Wild chamomile	A

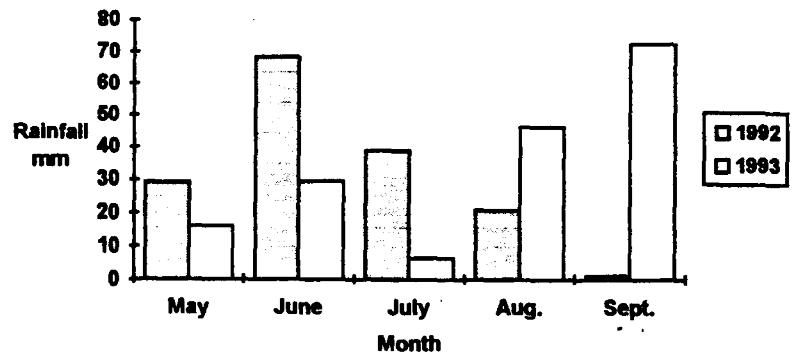
Alaska Native Wildflower Mix

Achillea ptarmica	Pearl yarrow	P
Arnica alpina	Arnica	P
Aster sibiricus	Siberian aster	P
Centaurea cyanus	Dwarf cornflower	A
Chenopodium capitatum	Strawberry spinach	A
Corydalis sempervirens	Rock harlequin	B
Epilobium angustifolium	Fireweed	P
Epilobium latifolium	River beauty	P
Eschscholzia californica	California poppy	A
Gallium boreale	Northern bedstraw	P
Hedysarum Mackenzii	Wild sweetpea	P
Heiraceum scarbriusculum	Yellow hawkweed	P
Iris setosa	Wild flag	P
Linaria vulgaris	Butter and eggs	P
Linum lewisii	Blue flax	P
Lupinus arcticus	Arctic lupine	P
Nemophila menziesii	Baby blue eyes	A
Oxytropis campestris	Northern yellow oxytrope	P
Parnassia palustris	Grass of parnassus	P
Polemonium acutiflorum	Tall Jacob's ladder	P
Sanguisorba officianalis	Burnet	P
Solidago multiradiata	Goldenrod	P
Tripleurospermum inodoratum	Wild chamomile	A

[z]P - perennial, A - annual, B - biennial.

APPENDIX B

Cumulative monthly rainfall for the 1992 and 1993 growing seasons.



APPENDIX C

Seed Sources

Country Meadow ® Mix, Denali Seed Co., Anchorage, Alaska.

Custom Wildflower Mix, Alaska Feed Co., Fairbanks, Alaska.

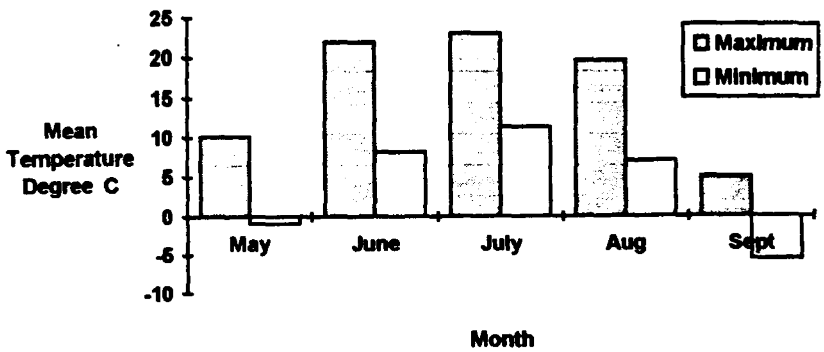
Alaska Native Wildflower Mix, Nauriaq Gardens, Fairbanks, Alaska.

Experimental Wildflower Mix, Big Dipper Gardens and Nauriaq Gardens, Fairbanks Alaska.

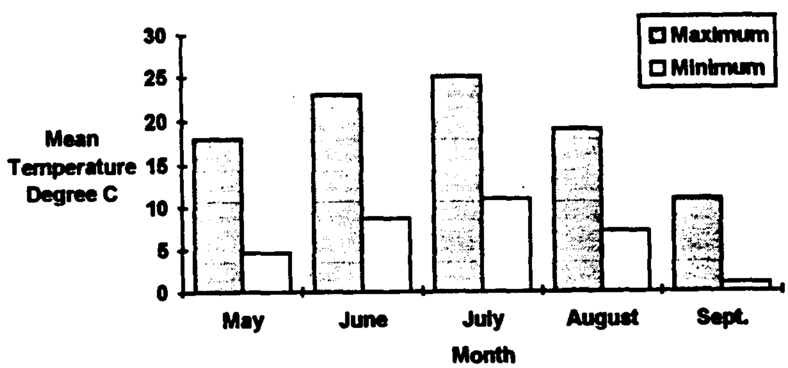
Poa glauca cv. Tundra, Alaska Plant Materials Center, Palmer, Alaska.

APPENDIX D

Average monthly temperature for 1992.



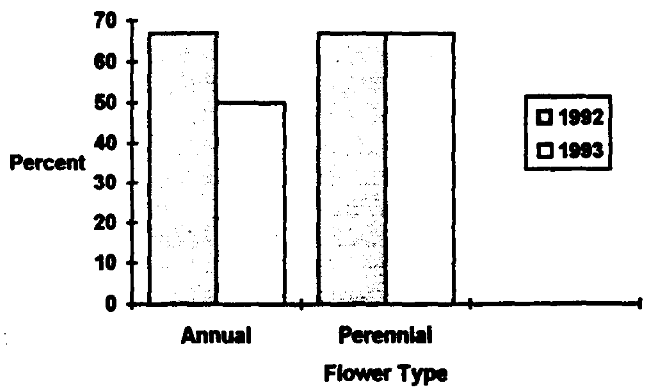
Average monthly temperature for 1993.



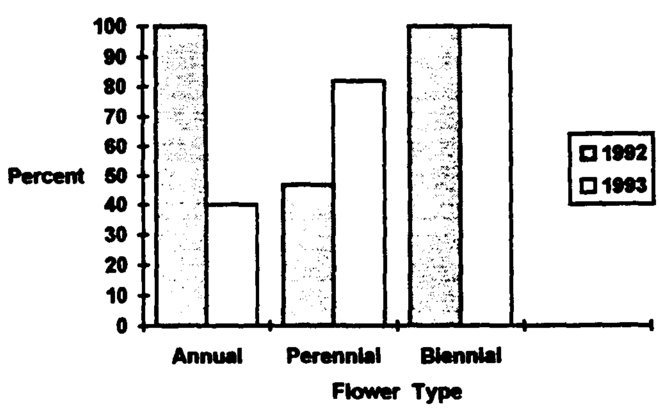
APPENDIX E

Percent of annuals, perennials, and biennials for the 1992 and 1993 growing season for six spring-sown wildflower mixes.

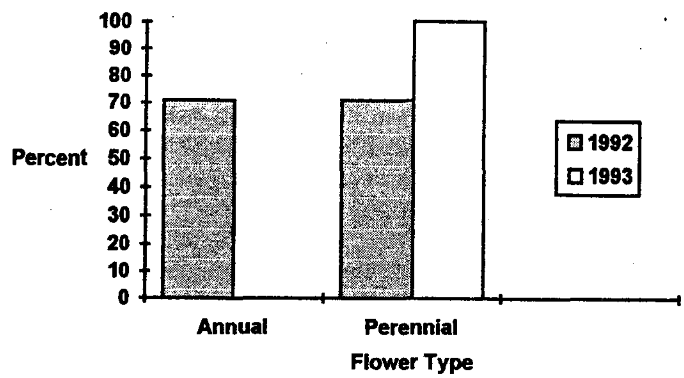
Experimental Wildflower Mix



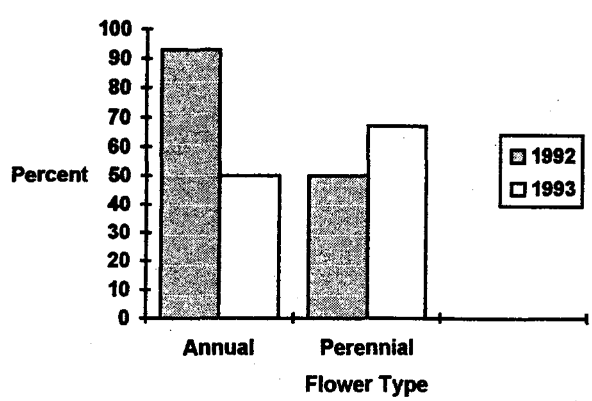
Alaska Native Wildflower Mix



Custom Wildflower Mix



Country Meadow® Mix



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